SHIP AVAILABILITY ORIENTED CONTRACT MANAGEMENT MODEL FOR IN-SERVICE SUPPORT CONTRACTS OF NAVAL VESSELS

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SHIP AVAILABILITY ORIENTED CONTRACT MANAGEMENT MODEL
FOR IN-SERVICE SUPPORT CONTRACTS OF NAVAL VESSELS

AL-SHAFIQ BIN ABDUL WAHID

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

Faculty of Engineering
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JUNE 2019

DECLARATION

I declare that this thesis entitled *"Ship availability oriented Contract Management Model for In-Service Support Contracts of Naval Vessels"* is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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DEDICATION

To Allah (SWT), my beloved Prophet Muhammad Rasulullah (PBUH), my mother and father, my wife and children.

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ABSTRACT

The rapid development of the ship building and ship repair industry in recent years has transformed the way organizations perceive the future industry growth. Greater growth of naval technology is clearly noticed as well. Disappointingly, the worldwide phenomenon reflects that availability of naval vessels remained lower than expected. The Royal Malaysian Navy (RMN) vessels currently maintained under in-service support (ISS) contracts suffer the same fate, despite continuous yearly effort to improve the ships' availabilities. The complexity of naval ship itself and its ever-changing roles and mission makes the situation more complex. Previous studies remained focused mostly on availability calculations and availability modelling of few factors only. There has not been any holistic study on all human and equipment factors impacting availability. The research aim is to demystify the complex naval ship availability issue by developing a decision-making model in improving ship operational availability of naval vessels under the ISS contract. Besides introducing a simplified view to the complex naval issue, this multiple-staged mixed-method sequential Delphi exploratory research has determined and ranked various downtime influence factors (DIFs) viewed holistically from both human and equipment perspectives, as well as determining the DIFs impact from the contract and project management perspectives. A panel of 30 experts and five top management experts in ISS contract in Malaysia participated in the research. 50 DIFs were identified, and a severity index (SI) was developed for each of the determined 15 severe DIFs. The developed SI highlights that almost 45% of the downtime causes are due to the top five severe DIFs with corrective maintenance (SI 0.142) ranked first, spares availability (SI 0.082) ranked second, cash flow shortages (SI 0.078), ranked third maintenance budget allocation ranked fourth (SI 0.075) and knowledge management including training and skills (SI 0.070) ranked fifth. In this study, an availability-oriented model has been developed to assist policymakers in decision making and for maintainers and logisticians in appreciating their individual contribution to improve availability. Contract managers are provided with a tool to better manage the contract at 'close to real time' with identified prioritization on severe issues added with recovery recommendation to improve the ongoing availability situation. The simple approach and model are more appealing to practitioners unlike previously where complex mathematical results and algorithms were made available. An interesting finding is that availability could be improved even with budget constraints.

ABSTRAK

Perkembangan pesat pembinaan kapal dan industri pembaikan kapal pada tahun-tahun kebelakangan ini telah mengubah persepsi masyarakat terhadap pertumbuhan industri masa depan. Kemajuan teknologi tentera laut juga lebih jelas kelihatan. Walau bagaimanapun, fenomena sedunia menunjukkan kesiapsiagaan kapal tentera laut kekal rendah daripada sasaran. Kapal Tentera Laut Diraja Malaysia (TLDM) yang disenggara di bawah Kontrak Sokongan dalam Perkhidmatan (ISS) mengalami nasib yang sama, walaupun terdapat usaha berterusan untuk meningkatkan kesiapsiagaan kapal. Kapal tentera laut yang rumit ditambah dengan peranan dan misi yang sentiasa berubah menjadikan keadaan lebih kompleks. Kajian terdahulu kerap tertumpu pada pengiraan tahap kesiapsiagaan dan penyediaan model yang melibatkan beberapa faktor sahaja. Tiada sebarang kajian holistik merangkumi faktor-faktor manusia dan peralatan dilaksanakan secara meluas. Matlamat penyelidikan ini adalah untuk mempermudah konsep kesiapsiagaan bersama sebuah model yang berkeupayaan menyokong proses membuat keputusan bagi meningkatkan kesiapsiagaan kapal di bawah ISS. Selain memudahkan pemahaman konsep kesiapsiagaan, penyelidikan jenis penerokaan menggunakan metodologi campuran melibatkan kumpulan fokus serta beberapa fasa Delphi yang berturutan ini berjaya menentukan dan mengukur faktor yang mempengaruhi ketidakaktifan kapal (DIF) dilihat secara holistik daripada perspektif manusia dan peralatan, serta impak DIF dari perspektif pengurusan kontrak dan projek. Panel pakar seramai 30 orang dan lima pakar pengurusan tertinggi organisasi ISS di Malaysia telah terlibat. 50 DIF telah dikenalpasti, dan Indeks Keparahan telah ditentukan bagi setiap 15 DIF utama. Indeks Keparahan (SI) mendapati hampir 45% ketidakaktifan kapal berpunca daripada lima DIF utama iaitu senggaraan baikpulih (SI 0.142) di tempat pertama, kesediaan alatganti (SI 0.082) di tempat kedua, masalah aliran tunai (SI 0.078) ketiga, kekurangan bajet (SI 0.075) keempat dan pengurusan pengetahuan termasuk latihan dan kemahiran (SI 0.070) di tempat kelima. Hasilnya, model berorientasikan kesiapsiagaan telah dibangunkan bagi membantu pembuat dasar membuat keputusan, serta penyelenggara dan anggota logistik dalam menghargai sumbangan masing-masing bagi meningkatkan kesiapsiagaan kapal. Pengurus Kontrak kini disediakan suatu alat bantuan mengurus, mengawal dan memantau kontrak dengan lebih efektif pada ‘hampir masa sebenar’ dengan keutamaan diberi pada DIF-DIF kritikal bersama cadangan kiraan pemulihan bagi kesiapsiagaan selanjutnya. Pendekatan dan model ini terbukti lebih mudah serta menarik kepada para pengamal berbanding sebelum ini di mana mereka hanya diperuntukkan dengan keputusan dan algoritma matematik yang kompleks. Satu penemuan menarik adalah bahawa kesiapsiagan kapal masih boleh ditingkatkan tanpa penambahan bajet.

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LIST OF ABBREVIATIONS

AAW	-	Anti-Air Warfare
ABC	-	Availability-Based Contract
Am	-	Mission Availability
Ao	-	Operational Availability
ASW	-	Anti-Submarine Warfare
ASuW	-	Anti-Surface Warfare
At	-	Technical Availability
AMT	-	Advanced Manufacturing Technologies
ANOVA	-	Analysis of Variance
BN	-	Boustead Naval Shipyard Sdn Bhd
BNT	-	BHIC Navaltech Sdn Bhd
BHIC	-	Boustead Heavy Industries Corporation Berhad
CBM	-	Condition Based Maintenance
CBS	-	Contract Build Specifications
CfA	-	Contracting for Availability
CM	-	Corrective Maintenance
COM	-	Class Output Management
ConCaMS	-	Contract Management Control and Monitoring System
CV	-	Coefficient of Variation
DLM	-	Depot Level Maintenance
DIF	-	Downtime Influence Factor
DSA	-	Defence Services Asia
EEP	-	Economic Enhancement Programme
EW	-	Electronic Warfare
FGD	-	Focus Group Discussions
FinAT	-	Final Acceptance Trial
FMEA		Failure Modes and Effects Analysis
FREMM	-	Fregate Europe Multimissione
FTV	-	Fast Troop Vessels
GAO	-	Government Accountability Office

GOM	-	Government of Malaysia
ICT	-	Information Communication Technology
ILM	-	Intermediate Level Maintenance
ILS	-	Integrated Logistics Support
ISS	-	In-Service Support
LCC	-	Life Cycle Cost
LCS	-	Littoral Combat Ships
LFT	-	Live Firing Trials
LTI	-	Loss Time due to Injury
MM	-	Maintenance Management
MMEA	-	Malaysian Maritime Enforcement Agency
MTTB	-	Meantime to Breakdown
MTTR	-	Meantime to Repair
OEE	-	Overall Equipment Effectiveness
OEM	-	Original Equipment Manufacturer
OLM	-	Onboard Level Maintenance
PBC	-	Performance-based Contract
PdM	-	Predictive Maintenance
PHM	-	Prognostics and Health Management
PM	-	Preventive Maintenance
PMI	-	Project Management Institute
PV	-	Patrol Vessel
RA	-	Research Aim
RAN	-	Royal Australian Navy
RCM	-	Reliability-Centred Maintenance
RI	-	Remaining Items
RFP	-	Request for Proposal
RFQ	-	Request for Quotation
RMN	-	Royal Malaysian Navy
RN	-	Royal Navy
RO	-	Research Objectives
ROVA	-	Return of Vessel Availability
RQ	-	Research Questions

SAR	-	Search and Rescue
SAT	-	Sea Acceptance Trial
SI	-	Severity Index
SLEP	-	Ship Life Extension Programme
SoS	-	System of Systems
SPSS	-	Statistical Package for the Social Sciences
STW	-	Setting to Work
SWBS	-	Ship Work Breakdown Structure
TGS	-	Temporary Global Support
TOC	-	Total Cost of Ownership
TOF	-	Task Order Forms
TPM	-	Total Productive Maintenance
UK	-	United Kingdom
USA	-	United States of America
USAF	-	United States Air force
USN	-	United States Navy
WOS	-	Weightage of Severity

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Security challenges facing Malaysia have evolved with the ever-growing new and emerging technologies. The Malaysia National Defence Policy (MOD Malaysia, 2018) states clearly that the Malaysian Armed Forces (MAF) has to be flexible, mobile and possess a high degree of readiness. This requires the MAF organizational structure and strategic assets to be built and consistently maintained enabling it to always be ready to address all threats simultaneously. However, these threats with varying degrees of criticality, have not compelled the government of Malaysia (GOM) to substantially increase its expenditure in defence. Prudent spending measures result in most new defence programmes shelved or deferred for the time being (Guan, 2016). This results in an inevitable increase in the criticality of maintaining operational availability of existing defence assets including naval vessels.

Ship operational availability is described as the number of days the warships are available for operational tasking in a year (GAO, 2015c). The duration a naval vessel is able to remain in an area of operations reveals the sustainability and deterrence of the naval vessel (GAO, 2015c). In contrast to merchant ships, naval vessels which possess different set of functions, complex design characteristics (Dell'Isola and Vendittelli, 2015, Submarine Institute of Australia, 2017) and a variety of military roles (Directorate of Maritime Strategy Canada, 2001, Royal Navy Canada, 2012) and concept of operations, are equipped with a greatly different set of systems and equipment onboard to suit its war, combat and battle management capabilities. Naval warships are also equally demanded for many other missions during peace and conflict other than war. The navy's military operations other than war (MOOTW) includes search and rescue, disaster relief, surveillance and control of the country's territory and approaches, peace support operations and many more (Directorate of Maritime Strategy Canada, 2001). Therefore operational availability of naval ships or warships is a complex problem (Dell'Isola and Vendittelli, 2015, Ng *et al.*, 2009).

Availability is also a measure of maintenance performance (Parida and Kumar, 2009). For many decades, maintenance was regarded as an unavoidable part of the production function and difficult to manage. Maintenance was initially considered as 'necessary rework' and was not paid too much attention. In fact, quite often in most organizations, maintenance is considered a burden, sometimes considered a needless cost, sometimes given the least priority in time, resources and budget. Dekker (1996) pointed that there was minimal focus given to maintenance due to the difficulty to relate its contribution to company profits, therefore often seen as a cost function only. Swanson (2001) explained that traditionally, many companies approach to maintenance was to react, activities would only be carried out because machinery had to be fixed as it had stopped working.

Ship maintenance was not well structured or organized in comparison with other industrial entities which observed that huge savings may be made when carrying out proper maintenance tasks (Leger and Iung, 2012). There have been several cases which had proven that a proper maintenance strategy could have saved the organization or the industry millions of dollars, but most of them involved the more glamorous industries such as aviation and oil and gas sectors (Parida and Kumar, 2009, United Nations, 1993). Ship maintenance was previously considered as tasks needed to be performed on daily basis as part of operation, a mere necessity to keep the ship going in order to fulfil its mission of travelling from point A to point B. The maintenance activities were done mainly based on the experience of the chief engineer and his crew, or instruction of the ship captain for the range of equipment onboard the vessels.

In Malaysia, the Royal Malaysian Navy (RMN) has been managing a fleet of naval vessels for the last 80 years, and there are various types of vessels in the fleet including fast attack crafts, transport ships, frigates, corvettes, tugs, and the latest batch of six patrol vessels (PVs) of MEKO 100 RMN design. These PVs were commissioned into the RMN from 2006 and maintained through the in-service support (ISS) contract between the government of Malaysia (GOM) and Boustead Naval Shipyard Sdn Bhd (BN Shipyard). Even though three separate ISS contracts have been implemented on three classes of navy ships over a period of three years each, the RMN continued to face great challenges to meet its targeted operational availability of its fleet of naval vessels. This obstacle is common to most navies worldwide including United States Navy (Marais *et al.*, 2013), Italian and French Navy (Dell'Isola and Vendittelli, 2015), Korean Navy (Paik, 2014) and Royal Netherlands Navy (van Donkelaar, 2017).

This is a result of having insufficient holistic study and concentrated effort in improving ship availability. As a result, the RMN PV ISS contracts continued to use legacy clauses that have not been formulated to meet its prime objectives in accordance to the National Defence Policy but seemed to have enough coverage to allow the contract to be implemented for purposes of maintaining the vessels. It has not been structured to meet a certain availability or productivity or reliability target, or to minimize contract risks, or to optimize maintenance activities, neither to follow certain crucial policies or philosophies of maintenance.

1.2 Organizational Challenges

BN Shipyard has been the leading shipyard in Malaysia for the repair of naval ships since its corporatization in 1991 and subsequently its privatization from being the government-owned Naval Dockyard Sdn Bhd in 1995. On shipbuilding, the shipyard had successfully completed mega-projects such as the shipbuilding of six PVs awarded in 1998, resulting with the award of the new and sophisticated littoral combat ship (LCS) contract for six vessels in 2014. On ship repair, the shipyard has continued to perform RMN vessels repair work year after year.

Nevertheless, similar to problems faced by other shipyards worldwide, the performance of BN Shipyard over the last decade has shown large areas for improvement especially in reducing extended delays in ship repair work and mitigating human-related issues. Even as the leader of naval repair and newbuilding works, BN Shipyard continued to face difficulties in maintaining profitability and on several occasions posted losses. Many reasons and excuses were given by the staffs and significant efforts were implemented by the shipyard top management to try curb these problems (Shamaun, 2017).

Irrespective of these management efforts, the 'blaming game' continued to occur between shipyard departments, between shipyard and the end-customer RMN, and between shipyard and vendors. The situation seemed similar to the explanation by Karube *et al.* (2009) that low organisational cohesiveness creates unnecessary conflict; thereby, dissipating managers' effectiveness towards meeting objectives through efficient coordination and communication. On many occasions, staffs were paying too much attention to the customer, at the expense of company's profitability and failure to abide by the internal procedures. Frequently procedures were bypassed as the staffs believed that "the end justifies the mean", delivering the ships is most important.

Similarly, the PV ISS organization suffered the same fate, as the organization was originally derived from a department of BN Shipyard which was later formed as a sister-company called BHIC Navaltech Sdn Bhd (BNT). The PV ISS contract was officially signed between the GOM and BN Shipyard, but the implementation was subcontracted out to BNT in 2011 for a period of three years. This was the first time a major ISS contract was awarded to the newly formed organization, with the aim of maximizing the ships' operational availability as part of the RMN fleet readiness. The PV ISS contract was subsequently renewed for a further 3-year term in 2014 with negligible improvement in the scope and clauses.

Many more issues surfaced beyond the above-mentioned organisational related problems, mostly due to insufficient knowledge and experience of the ISS concept by both contracting parties. The new ISS contract awarded to this newly-formed organization created additional issues including but not limited to maintenance philosophy, priority of work, budget appropriateness, effectiveness of processes, sufficiency of scope, inability to meet availability targets, design and engineering issues and also government policies and procedures. Accountability problems are rampant between stakeholders; 1) internal stakeholders, the various subsidiaries of the large Boustead Heavy Industries Corporation (BHIC) group of companies as well as externally, and 2) between the various companies and the various customers especially with the multiple departments of the RMN.

The tendency remained that stakeholders prefer to work in clusters, such as the finance department prefer to work with financial background personnel within the organization and with the supply branch of the RMN whilst similarly the engineering personnel are comfortable to work closely with the Engineering Branch of the RMN. The top management including the project managers of the BHIC group would deal mostly with the executive branch of the RMN who would normally be the top management and policy makers. This inevitably creates a discord whenever there is a project or contract management issue, whereby the clustered groups of stakeholders would defend their cluster and throw the blame to other clusters creating accountability issues whenever there is any question of non-performance.

This dysfunctional behaviour between stakeholders, often also driven by personalities, has been described in detail in a thesis by Shamaun (2017) called *Management of Resistance to change using lean principles in transforming a shipyard operation*. Shamaun (2017) also pointed out that on certain cases in the shipyard, because of the busied environment and hurried pace of a programme, projects were poorly managed resulting in project control and monitoring became cumbersome ending up with confusion and dispute between parties. Similarly, for the PV ISS contract, the overlapping areas of duty between engineering, finance and project management clusters create grey areas of accountability as there currently exist no mechanism to segregate the responsibility and contribution of each cluster of personnel to the success of the project. BNT as the ISS contractor shares the concern of Kwak and Smith (2009) that the issue of lack of accountability especially regarding department of defence (DoD) officials who openly place full responsibility on contractors therefore relieving themselves of pressure, and having the underlying assumption that large projects would not be cancelled despite poor project performance.

At the ground level on the ISS project, some random or selective data has been collected previously on naval ship maintenance and repair, but without specific objectives or guidelines, with questionable quality and considerable number of gaps resulting in very seldom been analysed. The consequential effect is the reduced motivation or mindset of the staffs to continue collecting data (GAO, 2014b) as they believe it would continue to be a waste of time as the data will remain not be analysed for maintenance decision making and no benefit would come out of it. This is similar to the findings of Jardine (1996) that it is common that data seems to be plentiful, may not be at the expected quality, nevertheless data analysis is fundamental in optimizing decision making in maintenance but decision policies based on incorrect information may not just be useless but also harmful. As the researcher was formerly involved during the design, shipbuilding and subsequently the ISS phase of the PV vessels, this has spurred the researcher to embark on this current research to study not only to improve on the current PV ISS contract issues but also to meet the targeted operational availability. Any successful improvement shall naturally spill over and benefit the remaining fleet awaiting to be awarded with new ISS contracts in future. This research is termed by Jardine (1996) as an *industry driven applied research* which is motivated by the practical need, the research problems arise directly from the industrial organizations, and the research will definitely bring benefits to the organizations involved.

1.3 Problem Statement

All navies in the world aspire to improve the operational availability of their fleet. Most navies such as the United States (US) Navy (Marais *et al.*, 2013), Korean Navy (Paik, 2014) and RMN (RMN, 2011b) have specific operational availability targets, but still remains a problem to be achieved. It remains a question as to why availability is still lower 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 and 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 and 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 formulated as one minus downtime or known as unavailability, with the resulting mathematical implication that the more unavailability or “downtime”, the lesser the availability achieved. Furthermore, there is a long list of human and equipment-related downtime influence factors affecting ship availability that are intertwined, ambiguous and uncertain, with uncertain significance and weightage. A few researchers have attempted to study individual factors such as Sandborn (2013) and Moon (2010) but none have been able to consolidate them comprehensively. It is hardly found that literature has attempted to consolidate factors involving human and equipment combined into one study involving ships due to the complexity.

Without simplifying the notion of naval availability, maintainers and support staffs remain confused and continue to be in “fire-fighting” mode trying to solve daily issues without any guidance on priority (Swanson, 2001). Improvement efforts could not be placed precisely, as the root cause of downtime from human and equipment related factors have not been identified. 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. To date, there exists no model or mechanism to assist the contract managers in managing the contract efficiently in meeting all contractual obligations at the targeted availability figures. Moreover, the model should be simple and practical, able to be understood by all levels of stakeholders in meeting targeted availability and able to assist contract managers to control and monitor the contract better. It is a documented fact that ship crews tend to change rapidly therefore a simpler model allows knowledge in processes to be retained easier as they are rarely trained in maintenance management (Wang et al., 2010).

1.4 Research Aim and Objectives

The aim of this research is to demystify the complex naval ship availability issue through the development of a contract management model in improving naval ship operational availability especially for the ISS contract. The research aims to bridge the knowledge gap concerning human and equipment related factors impacting ship availability. This model provides the linkage between human and equipment related factors holistically impacting naval ship availability that has to date been mostly tackled separately by policymakers, maintainers and logisticians as well as researchers who own conflicting goals and objectives (Davis, 2014). After all, according to Wang et.al (2010) the shipboard personnel are already overburdened being operators as well as maintainers, who would not appreciate long and complex methodologies for maintenance.

The outcomes of the model and the process would benefit every stakeholder. It helps to demystify the complex naval issue of improving the vessel and overall fleet operational availability faced by all levels of stakeholders. The step by step approach assists the policymakers to have a better grasp hence be able to make better decisions concerning all factors affecting the naval ship operational availability. Contract managers would have an efficient and handy tool to continuously track, manage and control the contract better with the necessary feedback and recovery information enabling faster decision making. Maintainers, storekeepers, trainers and all other stakeholders would have better appreciation of the tasks at hand with a clearer view of their individual contribution towards improving the navy's availability figures. Resources would therefore be ensured to be put to the best use.

Researchers on naval ships worldwide would have a holistic understanding of the entire cloud surrounding the complex naval availability issue, dissected to 'bite-size' for easy comprehension in order to participate in further research on individual or multiple combination of factors affecting naval ship availability. This would trigger more opportunities for international collaboration. The developed tool could be used internationally as a mechanism to compare contract performance, and project analysts would have a better systematic system for evaluation of contract or project. The outcome of the research would benefit other engineering fields in general that have continuously attempted to improve the productivity and availability of their assets.

The research aim could be achieved by meeting the following research objectives:

i) To determine the downtime influence factors (DIFs) to naval ship availability.

ii) To develop the DIF's impact matrix on contract and project management elements of the "iron triangle of cost, time, quality and scope".

iii) To develop the severity index as the mathematical algorithm to the model

iv) To develop a "ship availability oriented model" for ISS contract

1.5 Research Questions

Understanding the aspiration of all navies in the world to improve the operational availability of their fleet and handicapped with ongoing confusion and desperation due to the complexity issue above, the researcher emphasized that a list of critical research questions is necessary to be answered in this research. The research questions (RQ) are as in Table 1.1.

Table 1.1 Research questions through research objectives

<table>
<tr><td colspan="4">Research aim: The aim of this research is to demystify the complex naval ship availability issue through the development of a decision-making model in improving naval ship operational availability especially for the in-service support (ISS) contract. It could be achieved by meeting the following research objectives (RO) through the research questions (RQ):</td></tr>
<tr><th>Code</th><th>Research Question (RQ)</th><th>Code</th><th>Research Objective (RO)</th></tr>
<tr><td>RQ1a</td><td>What are the human and equipment related downtime influence factors (DIFs) affecting ship availability?</td><td rowspan="2">RO1</td><td rowspan="2">To determine the downtime influence factors (DIFs) to naval ship availability.</td></tr>
<tr><td>RQ1b</td><td>How can the DIFs affecting ship availability be-ranked and prioritized?</td></tr>
<tr><td>RQ2a</td><td>How do the DIFs impact the contract and project management elements of the “iron triangle of cost, time, quality and scope”?</td><td rowspan="3">RO2</td><td rowspan="3">To develop the DIF’s impact matrix on contract and project management elements of the “iron triangle of cost, time, quality and scope”.</td></tr>
<tr><td>RQ2b</td><td>Is it possible to improve ship operational availability by improving DIFs?</td></tr>
<tr><td>RQ2c</td><td>What areas can be improved when faced with budget constraints, if RQ2b is positive?</td></tr>
<tr><td>RQ3</td><td>Is it possible to develop an index based on ranking of the DIFs to indicate the severity of the DIFs?</td><td>RO3</td><td>To develop the severity index as the mathematical algorithm to the model</td></tr>
<tr><td>RQ4</td><td>Is it possible to develop a new model to assist stakeholders to better understand the availability concept and assist contract managers to monitor and control the contract better?</td><td>RO4</td><td>To develop a “ship availability-oriented model” for ISS contract</td></tr>
</table>

1.6 Scopes of the Study

The current research is constrained to the ISS contract for the maintenance of the PVs in Malaysia, which have been implemented by BN Shipyard through BHIC Naval Tech Sdn Bhd since June 2011 for 3-year terms. This is the approved and available full contract on maintenance of naval vessels for the researcher to conduct the research.

It is also crucial to point out that for purposes of this study, the scope is constrained to 'operational ships' in the fleet based on the scope of the contract (RMN, 2011b). Extended downtime for ships undergoing major refurbishment or refit is not included in the ISS contract and therefore not included in the study. This is especially important as the availability figure would evidently be significantly reduced or down to zero in cases of ship refit and major refurbishment such as ship life extension programme (SLEP). Nevertheless, these cases are not part of the study as they are implemented under separate refit or SLEP contracts, which is beyond the scope and provisions of the ISS contract. In accordance to Storch et. al (2007), basic actions carried out during maintenance that are significant during a ship's service life includes planned maintenance (dry dock and non-dry dock), unscheduled repairs and conversion or modernisation.

For ISS contract in Malaysia, the scope of research is limited to planned maintenance (non-drydock) and unscheduled repairs only, but with an additional category of emergency docking (unplanned drydock). The panellists involved in this Delphi study would be limited to experts of naval ship maintenance who are familiar with the clauses of the ISS contract, familiar with the day-in and day-out routines of the ISS contract, as well as navy key personnel who are directly involved and benefitting from the implementation of the ISS contract. The panelists would combine the necessary background in human and related equipment factors. The contract has only been implemented for two terms, therefore the number of qualified experts is also limited. The model developed for the ISS contract in Malaysia may need to be adjusted appropriately by other ISS organisations worldwide to cater for other types of ships and contract provisions depending on their individual scope of ISS contract.

1.7 Significance of Study

To date, 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.

The snowballing effect as a result of ineffective contract formulation impacts the contract manager threefold, 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 and simplified view to recover from the seemingly-hopeless situation. Similar to the manner applied by Wang *et al.* (2010), the overall concept is to locate the most troublesome areas and concentrate resources on them. The approach begins with the identification of the range of DIFs that influence naval ship availability, concentration on the severe or critical DIFs using 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 model for naval vessels that would provide a solution to systematically tackle the issues mentioned above. Given the targeted operational availability and the actual operational availability, the availability-oriented contract management model shall be capable of pinpointing the downtime in number of days lost for each of the severe DIFs and would be able to calculate the recovery operational availability in order to be back on track. The same applies when combined for the squadron operational availability at various locations, or even for the maximizing of fleet operational availability (Nguyen, 2017).

Besides the obvious transparency benefits to the maintainers and logisticians, the contract managers would have a tool to not only control and manage the existing contract better but also to be used during contract closure as well as improvement in new contract formulation utilizing the developed model. Top management and policymakers would have a tool to decide on whether the fleet has not been optimized or whether more vessels are required to be purchased to meet the operational needs of the nation. The result of the research shall also offer significant contribution to the body of knowledge as there currently exists restricted discussions and limited literatures on the downtime factors related to the naval ship maintenance impacting availability.

Stambaugh and Barry (2014) stated that for a ship valued at USD500million and a 30-year target service life, losses would amount to approximately USD50,000 per day if the ship was not able to operate. This shall be an indicative value to the RMN of potential losses due to unavailability caused by downtime. Therefore, the overall improvement achieved in increasing RMN ship availability from the efforts of all levels of stakeholders could save the GOM millions of Ringgit which could be better spent elsewhere.

1.8 Operational Definitions

The following are the key operational definitions referred to throughout the various chapters of the thesis.

i. *Availability:* the probability that the asset is available and capable of performing the intended function at any random point of time.

ii. *Complexity:* The state or quality of being intricate or complicated.

iii. *ConCaMS: An 'availability-oriented' model/system* designated Contract Management Control and Monitoring System.

iv. *Delphi Technique or Method:* A renowned method for eliciting and synthesizing expert opinion. The original intent of Delphi was as a forecasting technique, designed to predict the likelihood of future events using expert judgment in the military. It is primarily concerned with making the best you can of a less than perfect kind of information. The Delphi method is a flexible research technique that has been successfully implemented in many areas of study. It is well suited as a research instrument when there is incomplete knowledge about a problem or phenomenon. The Delphi technique works especially well when the goal is to improve our understanding of problems, opportunities, solutions, or to develop forecast. The technique has since been widely accepted throughout the world in many industry sectors including healthcare, defence, business, education, information technology, transportation and engineering. It allows researchers to maintain significant control over bias in a well-structured academically rigorous process using the judgment of qualified experts.

v. *Downtime:* time during which production is stopped especially during setup for an operation or when making repairs. Also referred to as inactive time. For this study, any time period that the asset or equipment or system is unavailable or not operational.

vi. *Downtime Influence Factors (DIFs):* Root cause of various downtime viewed holistically from equipment-related and human related factors.

vii. *In Service Support (ISS):* Performance of programme management, logistics services, and engineering that are required in order for an asset to operate properly and perform required functions throughout its lifecycle. However, the scope and duration of ISS contract varies between assets of various countries.

viii. *Iron Triangle:* A project management triangle also called the triple constraint and Project Triangle) is a model of the constraints of project management. Also referred to as the triple constraint or flexibility matrix, is a way to reconcile the key factors of scope, schedule, and cost as competing constraints on any project. The International Project Management Association (IPMA, 2006), in its *IPMA Competence Baseline* 2006 states that project success relates strictly to project management success as the ability to deliver the project's product in scope, time, cost, and quality. Display of an “iron triangle” in Figure 1.1.

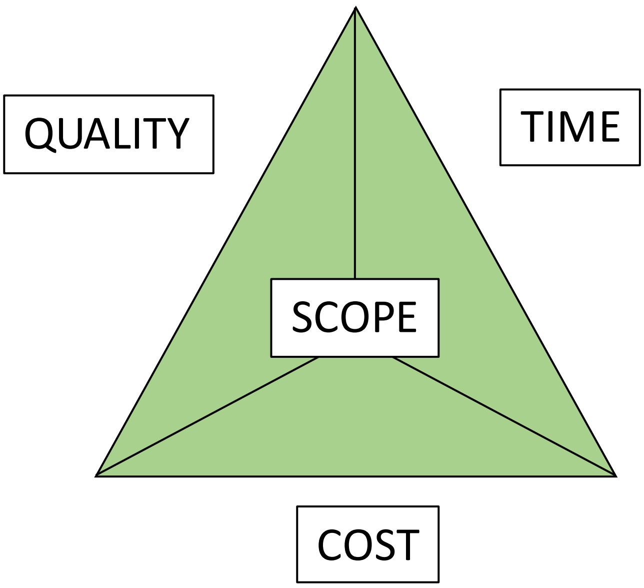


Figure 1.1 Project Management Iron Triangle (IPMA, 2006)

ix. *Maintenance:* British Standards Institution, BS3811 Glossary of maintenance terms in Terotechnology, BSI, London, 1984 defines maintenance as the combination of all technical and associated administrative actions intended to retain an item or system in, or restore it to, a state in which it can perform its required function.

x. *Mission Availability: Mission availabilit*y of naval ships reflects the number of days they are available for performing its mission tasking in a year

xi. *Operational Availability:* Operational availability (Ao) of naval vessels is a measure to reflect the number of days the ships are available for operational tasking in a year. Also reflected as the number of days the ships are able to spend in an area of operations.

xii. *Unavailability: The opposite to Availability.* The probability that the asset is unavailable and incapable of performing the intended function at any random point of time.

xiii. *Uptime*: Time during which production is in operation. Also referred to as active time. For this study, any time period that the asset or equipment or system is available or operational.

1.9 **Thesis Organization**

This thesis elaborates on the work undertaken in the research project and comprises of five chapters. Chapter 1 introduces the research project by providing the general background to the research, organizational challenges, problem statement, research aim and objectives, research questions, scope of study, significance of the research and operational definitions.

Chapter 2 provides an extensive literature review concerning the definition of maintenance, the significance of maintenance strategy and the relationship between the shipbuilding contracts with the ISS contract. This is followed by the categories of the maintenance activities concerning naval vessels, impact of design on maintenance, fleet-wide maintenance requirements and the impact of maintenance strategies to performance, availability and cost.

The chapter continues with the explanation on the concept of contracting for availability, spares and logistical support affecting maintenance and the consolidation of many factors and variables impacting the operational availability of a system and the implementation of effective maintenance strategies. Subsequently the review of studies on contract management philosophy, best practices, project management concepts, military versus conventional methodologies of contract management, similarities and differences between project management and contract management philosophies, past efforts in attempting to improve contract management practices, as well as other relevant literatures concerning the research subject. This chapter describes the various available research philosophies, methodologies and techniques to address research problems.

Chapter 3 fully describes the research methodology. Charts are provided to show the flow of works. Descriptions on the strategic selection of research variables via critical literature review provide leads to the preliminary model. The method of generating the generic DIFs and the strategic selection of the severe DIFs via survey and focus group discussion, which serve as the main method of data collection, is detailed out. The statistical method used to develop the DIF severity index describes the basic principle adopted in developing the formula to calculate ship availability. The chapter closes with description of methods for the development of the final ISS contract management model and its dashboard.

Chapter 4 discusses the results obtained and highlights their salient features. The first result is the simplification of the operational availability concept. The second result is the list of severe DIFs established. The third result is the formula developed to calculate the DIF severity index. The fourth result is the development of a ship availability- oriented contract management model. The fifth and final result is on the evaluation and validation of the model.

Chapter 5 concludes this research followed by explanation of the innovative contributions, areas of application and the limitations of the research. The chapter ends by highlighting several recommendations for further studies and concluding remarks.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents an overview on past and present trend in availability-centred activities related to ISS services in Malaysia and internationally. Firstly, a comprehensive literature review was conducted in the area of availability improvement on naval ships under ISS contracts. This includes relevant background information on the RMN including its vision and mission, its approved 15 to 5 transformation programme, ISS contract, the shipyard involved and on the squadron of naval ships under study.

The literature review continued on the common challenges of ISS service providers in Malaysia and internationally. This is followed by a review of all publications concerning the complexity of the naval platform as part of the naval force. Next stage of review involved the review on maintenance, downtime, availability, effective maintenance strategies and the relationship between them. Subsequently a very comprehensive review of all factors on downtime collected from all engineering fields including limited published literatures on downtime factors on naval ships. To improve naval ship availability, downtime should be reduced therefore this section on exhaustive collection of downtime factors is the essence of the literature review chapter as rightly pointed out by Handy (1999) as follows:

> "The whole is so often more meaningful than the sum of individual parts, as like a jigsaw, even though all the pieces are separately available, is nothing until put together".

Literature review continued on impact of design on cost, ship fleet-wide management and naval mission, impact of maintenance strategies on cost and availability, logistical support and the comparison of common type of ISS contracts. Subsequently a review of project and contract management constraints in relation to the ISS contract and ship availability, risk management, risk analysis and concluded with the presentation of the research gap.

Table 2.1 summarises the reading list of literatures completed, logged, summarized and referenced within this chapter relevant to the research interest. It is important to highlight that some publications cover a few topics simultaneously, the total number of uniquely referenced publications is 374.

Table 2.1 Number of reviewed journals, articles, reports and books

Topics	**Availability**	**Maintenance & ISS**	**Downtime factors (all engineering disciplines)**	**Contract & project management**	**Navy contracts, book of references, military standards**	**Risk assessment**	**Research methodology**	**Naval ships**
Reading list completed	**700 literatures**							
Summarized in Excel	**688 literatures**							
Logged in EN7	**505 literatures**							
Referenced*	148	205	395	6	9	14	56	9

The mapping of the research topic by literature is illustrated in Figure 2.1. The main topics of literatures are in-service support (ISS), availability, naval ships, maintenance, research methodology and naval ships. Each topic has various sub-sections of research interest included, but not limited to what has been displayed.

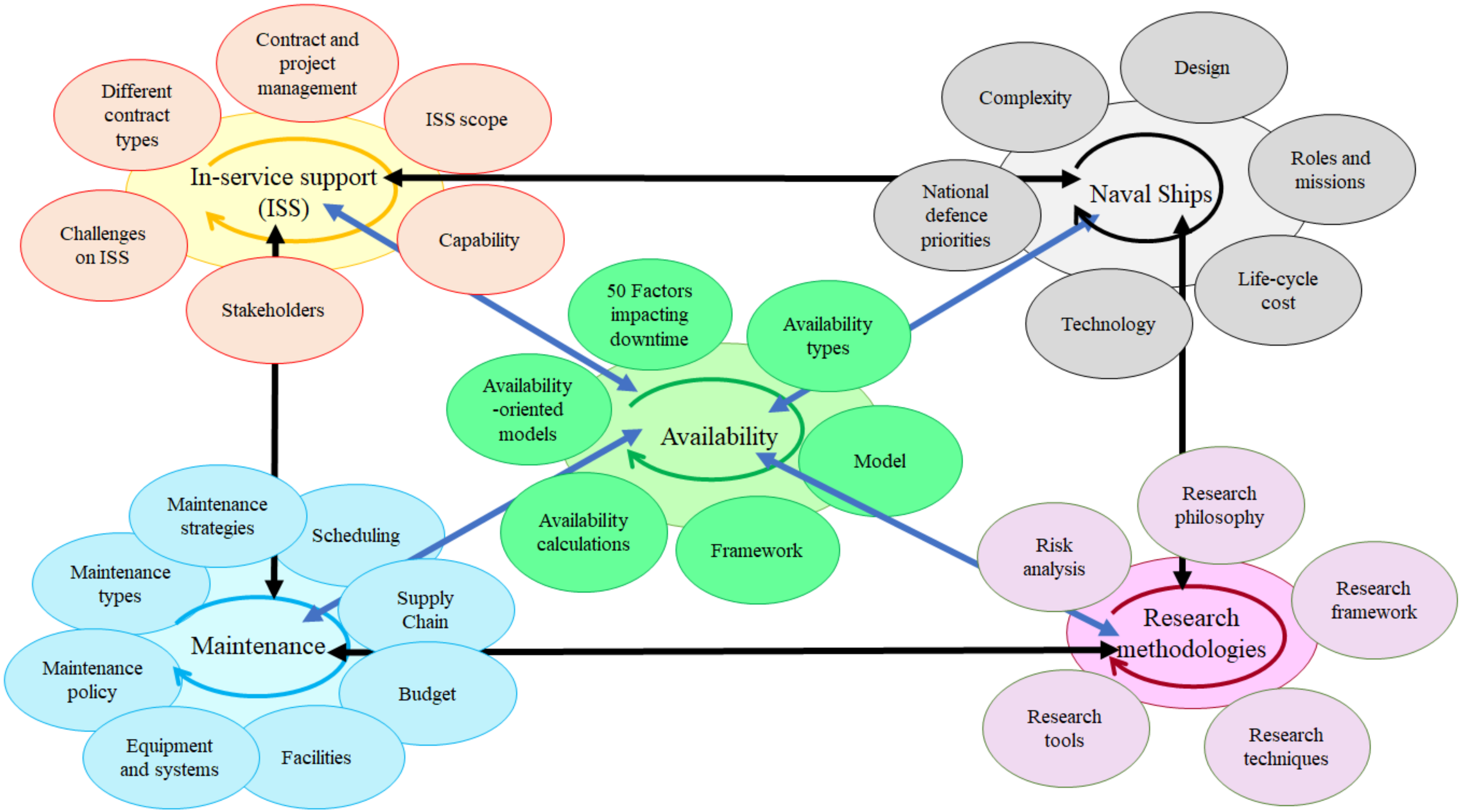


Figure 2.1 Research topic mapping by literature

2.2 Royal Malaysian Navy In-Service Support Contract

The RMN PV characteristics and ISS contract scope are explained in the following subsections. The subsections shall include a description of the contract, the stakeholders involved, the RMN vision and mission as well as the strategic plan.

2.2.1 Royal Malaysian Navy Patrol Vessels

The RMN PVs were designed at Blohm+Voss Shipyard in Hamburg Germany under the M2+4 concept. A total of six PVs of MEKO 100 RMN design were commissioned into the fleet between 2006 and 2010. The photo of a PV is as illustrated in Figure 2.2.

Figure 2.2 Photo of a Patrol Vessel KD PAHANG

Under this concept, two of the PVs were constructed in Germany in modules and later transported on a dock ship (RMN, 2011b) to BN Shipyard (formerly known as PSC Naval Dockyard Sdn Bhd) in Lumut, Perak, Malaysia for test and trials prior to delivery to the RMN. The PV onboard the Condock ship is seen in Figure 2.3.

Figure 2.3 Photo of PV on 'Condock Ship'

The PV's main characteristics are described in Table 2.2.

Table 2.2 PV main characteristics (RMN, 2018a)

PATROL VESSEL MAIN CHARACTERISTICS	
Vessel type:	New Generation Patrol Vessel
Displacement, tons:	1650 full load
Dimensions, feet:	298.9 x 39.4 x 9.8
Speed, knots	22
Range, nautical miles:	6050 at 12kt
Complement:	68 (11 Officers)
Number of vessels:	6

The balance four of the PVs were totally constructed at BN Shipyard in Lumut, refer Figure 2.4, with technical support from Blohm+Voss Shipyard in Hamburg Germany and applying technology transferred to the local shipyard personnel and vendors.

Figure 2.4 Photo of Boustead Naval Shipyard Sdn Bhd

Since commissioning, the PVs have been mostly homeported at the naval bases described in Table 2.3.

Table 2.3 Patrol Vessel locations

S/No	Patrol Vessels	Base Location	Responsibility of Area
1	KD SELANGOR and KD KELANTAN	RMN Base, Lumut Perak.	Fleet Operations Commander
2	KD KEDAH and KD PERAK	RMN Base Teluk Sapanggar, Kota Kinabalu Sabah.	Area Commander II
3	KD PAHANG and KD TERENGGANU	RMN Base Tg Gelang, Kuantan, Pahang.	Area Commander I

2.2.2 Description of the In-Service Support Contract

The PVs are currently being maintained through the ISS contract (RMN, 2011b) between the GOM and BN Shipyard. The PV ISS contract was negotiated in 2009 and signed in June 2011. Therefore, the contract has been implemented since June 2011 with renewal every three years. The ISS contract covers maintenance services, spare parts, training and computer support system for maintenance planning. BN Shipyard has awarded the contract for the maintenance of the vessels to BHIC

Navaltech Sdn Bhd (BNT), a subsidiary company of Boustead Heavy Industries (BHIC) which specializes in ISS activities. Previously BNT had successfully managed the ISS contract of two fast troop vessels (FTVs) and since the award for the ISS contract for the PVs, BNT has also been awarded the frigate ISS contract for the maintenance of two UK-made frigates in 2010. Within BHIC group, BNT has also been tasked with providing expert manpower for the ISS of the two Scorpene-class submarines.

The PV ISS contract is similar in clauses to frigate ISS contract but varies widely in implementation due to the fact that there are only two frigates and both are co-located at a single naval base which is the RMN's largest base in Lumut as opposed to the six PVs which are stationed at three separate naval bases in East and West Malaysia. The two French Scorpene-class submarines are maintained under a totally different ISS contract using the 'availability-based' maintenance concept.

2.2.3 **Stakeholders of the In-Service Support Contract**

The main stakeholders in the implementation of the PV ISS contract are the Ministry of Defence represented by the top management of the RMN, the respective PV officers and crew located at various navy bases, BNT as the main contractor, the various original equipment manufacturers (OEMs), the specialists on various areas, and the local vendors.

The PV base location of RMN Main Base Lumut, RMN Base Sepanggar, RMN Base Kuantan and RMN Supply Depot Lumut as well as the main stakeholders as explained in the PV ISS Administrative Order (RMN, 2011a) are described in Figure 2.5.

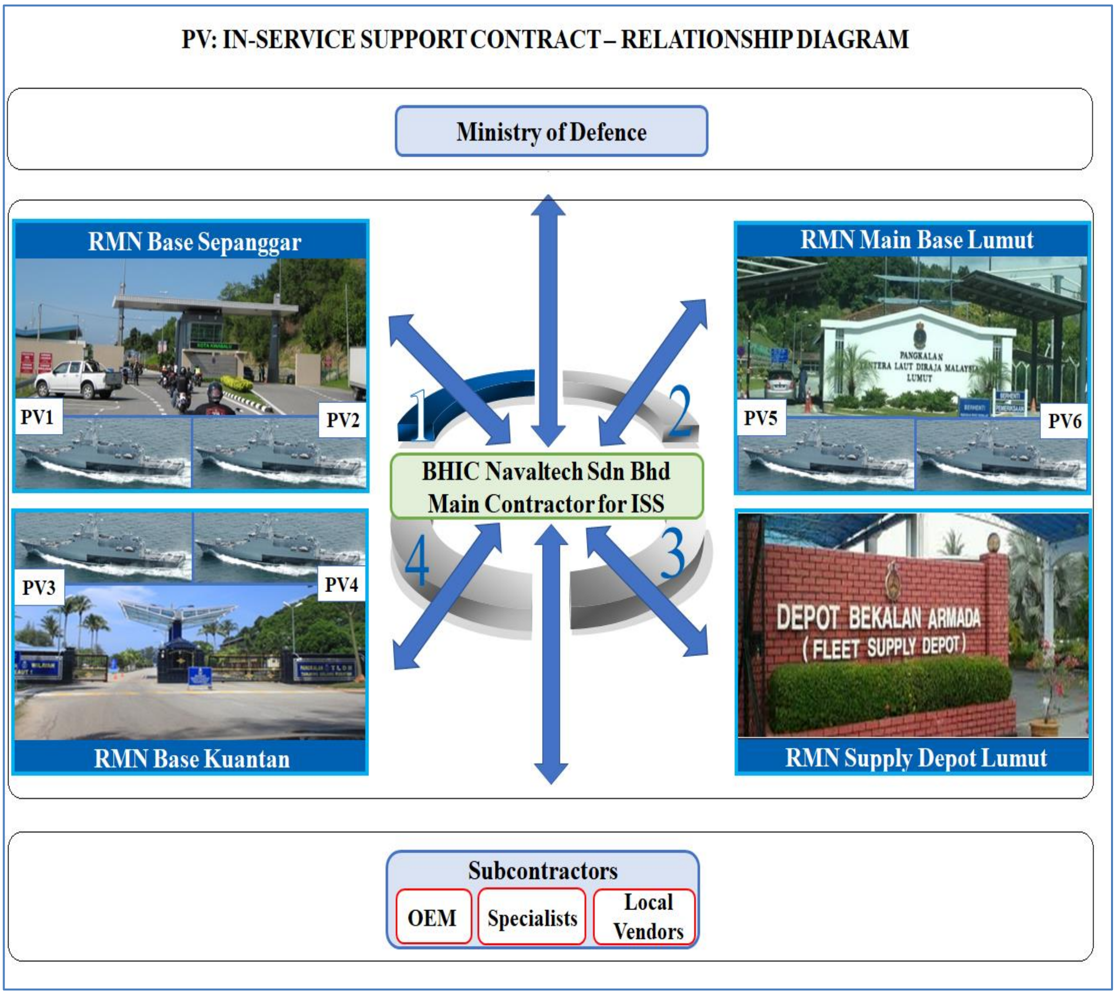


Figure 2.5 Stakeholders and their locations for PV ISS contract

2.2.4 Royal Malaysian Navy's Vision, Mission and Strategic Plan

The RMN's vision and mission from the RMN's official website (RMN, 2018b) is clearly described in Figure 2.6.


www.navy.mil.my/index.php/misi-visi?tmpl=component&print=1

TENTERA LAUT DIRAJA MALAYSIA

SEDIA BERKORBAN

MELINDUNGI KEDAULATAN DAN KEPENTINGAN MARITIM NEGARA

Misi ini bermaksud tugas khusus yang telah dipertanggungjawabkan kepada TLDM dalam menyedia dan mengatur gerak angkatan laut untuk memastikan keselamatan perairan negara semasa aman dan memastikan kemenangan ketika perang.

MENJADI TENTERA LAUT BERTARAF DUNIA

Visi ini bermaksud TLDM berhasrat untuk menjadi sebagai sebuah angkatan laut yang sentiasa bersedia dalam aspek operasi, sumber manusia yang berkeupayaan dan pengurusan proses kerja yang cemerlang.

Figure 2.6 RMN's vision and mission (RMN, 2018b)

The vision translated into English is "to become a world-class navy". This vision means that the navy intends to be always ready in operational aspects, human resources and management processes capable of excellent work. The Mission translated in English, means "protecting the sovereignty and maritime national interest". This mission means the specific task that has been entrusted to the Navy in preparing and arranging the movement of naval forces to ensure security during the country's waters safe and secure victory during conflicts. The RMN's strategic plan 2013-2020 could also be found in the official RMN's website (RMN, 2018c).

2.2.5 Royal Malaysian Navy's new Strategic Programme

During Defence Services Asia (DSA) exhibition in 2016, RMN Chief, Admiral Tan Sri Ahmad Kamarulzaman Baharuddin said because of fiscal challenges and the geopolitics situation in the South East Asia region, the RMN plans to roll out a new transformation and modernization plan called "15 to 5" (RMN, 2016). The "15 to 5" fleet transformation was part of its plan to strengthen and modernize its armada and be cost effective at the same time. He also explained that if the transformation programme is endorsed by the government, the replacement process will be done in stages and that the RMN will focus on building ships from the five classes harnessing the abilities of the local industry. The “15 to 5” transformation plan is illustrated in Figure 2.7.

Figure 2.7 RMN’s “15 to 5” transformation plan

In accordance to Chief of Navy, RMN (Kamarulzaman, 2017), there are currently 15 classes of ships in the RMN, coming from seven nations with an average age of 30 years. This represents a large cost in terms of maintenance and operations. The "15 to 5" plan calls for:

i) Phasing out of the older vessels in the fleet. This would lead to optimized resources.

ii) Improving procurement processes (reduced and optimized procurement requirements, reduced ill practices) would lead to additional savings for the RMN.

iii) Use these savings to fund the "15 to 5" plan, while focusing on local shipyards and defence industry.

The Chief of Navy (Kamarulzaman, 2017) said that the five classes that would form the future RMN would be:

i) New generation patrol vessel (Kedah-class PV)
ii) Littoral combat ship (Gowind-class)
iii) Littoral mission ship
iv) Multirole supply ship
v) Submarines (Scorpene-class)

The RMN fleet would remain at 55 vessels meaning some additional procurement even for existing classes such as the two Scorpene-class submarines already deployed in Malaysia.

2.3 Common challenges of ISS service providers globally

ISS is a common term used internationally. Nevertheless, different ISS contracts are implemented globally, mostly by the armed forces in order to ensure that their asset are able to be maintained and operated continuously until the end of its service life. However, the scope, asset type and duration of ISS contracts vary from country to country. In accordance to Berkok *et. al* (2013) in his paper titled “In-Service Support best practises of selected countries” when comparing the ISS of Australia, France and UK, the ISS implemented in a country depends on the structure and status of the defence sector in the economy. Factors such as geographical location and capability of local industries play an important role in influencing the scope of the ISS contract.

There exists many challenges in the implementation of ISS services and some appear common to many organizations including the RMN, since the length of ISS phase of a vessel is quite considerable (Berkok *et al.*, 2013a, Ford *et al.*, 2015) and sometimes extend to several decades (Erkoyuncu *et al.*, 2009).

Recording of data on defects will often vary, with some vessels recording all defects and some only recording most pertinent defects (Ford *et. al*, 2013). Some navies including the RMN still maintain manually-logged log books according to Fleet Operational Directives and simultaneously input into the maintenance management system. Inconsistency between recorded data and recording errors are understandably a common phenomenon. Lazakis *et. al* (2010) explained the complexity of data acquisition and improper maintenance recordings onboard naval vessels.

Failure to effectively engage with stakeholders is a common cause of project failure (OGC, 2005). Ford *et. al* (2013) reviewed in detail all stakeholder needs for naval surface ship under the ISS contract in the Royal Navy (RN) to reduce the risks associated with the stakeholders. Recent development in shifting from self-reliance to greater levels of industry support in the Royal Australian Navy (RAN) has created new issues on accountability, deskilling of critical engineering functions and a significant issue on large staff turnover (Henry and Bill, 2015). The authors continued to explain the negative effects traced on stakeholders due to frequent name changes, geographical diversity and short staff posting cycles. Shifting from in-house to out-sourced ISS have been significant in many North Atlantic Treaty Organization (NATO) countries since the 1980s (Berkok *et. al*, 2013).

Warships are complex in nature (Dell'Isola and Vendittelli, 2015). Assessment of “material state” of a complex system is often not binary or “objective” in nature such as available and unavailable (Ford *et. al*, 2015). Sometime they are “subjective”, such as available but degraded. According to Ford *et. al* (2015) an optimum “material state” requires balanced information between “objective” and normally measurable data such as temperature measurement, and “subjective” often qualitative data requiring interpretation.

Maintaining high operational availability of complex assets continuously is an unsurmountable task, therefore a large improvement in maintenance could easily be achieved if the complexity of the components is low (Yuo-TernTsai *et al.*, 2004). There are many systems and activities running continuously on a vessel, and it would be normally fair to believe that the ship would be an outstanding overall performer if a significant number of its systems are performing well. However, in actual fact, a high level of performance in just one system may very well render the overall performance of the ship useless. Therefore, contrary to popular belief, consideration on performance of individual systems or activities cannot provide a useful view on overall performance of the asset such as a naval vessel (Dwight, 1999).

In a recent literature called “Operational availability of warships – a complex problem from concept to in service phase” by Dell'Isola and Vendittelli (2015), the requirements of improving ship availability has been rejuvenated, especially the criticality of achieving the balance of availability and life cycle cost (LCC) of warships focusing on proper design process, methods, models and tools to help achieve this. Dell'Isola and Vendittelli (2015) was of the opinion that an ‘availability-based” contract needs to be formulated which is long enough to ensure return on investment for the supplier. This concept has been implemented on the Fregate Europe Multimissione (FREMM) programme of the French and Italian navies, and also to some countries like United Kingdom (UK) and Australia that have moved towards contracting for availability. However, this is not the case for the many navies globally which adhere to their traditional contracts in maintaining the naval vessels, in accordance to their existing policies. Malaysia to date remains with the existing conventional or traditional policy of ‘per-repair’ contracts similar to most navies around the world including US Navy. List of contract problems identified on RMN PV ISS contracts are:

i) Target Availability described in the contract, but not achieved. Similar problem are faced by many navies.

ii) RMN PV ISS contract provisions have not been improved as there has never been any study or analysis conducted for the contract. Extension of contract repeated similar problems over and over again. Similar problems also could not be avoided on ISS contracts for other ship classes.

iii) Likelihood for the RMN of moving from traditional "per-order" based contract to Performance-based Contract (PBC) for surface vessels is very unlikely, as it will incur considerably higher cost. Ministry of Defence (MoD) continues to face budget constraint. Stakeholders are at wits-end to figure out how to improve operational availability with budget constraints, realizing the minimal chance of moving towards PBC.

The challenges on ISS service providers will continue with new technological breakthroughs as it has been for the past decade. The search for a "silver or a magic bullet" that has previously formed an allusion that a "new" method or technological solution or a new contract can provide a fix to complex issues or provide problem resolution at a substantially lower cost and within an improved timeframe. The Rizzo report of the RAN has confirmed that after years of searching by the defence maritime sector, the "silver bullet" has yet to be found (Henry and Bill, 2015).

2.4 Complexity of a Naval Platform as part of a Naval Force

The complexity of a naval platform as an integral part of a naval force is explained in the following subsections. The subsections describe the roles of the navy, the complexity of the navy force planning scenario, naval force capability, naval ship design and complexity of managing equipment and human factors.

2.4.1 Multiple Roles of the Navy

The roles of the navy have also developed into the "trinity of roles". The evolution from Booth model to Leadmark model can be described Figure 2.8.

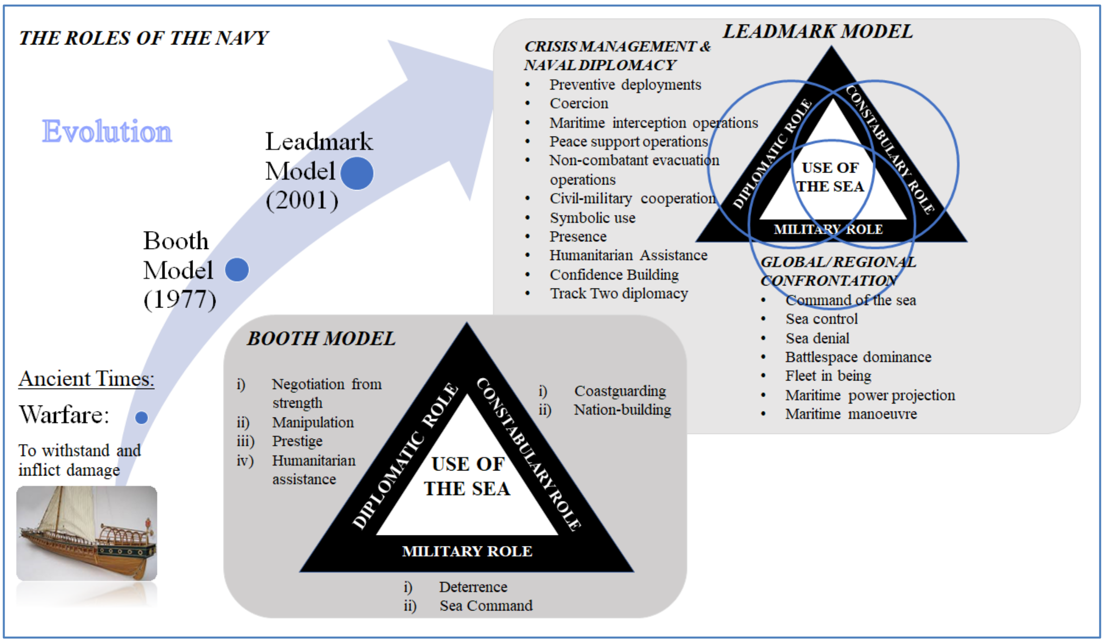


Figure 2.8 Evolution of the "trinity of roles" of the navy (adapted from Leadmark (2001)

The "trinity of roles" of the navy covers three areas namely:

i) **Military role:** Appropriately forms the base of the trinity, for the essence of navies is their military character. Actual or latest violence is their purpose. It is a navy's ability to threaten and use force that gives meaning to its other modes of action. It derives its diplomatic impact from perceptions of its military character. Clearly, it derives its utility in conflicts from its ability to exert brute force successfully.

ii) **Diplomatic role:** The management of foreign policy short of the actual employment of force. Diplomatic applications support state policy in particular bargaining situations or in general international intercourse.

iii) **Constabulary role:** Is internally as much as externally oriented. These roles are rarely concerned with the armed forces of other states; they are mainly concerned with extending sovereignty over the state's own maritime frontiers.

2.4.2 **Complexity in the Navy Force Planning Scenarios**

The naval force planning scenarios and spectrum of conflict reflect the situations during peace, conflict and war. It illustrates the variety and complexity of military operations across the spectrum of conflict as reflected Figure 2.9.

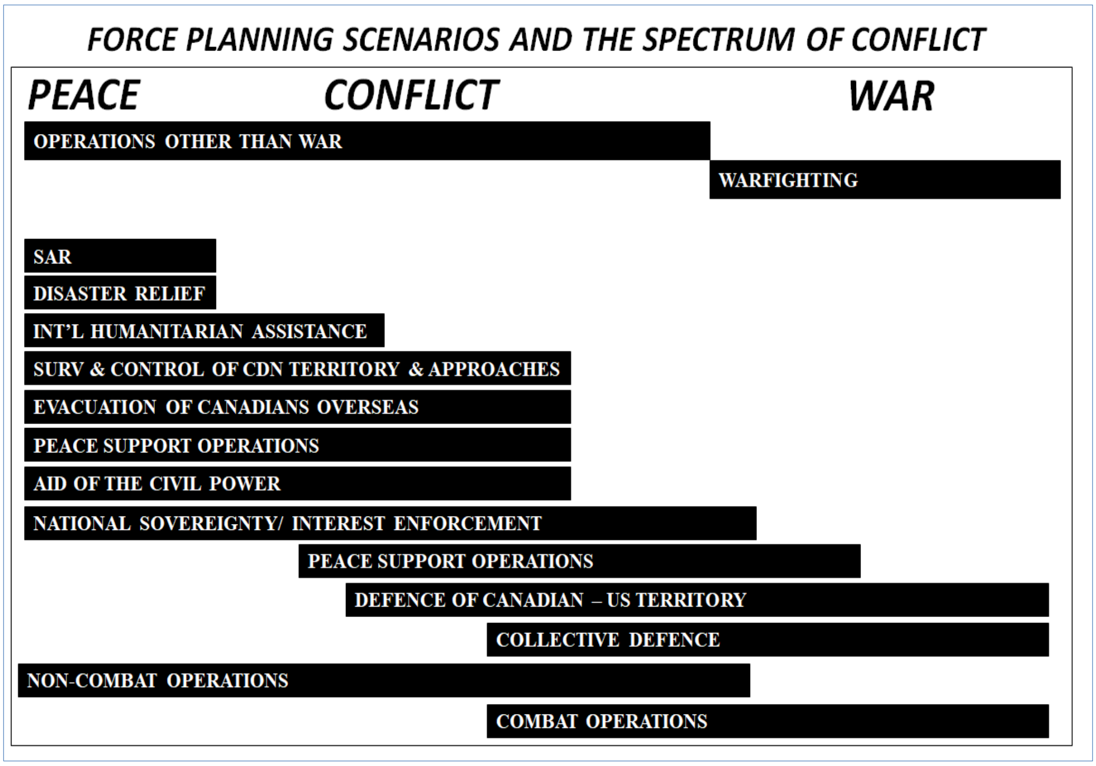


Figure 2.9 The Navy's force planning scenarios and the spectrum of conflict (Royal Navy Canada, 2012).

2.4.3 **Complexity in the Naval Force Capability Hierarchy**

Naval force capability hierarchy is very complex. In naval terms, models of hierarchical complexity could be translated into naval ranks and typology for naval systems of systems (SoS) such as described in Table 2.4.

Table 2.4 Naval SoS levels (Olivier and Ballestrini-Robinson, 2014)

Rank	Typology	Naval SoS Description
1	Complete Major Global Force Projection	Capable of carrying out all the military roles of naval forces on a global scale. It possesses the full range carrier and amphibious capabilities, sea control forces, and nuclear attack and ballistic missile submarines, and all in sufficient numbers to undertake major operations independently.
2	Partial Global Force Projection	Possesses most if not all the force projection capabilities of a "complete" global navy, but only in sufficient numbers to undertake one major "out of area" operation.
3	Medium Global Force Projection	May not possess the full range of capabilities, but have a credible capacity in certain of them and consistently demonstrate a determination to exercise them at some distance from home waters, in cooperation with other Force Projection Navies.
4	Medium Regional Force Projection	Possesses the ability to project force into the adjoining ocean basis. While may have the capacity to exercise these further afield, for whatever reason, do not do so on a regular basis.
5	Adjacent Force Force Projection	Possesses some ability to project force well offshore, but not capable of carrying out high-level naval operations over oceanic distances.
6	Offshore Territorial Defence	Possesses relatively high levels of capability in defensive (and constabulary) operations up to 200 miles form shore, having the sustainability offered by frigate or large corvette vessels and (or) a capable submarine force.
7	Inshore Territorial Defence	Primarily inshore territorial defence capabilities, capable of coastal combat rather than constabulary duties alone. This implies a force comprising missile-armed fast attack craft, short-range aviation and a limited submarine force.
8	Constabulary Defence	Not intended to fight, but ot act purely in constabulary role.

Capability levels transcend across several hierarchical echelons and exist over several functional domains. Illustration of the complex cross-functional capability framework (Olivier and Ballestrini-Robinson, 2014) is described in Figure 2.10.

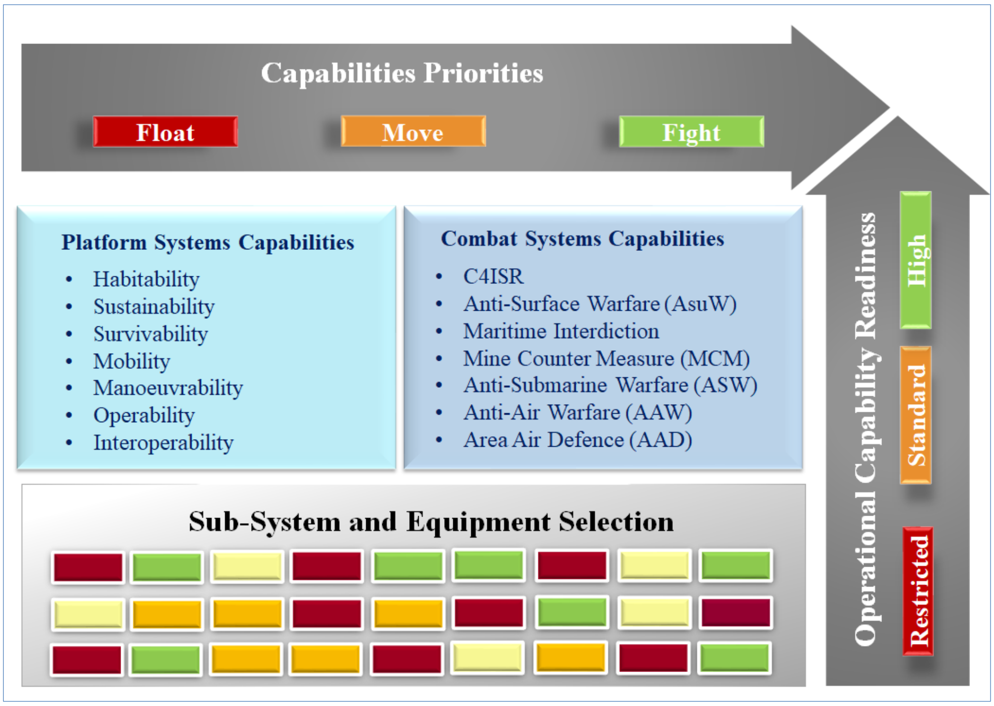


Figure 2.10 Illustration of cross-functional capability framework (Olivier and Ballestrini-Robinson, 2014).

2.4.4 **Complexity in Naval Ship Design**

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 (Australian National Audit Office, 2001). 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 such as cost fluctuations, design parameters, technology selections and mission success (Olivier and Ballestrini-Robinson, 2014). Pascual *et al.* (2008) identified that design complexity as causes of greater risk for asset downtime.

It is true that ship design improvements continue to be researched each day, on improving various ship characteristics such as rudder design (Liu and Hekkenberg, 2016), propeller design (Van der Ploeg *et al.*, 2016), optimizing ship's body (Van der

Ploeg, 2011) and designing ships for minimal fuel consumption (Hagesteijn and Hooijmans, 2011). Nevertheless only a few researchers or designers are able to consolidate these individual design advancements, together with any corresponding impacts to other ship characteristics, into the next phase of a total ship design effort.

2.4.5 Complexity in managing Equipment and Human factors

The ship maintenance activities encompass human and equipment related activities. Therefore, the availability of the naval vessels is dependent on the complexity arising from the blending of equipment and human related factors. There is a complex relationship between the tangibles (equipment related) and intangibles (human related) in achieving the targeted availability of the vessel. There are lots of literature which can be found specifically on equipment and components failure, testing, design, maintenance issues, improvements, and reliability and availability rates such as mean time to repair (MTTR) and mean time between failures (MTBF).

Rosenberger and Pointner (2015) explained that in accordance to EN 50126, availability is defined as the ability of a product to be in a state to perform a required function under given conditions at a given instant of time or given time interval assuming that the required external resources are provided. Rosenberger and Pointner (2015) also introduced availability as in Equation (2.1)

$$A(\%)=\frac{MTBF}{(MTBF+MTTR)} \times 100 \qquad (2.1)$$

Where, MTTR is the period of time required to rectify a defect. MTBF means the average time period between two defects occurring. It is generally calculated on the basis of the component failure rates. Consequently, it is assumed that loss of availability is caused only by component failures.

Rosenberger and Pointner (2015) explained further however in practice, further possible causes of faults must be considered in addition to this value. From his research perspective, such external error sources may be based both on the given technical infrastructure and on other "incalculable" influences. Nevertheless, this has not been taken into consideration when calculating availability. Rosenberger and Pointner (2015) continued to explain that it is apparent that numerous other factors exist that may have a significant impact on both the MTBF and the MTTR, and therefore on the availability of the system. Furthermore, reference is also made to the "external resources". Jonsson (1997) described that an interesting future study would be on studying the links between maintenance management components, and explain the correlation between components and also between high performance, competitive advantage and maintenance components.

These are among the points supporting the researcher's attempt to consolidate both equipment and human related maintenance downtime factors into the research. At the same time, there has been tremendous progress on socio-technical systems which include studies on human factors such as human-factors engineering, usability engineering and ergonomics (Chang, 1999, Sawyer, 1997, Ng *et al.*, 2009, Dunn, 1978, Reason and Hobbs, 2003). However, discussions on human factors have mostly concentrated on minimizing human errors, which can be easily explained by example of the PEAR concept in aviation (Reason and Hobbs, 2003) maintenance which consists of:

i) People who do the job;
ii) Environment in which they work;
iii) Actions they perform;
iv) Resources necessary to complete the job.

Nevertheless, what is most difficult to comprehend therefore most difficult to quantify is the other side of human factors, maybe easier to be referred to human-related factors. These are factors that relate directly or indirectly to maintenance and availability and happening in parallel to issues and faults to equipment and systems. Jonsson (1997) described this clearly with his statement that human aspects and failure of a system are consequently close connected. They co-exist in the real world and there exists so many unexplained interdependencies between these equipment related factors and non-equipment related factors we identify as human-related factors.

The fact remains that these non-equipment related factors can never be calculated or analysed by studying just the issues related to the equipment and system such as by calculating MTTR and MTBF. Nevertheless, these additional factors exist at equal stand to the equipment related factors when studying the factors impacting downtime and ultimately the ship availability. The details of the various equipment and human-related factors to ship availability shall be described in detail in the following sections of Chapter 2. However, there has not been any literature that could be found to date that has successfully consolidated these factors holistically and implement a mechanism to ascertain the ranking and interdependency relationships between them.

2.4.6 **Conclusion on Naval Asset Complexity**

Even though a naval ship or platform may seem to be similar to other assets requiring day-to-day operations and maintenances such as utility networks, power stations, railway system, oil and gas installation, manufacturing and processing plants, wind turbines and airports but a few differences makes it significantly more complex.

The main difference that creates more complexity is that a naval ship is floating and movable. Furthermore, they have cross-functional capability to meet different roles and missions depending on time and conditions and political scenarios. Unlike other assets, the complexity increases rapidly as the naval ships are expected to be able to change its roles and missions in an extremely short turn-around-time depending on situations. As a consequence, the supportability for maintenance also changes depending on ever-changing areas of operations and time-on-mission. Refer to example in the complexity matrix as in Table 2.5.

Table 2.5 Complexity Matrix

Asset Type	Navy Ship (military assets)	Other Assets - static (non-military)
Mobility	Movable.	Static.
Location	Floating in water.	Static on ground.
Roles	Changes during peace, conflict & war.	Fixed.
Strategic Roles	Yes, as part of multi-asset naval force or armed forces.	No.
Operational Equipment & Systems	Sophisticated, hierarchical.	Ranges from simple to sophisticated, hierarchical.
Defence & Warfare Systems	Comprehensive, but difficulty at sea.	Ranges from simple to comprehensive, but less difficult since on ground.
More similar assets	Aviation especially Air Force.	Manufacturing, hospital, wind turbine, mining, offshore platforms, etc.
Complexity	Very complex.	Ranges from simple to complex

2.5 Relationship between Maintenance, Downtime and Availability

The relationship between maintenance of naval ship equipment and systems to uptime and downtime and availability is explained in further details in the following subsections. The objective of these subsections is to elaborate on the relevancy of each concept towards the other.

2.5.1 Maintenance of Naval Ship Equipment and Systems

Lazakis *et al.* (2010) highlighted that initially ship maintenance was considered as a financial burden and that the benefits of applying a systematic maintenance policy to minimize downtime and increase operational availability only emerged in the past few years. The reactive maintenance strategy phenomenon was rampant worldwide, across various industries and through the cultural divide. This negative connotation only changed gradually and maintenance became a separate, fully recognized and essential business function (Pintelon *et al.*, 2000). It was only after World War Two that more attention was attributed to it in aviation (U.S Department of Transportation, 2011) and in addition in other industrial sectors like defence, nuclear, chemical and petrochemical (Mushiri and Mbohwa, 2015).

For the merchant marine sector, the shipping industry has made great progress based on studies and recommendations by academicians as well as consultation by international maritime organizations, governing bodies and classification societies. Classification societies have added value to the maritime industry through the introduction and promotion of highest standards in ship safety and quality shipping (Goh and Yip, 2014). Naval vessels, on the other hand, are of a different category. They have different designs to complete their different missions (Olivier and Ballestrini-Robinson, 2014), 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) and anti-Air warfare (AAW) (Turgut, 2013), electronic warfare (EW), search and rescue (SAR), humanitarian and many other navy related functions (Royal Navy Canada, 2012). Compared to merchant vessels, they differ in their concept of operations, range of equipment, concept of equipment redundancies and vary in their concept and priority of maintenance (Olivier and Ballestrini-Robinson, 2014). They are mostly not forced to adhere to the merchant ship's requirements of meeting the environment standards, and most importantly are not strictly bounded by requirements of meeting the organization's targeted profit as compared to commercial organizations.

Even though it is quite normal for naval ships to have their life-cycle cost calculated prior to delivery, the most visible is normally more evident, that is the acquisition cost. 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. 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' and also due to the unfamiliarity of organizations towards this area, resulting in very limited technical and financial data being collected to study and compare projected maintenance activities and its associated costs, against actual maintenance activities and its associated costs.

From a broad theoretical and practical aspect, maintenance is defined as the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function. Thus observed, maintenance is a complex functional system, united by a single goal and unique criterion function. In engineering sense, the system of maintenance of one machine, device or any other technical system can be realized in various ways and variants. The differences are pointed out according to the ways of looking at maintenance, and the dilemmas regarding the realization of maintenance system in specific cases, are probably most evident in methodologies which reflect the principal approach or maintenance 'philosophy'(Popovic *et al.*, 2011). What does "performing good maintenance" mean? According to Cooke and Paulsen (1997), good maintenance is defined as 1) observing minimal corrective maintenance activities and 2) performing as little scheduled or preventive maintenance as possible.

Out of several possibilities which include conventionally known preventive and corrective maintenance, two basic approaches are popular these days (Wireman, 2004) and (Vasic *et al*., 2006):

i) Reliability-centred maintenance (RCM) and
ii) Total productive maintenance (TPM).

Maintenance decisions in the case of RCM methodology should be theory based, which means they are to be made after a long-term and thorough study of all the characteristics of the system being maintained, especially on the basis of reliability characteristics. When it comes to TPM methodology, maintenance is decided on the basis of the system current state which is followed and observed, especially in the aspect of task solving efficiency; that is the effects which are accomplished through its work. RCM methodology is based on reliability theory and other disciplines of system sciences.

This methodology is, above all, directed to preventive maintenance, but enables managing all kinds of corrective maintenance, as well. The main precondition for RCM methodology application is the existence of a complex information system which provides data on failures and the procedures for their overcoming. Unlike the previous, TPM methodology is much simpler, and therefore much cheaper. However, according to Vasic *et al*. (2006), it should be acknowledged that a TPM implementation is not a short-term fix programme and requires continuous effort of introducing this new mind-set of equipment management to the organization.

It is based on the insight into the system state at every moment, and the experience of maintenance decision makers, and hence does not require detailed information on reliability and the events from the previous period. Thus, TPM methodology is flexible and it enables making decisions about maintenance for units and machines that are used relatively shortly, as well. Since RCM and TPM methodologies are rather conflicting and differ in many important details, it is logical to find a compromise solution between those two approaches (Popovic et al., 2011). Figure 2.11 describes the three basic goals of TPM, namely zero defects, zero breakdown and zero accidents as introduced by Fredrikkson and Larsson (2012).

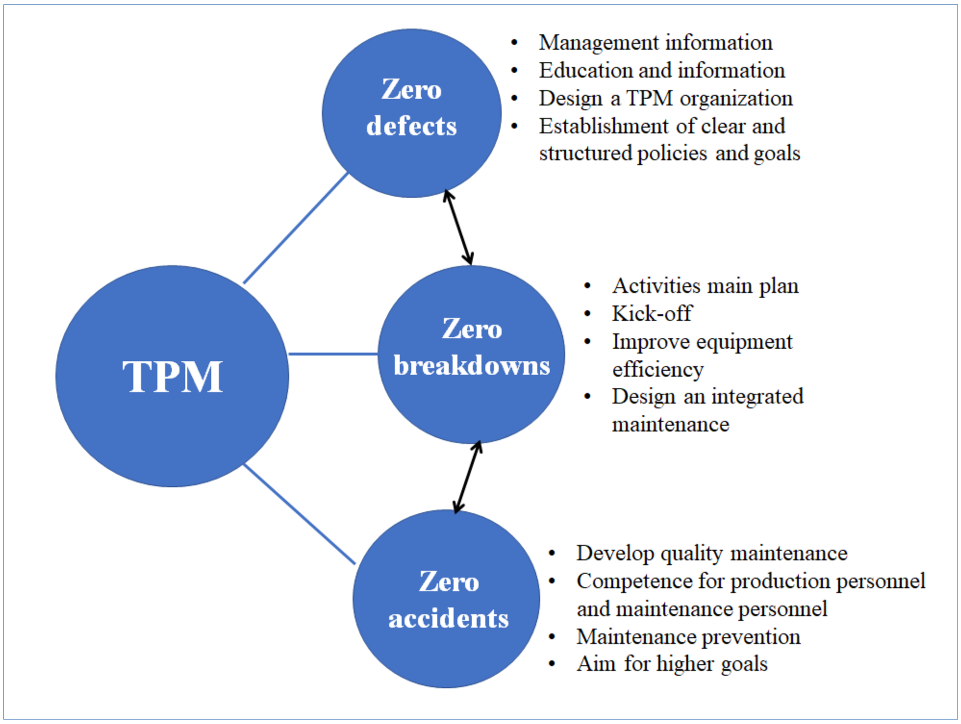


Figure 2.11 The three basic goals of TPM (Fredrikkson and Larsson, 2012)

These approaches still remain confusing to many organizations whose prime priority is to conduct whatever maintenance required as long as they are following established procedures and the results are recorded. Coupled with the complexity in the process of designing the appropriate maintenance system the aim remains for researchers in finding compromise solutions regarding the relations among different maintenance procedures and the ways of their implementation.

2.5.2 **Uptime and Downtime**

The relationship between uptime and downtime as well as the components of both is best described in Figure 2.12 as adapted from Hou Na *et al.* (2012). Decreasing downtime will proportionately increase the uptime, and uptime denotes availability which will be defined in the following section. According to the authors at present there are various understanding of downtime. In relation to the PV ISS contract the interpretation of the elements are as follows:

i) The "time" element has to be interpreted as the ship time rather than solely the equipment or system time.

ii) "Inactive time" could be attributed to ship extended docking.

iii) The "operating time" would include sailing as well as anchoring.

iv) "Not operating time" can be assumed as standby in harbour, similarly to alert.

v) Under "maintenance time" in addition to corrective maintenance (CM) and preventive maintenance (PM), predictive maintenance, emergency repair and docking and maintenance training should be considered as downtime.

vi) Under "delay time", both "support" and "action delay" time could be further subdivided into delay time due to customers and delay time due to contractor.

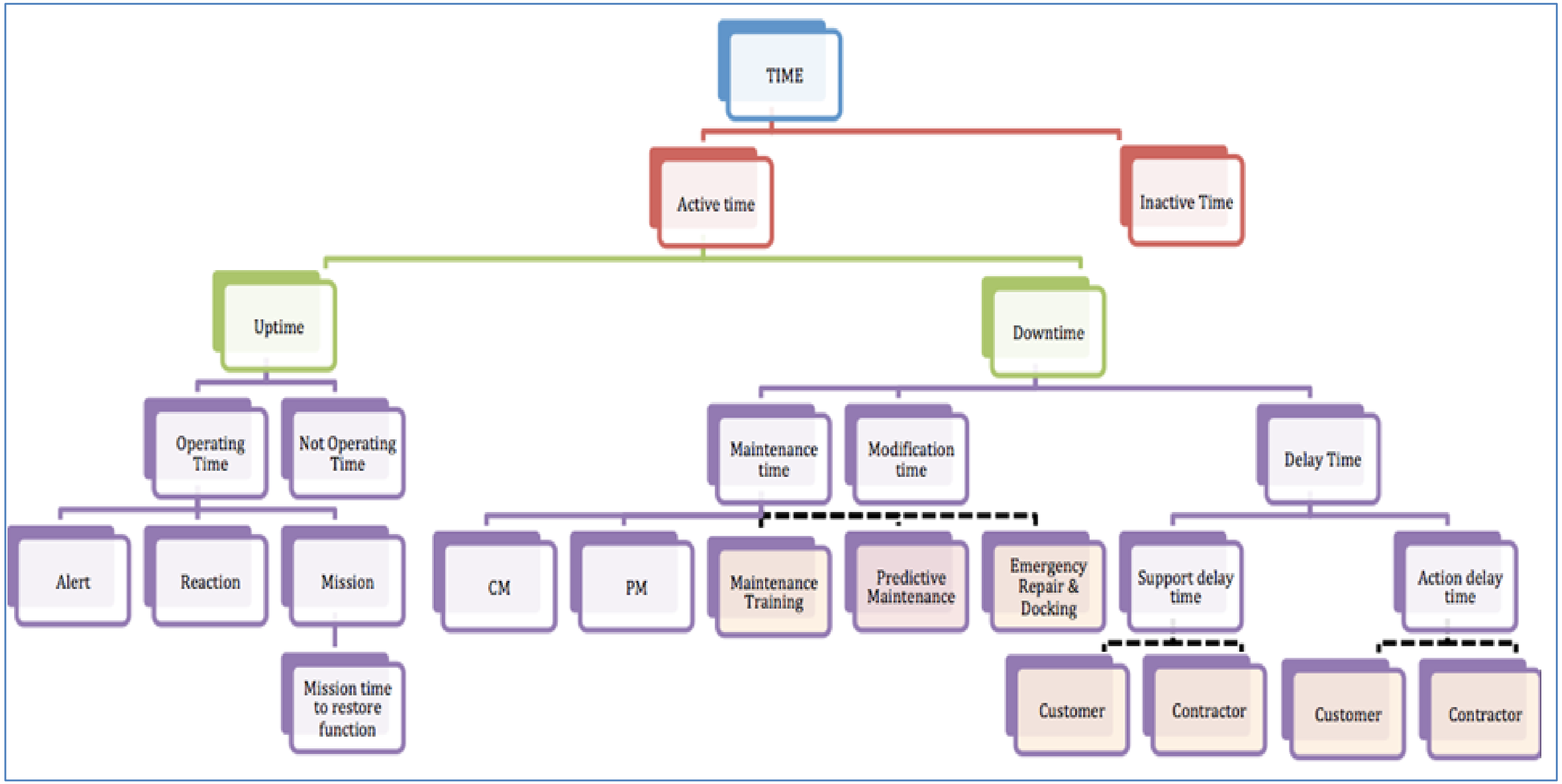


Figure 2.12 Relationship between uptime and downtime including the components (adapted from Hou Na *et al.*, 2012)

2.5.3 **Availability**

The definition of availability varies from country to country, and also between fields and applications. For purposes of this study the definition of operational availability has been defined in the operational definitions in Section 1.9. Operational availability is specifically further defined as the ship's ability to sail, meaning float and move, with basic capability for fighting and defence. The availability of a naval vessel is reflected to the hierarchical capability decomposition chart in Figure 2.13.

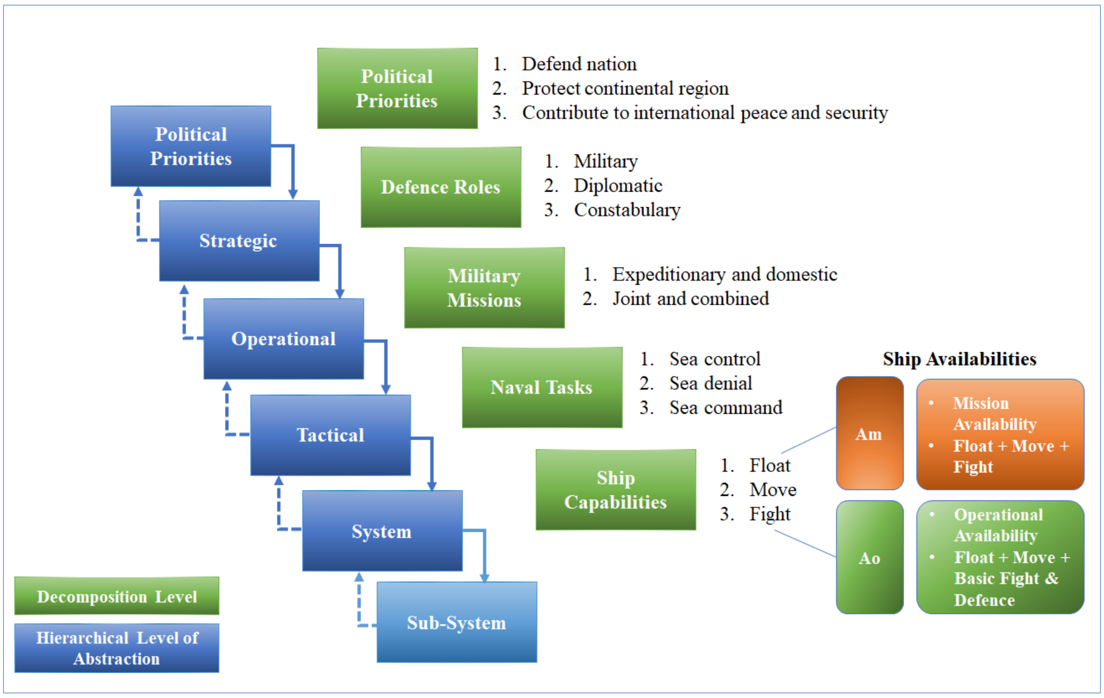


Figure 2.13 Hierarchical capability chart with types of availabilities (adapted from Australian National Audit Office, 2001)

The normal types of availabilities familiar to the RMN included operational availability (Ao) and mission availability (Am). Mission availability means the probability or length of time that the ship is available and capable of performing its intended mission of war-fighting, therefore the state of the systems and manpower onboard has to be significantly higher than the operational availability of the vessel. For this research, the ship availability is focused on its ability to float and move as a naval vessel, albeit with basic fighting and defence systems in place as a deterrent mechanism. Mathematically, availability is expressed as "1 minus unavailability" as in equation 2.2.

$$\textit{Availability (Ao)} = 1 - \textit{Unavailability (U)} \tag{2.2}$$

Therefore, the more we reduce the unavailability or also known as downtime, the higher the availability figure shall be. As explained in Section 1.4, it is also crucial to point out that for purposes of this study concerning availability of ships in accordance to the implementation of ISS contract of naval vessels in Malaysia, the scope is constrained to 'operational ships' in the fleet which does not include extended downtime for ships undergoing major refurbishment or refit as they are not included in the ISS contract and therefore not included in the study. In the RMN, the standard or reference used for determining whether the vessel is considered operational or not has been based on the Fleet Operations General Memo No 5/2000 Urgent Defect Readiness Report (Fleet Operational Commander ORDR, 2000) and the Fleet Operational Directives.

The commanding officer of each vessel would manually provide declaration of the ship's status of readiness whether under category one, two, three, four and five. Based on the categories, the ship would be considered operationally available or otherwise, similar to whether the ship would be mission available. This top-down manual-approach has remained in the RMN, sometimes called return of vessel availability (ROVA), as opposed to many other navies that have embarked on bottom-up system-approach whereby the availability is automatically calculated based on feedback received from the equipment and systems. When the designated equipment and systems are defective or non-operational, the resulting status would be that the ship is not operationally available. This is consistent with Balafas *et. al*, (2010) that the readiness measure of the ship as a warfighting asset is the operational availability.

A good example of availability relationship to maintenance involving equipment and human related factors is best described by Life Cycle Engineering (2018). High failure rates for diesel engines threaten ship availability and mission readiness. Nevertheless, most failure were not caused by manufacturing or latent defects but as a result of other non-equipment related factors including insufficient training, change in inspection process, shift in maintenance process, increase complexity of control systems and wrong choice of lubrication. When efforts were placed to overcome the challenges, the availability increased from 52% to 96%.

2.6 Significance of Implementing Most Effective Maintenance Strategy

This section describes the significance of implementation of the most effective maintenance strategy. The background of maintenance, shipbuilding contracts leading to ISS contracts and categories of maintenance activities is detailed in the following subsections.

2.6.1 Background

According to a study conducted in 1989, the estimated cost of maintenance for a selected group of companies increased from $200 billion in 1979 to $600 billion in 1989 i.e. three-fold in just 10 years (Wireman, 1990). On the other hand, the overall equipment effectiveness (OEE) for a typical factory is only 45% (Kotze, 1993). OEE is a function of equipment availability, performance efficiency and quality rate of products. It is the performance metric often used for TPM (Nakajima, 1988).

The above paragraph indicates that if maintenance is handled effectively there is a scope for improving the profits and productivity of a company or organization. For maintenance to make these improvements it should be recognized as an integral part of business strategy or the competitive strength equation (Hora, 1987). In particular, there is a growing need to understand the relationship between a company's business and maintenance strategies. Lack of understanding of this relationship and only cutting down the costs of maintenance can affect the company's competitive strength equation and its ability to compete in the market (Pinjala *et al.*, 2005).

Proper maintenance would improve the quality, efficiency and effectiveness of production systems, and hence enhance company competitiveness, i.e. productivity and value advantages, and long-term profitability (Alsyouf, 2004). This statement is further supported by a survey (Pinjala *et al.*, 2005) conducted in a sample of about 150 companies within Belgium and to some extent in the Netherlands. In this paper, the result of the empirical study shows that companies with different competitive priorities (business or organizational strategies) pursue different maintenance strategies. The results indicate that quality competitors have more pro-active maintenance policies, better planning and control systems, decentralized maintenance organization structures when compared to others. They manage maintenance much more effectively when compared to others. There is also a difference in the distribution of advanced manufacturing technologies (AMT) usage, automation, maintenance personnel (management/supervision and technicians), expenses and budget figures. Quality competitors have more AMT usage, automation, maintenance personnel and spend more on budget, followed by cost and flexibility competitors.

As a simple example of the relationships, we take note that maintenance complexity has increased over the years (Morrison and Upton, 1994). The level of variety in the technology used to manufacture products causes another complexity in maintenance problem (Blaikie, 1993). It is a known fact that maintenance has a crucial role to play in achieving superior product and service quality, and cost effectiveness of operations. This means more focus is needed in some of the maintenance strategy elements like maintenance modifications and human resource policies. With more equipment design modifications and continuous improvements, the number of maintenance tasks required can be reduced and hence the related costs. Moreover, complex maintenance environments require high training and recruitment of professional staff and crew with high skills. In addition, more team-oriented maintenance involving production operators is crucial to maintain product quality and reduce maintenance costs. Interestingly, it was concluded as one of the findings of the survey of 150 companies that in most companies, teamwork is still at a medium level. This may be an effect of worker's attitude, training level or management philosophy (Pinjala *et al.*, 2005). Role of leadership is therefore proven to be crucial.

TPM is having a major impact on bottom-line results by revitalizing and enhancing the quality management approach to substantially improve capacity while significantly reducing not only maintenance costs but overall operational costs (Kennedy, 2005). In other words, there is a clear relationship between business and maintenance strategies. Nevertheless, prior to 2005, there were meagre or no direct studies on the relationship between business and maintenance strategies (Pinjala *et al.*, 2005). Due to this fact there is to date limited literature available on this matter.

2.6.2 Shipbuilding Contract prior to In-Service Support Contract

In accordance to the PV shipbuilding contract (Government of Malaysia, 2000), the five main stages are Pre-Contract Signing, Design, Procurement, Construction, Test & Trials and Delivery, Early Post Delivery (Warranty Period) and Subsequent Post Delivery (ISS Contract). During the warranty period, the ship has been handed over to the navy and commissioned. However, the ship is still under warranty by the shipbuilder for a period of one year. Two warranty engineers are assigned by the shipbuilder to be onboard the vessel to provide warranty support during this 1-year duration, as well as to provide continuous training to the ship crew. During this warranty period, the ship shall be operated by the navy and all onboard maintenance shall be conducted by the navy personnel. Certain equipment and systems such as the guns and weapon systems would normally have extended warranty period between three to five years after the delivery period. Following the end of the warranty period, the ship shall be completely under the responsibility of the navy for the operations and maintenance activities. Unless an ISS 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 crew and support team personnel allocated to maintain the ship. The ISS contract should be signed with a reasonable budget, otherwise maintenance of the vessel would be on piece-meal basis and problematic due to minimal budget allocated.

In accordance to Ford *et al.* (2013) the in-service support (ISS) phase is considered 70% of the ships through life cost. During ISS phase, the number of involved stakeholders will vary as the vessel cycles through tasking, upkeep and regeneration. A maintenance or ISS contract for the vessel should be prepared, negotiated and awarded. As soon as the ISS contract is awarded, a dedicated team of personnel from both the contractor and the navy would be given a dedicated budget to enable them to work closely in coordinating provision of spares and services by the various OEMs and vendors. Traditionally the ISS contract would be given for three years and would normally be extended for three years terms until the end of the ship's life of approximately 25 to 30 years later.

The maintenance activities in accordance with the ISS contract happens in stages in accordance to the maintenance cycle. Numerous maintenance cycles happen concurrently onboard the ship on a daily basis, and some may even happen concurrently. During the contract period, there would be uptimes and downtimes for the naval vessels, of which the ship availability is calculated. Various factors impact availability of the vessels, but there is no recorded information, guideline, framework or model previously or in the contract to manage this. At the end of the 3-year PV ISS contract period, contract closure exercise takes place but minimum efforts are placed to capture lessons learned including the conduct of availability study for purposes of improvement. Instead, the priority given to everybody is to hasten the process of contract extension.

2.6.3 **Categories of Maintenance activities onboard Naval Vessels**

Balafas *et al.* (2010) described the normal categories of maintenance activities in the military including onboard the navy vessels as follows:

i) Operator level maintenance (OLM) - which is normally carried out by ship crew using onboard spares. This basically is the simplest level of maintenance to be conducted onboard the vessel, which does not require sophisticated training, tools nor does it take too long to complete.

ii) Intermediate level maintenance (ILM) – This is a higher level of maintenance that requires a more comprehensive approach which may take a longer period of time to complete, require special tools and specialized training. There are some minor differences between various ISS contracts whereby some contracts do allow some ILM work to be carried out by ship crew and the majority to be carried out by the shipbuilder or the shipbuilder's nominated vendors or OEMs. But the common and effective concept is to have all the ILM activities be coordinated by the shipbuilder, and through the vendors and OEMs nominated by the shipbuilder as the contract holder.

iii) Depot level maintenance (DLM) – This is a highest level of maintenance that is normally conducted by the shipbuilder and the OEMs, which requires the most sophisticated tools and spares, and would normally take an extended amount of time to complete. The DLM maintainers are specially trained for this scope of work and are normally trainers themselves.

Several navies around the world including the RMN implement this OLM, ILM and DLM concept of maintenance as part of their ILS requirements. The Royal Australian Navy (RAN) through Henry and Bil (2015) has reduced the recognized maintenance categories from the OLM, ILM and DLM to only two levels; organic (ship level) and external (not conducted by ship's crew). The researcher found that it is still similar as the original concept of OLM for ship's crew while the ILM and DLM are conducted by external parties.

2.7 Downtime Influence Factors to Availability of Naval Ships

There are various literatures that have been written by multiple authors over the years on factors impacting availability of equipment, systems and plants. Nevertheless, there are only a limited number of literatures on factors impacting downtime specifically on naval ship availability. This is not a surprise, as attempts to investigate consequences and causes of downtime are rarely found Prasertrungruang and Hadikusumo (2009).

2.7.1 Equipment and Systems

Forsthoffer (2005) in his book called "Auxiliary Systems" claimed that 60-70% of unscheduled critical equipment shutdown are caused by auxiliary systems. Sinnasamy *et. al*, 2017 studied the condition-based monitoring system of the diesel engines onboard the RMN vessels, and acknowledged that any malfunction or failure would jeopardize the military operation of the navy. There have been many literatures from various disciplines discussing about downtime of equipment of systems, and mostly focus on a single equipment such as Al-Najjar (1998) on roller bearings for paper mills, Papavinasam (2013) on corrosion control impacting downtime for oil and gas industry, Odeyinde (2008) on rotating equipment in refineries, GAO (1981) on factors to improve availability of missiles, WEC/ UNIPEDE (2001), WEC/ UNIPEDE (1991) and Glorian and Spiegelberg (1998) on thermal generating plants, Lazakis *et al.* (2010) for naval ship diesel engines, Rosenberger and Pointner (2015) signalling system for railways and Nepal and Park (2004) for construction equipment. WEC/ UNIPEDE (2001) on power plants including nuclear recommends for countries that are able to do so to divide the overall unavailability factors into unavailability of the industry's designated seven main components.

The normal approach would be to study these items as critical equipment or focused components, with a natural assumption that they will be affecting the availability or reliability of the total asset such as a factory, refinery, mill or a naval ship. However, Balafas *et al.* (2010) raised the issue that many authors tend to limit their research and modelling to a limited number of parts, such as those that are most costly to buy or repair. Therefore, based on this, the researcher aims to go beyond the norm by widening the scope to include the complete range of systems on the whole ship.

The common usage of terms includes MTTR and MTBF, which have been described in detail in Section 2.4.5. Since this research is focused on naval ships, the equipment and systems have been broken down further into segments which relate to ship work breakdown structure (SWBS). Therefore, the equipment and systems are broken down into hull and design, main propulsion, electrical, weapons systems including guns and missiles, auxiliaries and outfittings. Each SWBS segment play an important role to the naval ships, nevertheless some segments may be ranked higher than the rest based on the of ship operational availability definition selected for this study.

There is abundance of research material from many disciplines that studied the downtime of equipment and components including efforts on simulation and modelling, such as Dell'Isola and Vendittelli (2015), Forsthoffer (2005), GAO (1982), Rosenberger and Pointner (2015), GAO (2014a), GAO (2014b), GAO (2014c), Bloch and Geitner (2012), Jardine *et al.* (1996), Allred (1995), Prasertrungruang and Hadikusumo (2009), Glorian and Spiegelberg (1998), IAEA (2005), Dhillon (2002), Sinnasamy *et al.* (2017). Therefore, equipment and systems are justified factors to downtime and operational availability of any asset.

2.7.2 **Maintenance Policy**

In a paper by Edwards *et al.* (1998), maintenance policy is critical on construction plants. Maintenance policy is a factor raised by Dell'Isola and Vendittelli (2015) affecting operational availability. In the paper on maintenance spare parts planning in Driessen *et al.* (2010), maintenance policy has been described again as an important factor. A paper on maintenance policy selection for ships using analytic hierarchy process (AHP) was written by Goossens (2015). Maintenance policy has been discussed again in papers by Jazouli and Sandborn (2011), Alabdulkarim *et al.* (2015), Colosi *et al.* (2010), Operational Availability Handbook (July 2004), GAO (2014b), GAO (2014c), Sullivan (2011), Stackley (2009), Dhillon (2002), Jonsson (1997), Gits (1994), Ford *et al.* (2013), GAO (1982), Jardine *et al.* (1996), Marquez and Gupta (2006), Pascual et. al (2006), Park *et al.* (2010), Nepal and Park (2004), Stambaugh and Barry (2014) and NAVSEA (2014).

For the Irish Navy, a constraint-based approach to ship maintenance paper by Boyle *et al.* (2011) also described the importance of having a maintenance policy. Colosi *et al.* (2010) described the effects of personnel availability and competency on fleet readiness through its impact on maintenance policy. Farajiparvar (2012) indicated that in Iran, the concept and philosophy of maintenance has not been understood in most Iran industries, thus more investment is strongly required to improve maintenance conditions. Resorting to failure and failure-based maintenance policy is still being applied as the common strategy in Iran. Maintenance policy therefore is a proven factor impacting operational availability, due to its influence on downtime.

2.7.3 Awareness on Importance of Maintenance, and Attitude

Attitude is one of the factors recorded by GAO (1982) that limit the availability of F-15 aircrafts. Another study by Leva *et al.* (2013) also described the same for aviation segment. Geitner and Bloch (2012), highlight the importance of having self-motivated engineers' attitude is also mentioned. Geitner and Bloch (2012) further described that 42% of the failure causes of US plants are due to attitude. Morris and Sember (2008) explained the issues of morale and attitude of customer involved in maintenance including existence of unreasonable customers. The Social Security Administration and Information Technology special report (U.S. Congress, 1986) also described the problems relating to attitude which include fraud and sabotage. Risk management in construction projects by Banaitiene and Banaitis (2012) paper also included issues related to attitude when it comes to owner dissatisfaction and contractor's attitude. A paper by Attwater *et al.* (2014) with regard to measuring performance of asset management systems also mentioned about attitude issues when it involves complacency. GAO (1982) described issues faced in the maintenance of US Air force F-15 aircrafts whereby mechanics frequently remove aircraft components which they suspect are broken and send them to testing and repair. However, many components when tested are found to be in perfect working order. This is an indication of either an attitude or awareness problem.

A study on the causes of military turnover by Mafini and Dubihlela (2013) related to technical air force personnel found that some of the individual-related factors were dissatisfaction and commitment issues, related to job attitude. Management attitude in refusing to implement any maintenance policy and strategies in their Ghana manufacturing firms has led to plethora of renovations and replacement of structures and equipment which has cost the nation dearly in monetary terms and has stunted national growth (Obeng-Odoom and Amedzro, 2011). Project stakeholders varying attitudes towards project success is also described as a factor by Zahedi-Seresht *et al.* (2014). In a paper on improving reporting and coding of human and organizational factors in event reports by Chang for WANO (1999), low morale and attitude has been categorized as factors that affected reporting.

Another empirical study by Blaikie (1993) shows that 75% of maintenance problems can be prevented by operators at an early stage, by frequent looking, listening, smelling and testing. Awareness and attitude have been highlighted by numerous other authors confirming that it qualifies as factor impacting downtime. There are other literatures concerning awareness and attitude. (Jonsson, 1997; Marquez and Gupta, 2005; The Social Security Administration and Information Technology Special Report, 1986).

2.7.4 **Maintenance Budget Allocation**

The overall goal of the naval ship structure service life considerations as per Stambaugh and Barry (2014) is 1) to achieve minimum total ownership cost (TOC) and reduce risk of required operational availability, 2) maintain ships as 'reliable performers" having a lower average annual downtime, 3) avoid cost of unplanned maintenance from emergency dry-docking often exceeds available maintenance budget and 4) reduce losses due to lower operational availability. Reduction of support budgets is also factor raised by Dell'Isola and Vendittelli (2015) affecting operational availability.

In a report in Jonsson (1997), US Navy claimed that they discussed budget and cost issues, including maintenance and modernization costs, but failed to prepare the decision memorandum because they were under time pressure to identify budget savings. In a paper on Transforming Wartime Contracting (Commission on Wartime Contracting, 2011), management of budget is listed as one of the crucial factors on overall controlling of cost and reducing risk. Operations budget was listed by Dhillon (2002) who described budget as a factor for equipment maintenance. GAO (1982) described the problems faced in maintaining F-15 aircrafts of the US Air force whereby in many cases facilities are not fully operational due to budget constraints and aged facilities which created significant downtime.

Lock (2014) described availability of required funds (cash flow and budget) are among factors to effect success, similarly to Walker (2005) that explained the problems of tightening budgets. Other papers that stressed on budget as a critical factor include Bateson (1985), Kazi (2005), Sullivan (2011), Swanson (2001), Henry and Bil (2015), Garel (2013), Romzek and Johnston (2002), Nepal and Park (2004), Stambaugh and Barry (2014), Apte *et al.* (2008),Yuan (2016), Atkinson (1999), Pascual *et al*. (2006), Koehn *et al.* (2004), Eckstein (2016), Erwin (2014), Balafas *et al.* (2010), Odeyinde (2008) and Seresht *et al*. (2014).

2.7.5 **Information Management**

A paper by Cox (2014) studied the management of information modules by examining the issue of information management from both a business and an information technology (IT) perspective. It also describes the issues on lack of information management, as similarly studied in GAO (2002) and Ljungberg and Grundén (2009) on managing and preserving electronic records. Belkhamza and Zakariya (2012) studied the measurement of organizational information systems success, describing the new technologies and practices. Mathew *et al.* (2006) revealed how crucial information management is on asset management. Some problems on army vehicle maintenance was found by Harz (1981) as partly due to information management problems.

Nevertheless, new emerging technologies such as big data analytics have the potential to create a significant impact in the shipping industry (Zaman et *al.*, 2017). In the recent years, new software AMPS7.0 (Atos, 2015) has been developed to support big data initiatives in asset management". The SEA-CORES (University Southampton, 2016) has been developed in response to the increasing complexities of modern warships and the amount of data their systems produce. The technology could transform how the Royal Navy and BAE Systems maintain and support warships in the future by using the genetic algorithms to identify the relationships between a ship's systems, calculate their different permutations and ultimately recommend a strategy to optimise the vessel's performance. The Singapore Navy has also began leveraging data analytics for predictive maintenance in enhancing its operational effectiveness (Naval Technology, 2018).

Other literatures that discusses information management includes GAO (1982), Ford *et. al* (2013), Geitner and Bloch (2012), Jonsson (1997), The Social Security Administration and Information Technology Special Report (1986), IAEA (2005), Jardine *et al*. (1996), Dekker *et al* (1998), Keating (1996a), GAO (2002). Therefore, information management is one of the factors that have been found to affect downtime of equipment and systems.

2.7.6 **Preventive Maintenance**

Preventive maintenance (PM) is a factor raised by Dell'Isola and Vendittelli, (2015) and Rosenberger and Pointner (2015) as affecting operational availability. Edwards *et al.* (1998) argued about some PM incurring unnecessary costs. Dhillon (2002) also explained about PM as part of his failure modes and effect analysis (FMEA) approach in engineering maintenance. When studying factors that impact component downtime, Pecht (2009) explained that PM is advantageous for products and parts whose failure rates increase with time such as wear out.

Pogačnik *et al.* (2015) reported on the aviation industry that buying new asset as a possible solution to reduce operational and maintenance costs implicitly means breakdown or corrective, because PM remains the same. Marquez and Gupta (2006) describes PM as part of the overall maintenance management (MM) complexity, while Katsikas *et al.* (2014) explains about the importance of monitoring vessel performance which costs at least USD20,000 a day not including repair costs, PM and predictive maintenance. A comparison between corrective maintenance (CM) and PM is elaborated by Kadry (2013). PM is also explained by Alabdulkarim *et al*. (2015), described the difference between onboard based PM and harbour based PM.

Pan *et al.* (2012) introduced a single machine-based scheduling optimization model integrated with PM policy for maximizing availability. Mathew *et al*. (2006) explained on the negative sentiments surrounding maintenance activities including PM, which is part of total ownership cost (TOC). TOC seeks to combine aspects related to acquisition cost, operating cost, maintenance cost, and man power costs (both staffing and training) over the life-cycle of the system.

Marais *et al.* (2013) explained that deferring maintenance allows the cost of performing maintenance to be postponed, saving short term cost, but the choice to defer maintenance may also result in the system moving to a state of further degradation. As a result, later maintenance task needed to restore the ship's capability or reliability may become costlier. While these trade-offs are conceptually well understood, they have not been adequately quantified to allow decision makers to make the best decisions when found are constrained. Without maintenance especially PM, long-lived systems will deteriorate due to use or age. PM is especially important for costly systems that are subjected to punishing tasks, such as navy ships.

When performed properly, maintenance not only ensures the proper functioning of the ships but proper maintenance can also reduce the TOC by extending a ships lifetime, when required by programmatic decisions and by reducing the ships operating costs. However, many US Navy fleets are plagued with less than expected availability and shorter than hoped lifetimes, which increase TOC. Therefore Marais *et al*. (2013) explained that deferring PM has three main effects:

i) The system deteriorates more rapidly, bringing the time at which failures are unacceptable frequent earlier in the system's life
ii) It increases the cost of bringing the system back to the desired reliability
iii) It may result in reduced performance. Thus, deferring PM can increase TOC and decrease expected service life.

Popovic *et al.* (2011) described PM as predetermined maintenance at his institute in Belgrade, as one of the five categories of maintenance concepts implemented at the Institute for Manufacturing Bank Coins and Bank Notes. He claimed that this affects about 20% of his issues on the maintenance of the machines. Other supporting literatures justifying that PM affects downtime and should be listed as one of the factors (Driessen *et al*., 2010; Geitner and Bloch, 2012; Jonsson, 1997; IAEA, 2005; Gits, 1994).

2.7.7 **Corrective Maintenance**

Following the statement by Marais *et al*. (2013) in Section 2.7.6 concerning PM, continued to explain that the impact of deferring CM for a single unit system is obvious. The system is not available and performance goes to zero. Once the unit has failed, reliability no longer has any meaning if it is not repaired. In contrast, consider the impact of deferring CM on a multi-unit system, by definition CM is needed when a unit has failed. Ignoring for the moment the possibility of redundant backup units, deferring CM of a failed unit results in system performance loss caused by the failure continuing, but the system may still be functioning but degraded. CM is a factor raised by Dell'Isola and Vendittelli (2015) affecting operational availability.

Deris *et al.* (1999) continued that if the failure of the unit does not affect the remaining units, the reliability of the system is not affected. In contrast, if other units are affected, either by deteriorating more rapidly as a result of the failure or by having to work harder to compensate for the failure, those units and hence the system becomes less reliable. Popovic *et al*. (2011) also called this as “domino effect”, whereby the failure in question affects other neighbouring machines in the production process.

Eti *et al.* (2004) stated that many industries in Nigeria operate productively for less than then 50%, part of this embarrassment is caused by high downtime. He explained that frequent maintenance and breakdown maintenance (corrective) are among factors impacting the extended downtime. Weibull (2017) explains about the factors affecting availability which includes CM for components failure. Cooke and Paulsen (1997) described the seriousness of CM which he considered as “critical failure’ which requires shutdown. Dhillon (2002) explained about CM avoidance and failures. Ross (2009) compared planned maintenance to CM, and that considerations of human factors can reduce the impact of maintenance on cost and downtime.

Popovic *et al*. (2011) described CM as one of the five categories of maintenance concepts implemented at the Institute for Manufacturing Bank Coins and Bank Notes in Belgrade, alongside predictive maintenance, condition-based maintenance, predetermined maintenance and opportunity maintenance. In his report, he claimed that CM has significant impact on his machines. Another proof that CM is a serious issue on maintenance is the statement by Marais *et al*. (2013) that over the DDG 51 Arleigh Burke Class Destroyer programme lifetime, more than 80% of maintenance performed has been CM. She also claimed that large proportion of CM is not unusual for different class of surface ships. Jonsson, (1997) explained the results of his study on Swedish industries that half of their maintenance time is spent on CM. Other literatures explaining about CM include Pogačnik *et al.* (2015), Kadry, (2013), Chang for WANO (1999), GAO (1981), Driessen *et al*. (2010) and Schreiber *et al.* (2000). With the mentioned literatures, it has been proven that corrective maintenance affects downtime.

2.7.8 **Predictive Maintenance**

There have been a few literatures relating down time to specific equipment and systems. Marquez and Gupta (2005) describe the definition of PdM and how it involves in contemporary maintenance processes, Katsikas *et al*. (2014) explain how PdM and PM has improved and reduced costs. Dell'Isola and Vendittelli (2015) also relates PdM to ship operational availability. Edwards *et al*. (1998) described predictive maintenance (PdM) and their relevance to construction plants. Popovic *et al*. (2011) described PdM as one of the five categories of maintenance concepts implemented at the Institute for Manufacturing Bank Coins and Bank Notes in Belgrade, and he claimed that this affects about 35% of his problems on the maintenance of the machines. Therefore, PdM has been proven as one of the factors affecting downtime (Geitner and Bloch, 2012; Cooke and Paulsen, 1997; Swanson, 2001).

2.7.9 **Equipment Technology and System Complexity**

Equipment technology and system complexity are factors listed by Dell'Isola and Vendittelli (2015) affecting operational availability. The level of variety in the technology used to manufacture the product causes another complexity in maintenance problem (Blaikie, 1993). The increase in automation and reduction in buffers of inventory have clearly put more pressure on the maintenance system (Marquez and Gupta, 2005). Modern ships comprise many interdependent systems (Mavris, 2007). These systems must be robust in their ability to survive extreme events that may damage or disrupt vital services to parts of these systems while being capable of multiple types of missions. Mavris (2007) continued to state that as a result of their inherent complexity, these systems will exhibit emergent behaviours which can be difficult to predict.

Other literatures on complexity due to equipment and system technology are found in McNamara *et al.* (2015), Jonsson (1997), Psenka and Elyse (2008), Pecht (2009), Ross (2009), Kobbacy and Murthy (2008), Dean (2003), Walsh (2014), Darnall and Preston (2010), Deris *et. al*, Xia and Chan (2011), Ford *et al*. (2013), Dhillon (2002), Blaikie (1993) and Glorian and Spiegelberg (1998).

2.7.10 **Scheduling Issues**

Scheduling issues is a very wide topic of discussion, involving scheduling of maintenance activities and ship operational schedule as they are closely related. There has been scheduling models produced to try alleviate scheduling issues such as by Pan *et al.* (2012) on scheduling optimization model integrated with PM policy for maximizing availability. Jonsson (1997) explained that there is an enormous number of models for planning maintenance activities and preventing failure in the literature and in practice there are proper models for most situations (e.g. Dekker, 1996). They are however, not much used because of high complexity, lack of knowledge and data (Jonsson, 1997).

In a lot of cases there is conflict between ship operational requirements and maintenance which normally result in ship having to forego or delay maintenance activities. Marais *et al*. (2013) explains that deferring maintenance may also result in the system moving to a state of further degradation. If this is true, later maintenance task needed to restore the ship's capability or reliability may become costlier (Button *et al.*, 2015).

Dekker *et al*. (1998) agreed with many other researchers that a significant amount of time is spent "fire-fighting" whereby it is more appropriate to focus on fundamental problems of maintenance so they could be scheduled and planned well. Swanson (2001) described reactive maintenance also as a fire fighting approach to maintenance. Other scheduling related literatures are described in Swanson (2001), Persson and Stirna (2015), Wilson (2015), Wilson (2014), Peters (2014), Bawa (2009), Kerzner (2013), Burford (2012), Badiru (2009), Darabaris (2006), Deris *et al.* (1999), GAO (1981), Banaitiene and Banaitis (2012), Colosi *et al.* (2010), Park *et al*. (2010), Odeh and Battaineh (2002), Xia *et al*. (2011), Dhillon (2002), Miau and Holdaway

(2013), Pogačnik *et al*. (2015), Atkinson (1999), Márquez (2007) and Nepal and Park (2004). The cited literatures have proven that scheduling issues impact downtime.

2.7.11 **Maintenance of Special Tools and Test Equipment**

Special tools and test equipment are factors raised by Dell'Isola and Vendittelli (2015) affecting operational availability. There have been numerous cases whereby required tools and test equipment are not available to maintainers, sometimes not calibrated, and there have been cases (Mathew *et al*. 2006) also whereby the tools used by the maintainers do not always deliver what they expected. Low availability of computerized test equipment was identified as a serious issue on F-15 aircraft maintenance (GAO, 1982). Other literatures on issues concerning tools and test equipment is listed in Pecht (2009), Dhillon (2002), Atkinson (1999), Staub-French and Nepal (2007), Harz (1981). Therefore, tools and test equipment including special tools are confirmed factors to downtime and is included in this research.

2.7.12 **Availability of Facilities**

Facilities is a factor raised by Dell'Isola and Vendittelli, (2015) affecting operational availability. GAO (1982) described the problems faced in maintaining F-15 aircrafts of the US Air Force (USAF) whereby in many cases facilities are not available, such as loss of air-conditioning necessary to operate the relevant equipment in a controlled environment. Occasionally the power supply also created significant downtime. The author also described the situation possibly as a result of aged facilities and shortage of facility maintenance funding.

GAO (1981) also identified that navy's transportation practices for fleet-returned missiles sometimes delay missiles prompt return to weapons stations for reissue or maintenance. Other papers describing issues related to facilities are Denman (1999), GAO (2015a), IAEA (2005), Badiru (2009), GAO (1982), Rosenberger and Pointner (2015), Banaitiene and Banaitis (2012), Deris *et al*. (1999), Henry and Bil

(2015), Pogačnik *et al* (2015), Nepal and Park (2004), Harz (1981), Balafas *et al*. (2010), Darabaris (2006). Dhillon (2002) explained the importance to plan and maintain facilities to always be at acceptable standards. These studies are among many more studies to prove that availability of facilities is a factor affecting downtime.

2.7.13 **Spares Availability**

Spares availability is a factor raised by Dell'Isola and Vendittelli, (2015) affecting operational availability. Failure in the availability of parts resulted in many cases of "cannibalization" from other assets. This is quite rampant even in the military. GAO (1982) described the cases whereby aircraft parts are cannibalized from grounded aircraft in order to try maintain the mission-capable rate. Koehn *et al*. (2004) recommended replacing all mission-critical spares simultaneously at scheduled intervals or just in time before a mission, even before the end of their service life. Nevertheless, this has proven to be a significantly costly option in improving operational availability. More details of the impact of spares to downtime and availability are described in Section 2.13.

Other literatures describing impact of spares to downtime and availability include McNamara *et al*. (2015), Rosenberger and Pointner (2015), Banaitiene and Banaitis (2012), Driessen *et al*. (2010), GAO (1994), Keating (1996a), Dhillon (2002), Denman (1999), Gits (1994), GAO (1981), Jardine *et al*. (1996), Marquez and Gupta (2005), Colosi *et al*. (2010), Nepal and Park (2004), Harz (1981), Balafas et al. (2010) and Sandborn (2013). Therefore, there have been numerous studies to justify that spares availability as one of the factors affecting downtime.

2.7.14 **Obsolescence Issues**

Obsolescence involves system, equipment and components. Spares obsolescence is a factor raised by Dell'Isola and Vendittelli (2015) affecting operational availability. Adriaansen (2004) explains the impact of obsolescence on subsea control and data acquisition based on experience and challenges. Iselin *et al.* (1993) describe strategies to avoid obsolescence while Allman and Nogales (2015) explain the practical guide on obsolescence issues. Mequignon and Haddou (2014) discuss the lifetime environmental impact of obsolescence on buildings and Finch (2012) explains obsolescence issues on facilities.

Moir and Seabridge (2012) explain the impact of obsolescence on design and development of aircraft systems. Finch (2012) describes issues on cost due to obsolescence of electronic systems. Bartels *et al.* (2012) explain strategies to the prediction, mitigation and management of product obsolescence. Clavareau and Labeau (2009) discuss the maintenance and replacement policies under technological obsolescence. Issues regarding obsolescence on spare parts are described by Driessen *et al*. (2010), Stambaugh and Barry (2014), Nepal and Park (2004) and covered also by Colosi *et al*. (2010). Berkok *et al.* (2013b) explain factors and organizing substitutions to minimize cost in the Canadian navy, which include handling obsolescence management.

Further obsolescence literature on defence sector is by Freeman and Paoli (2015) on additive manufacturing and obsolescence management. Swiss military also explains on their concern on obsolescence issues in Ladetto (2015). Other papers on additive manufacturing and obsolescence is by Erkoyuncu *et al.* (2015). Rojo *et al.* (2009) claimed that US Navy estimates of obsolescence issues cost them up to USD750 million annually. Sandborn (2013) explains that it is not unusual that 70-80% of electronic components become obsolete before the system has been deployed. Therefore, obsolescence is proven to have an impact on downtime, therefore listed as one of the factors for the study.

2.7.15 **Design and Design Change issues**

Impact of design on maintenance and downtime has been observed historically. As pointed by Garel (2013), the design of new ships using systemized scientific instructions began as early as 1765. Over the last few decades, naval ship design has been understood to be a networked System-of-Systems (SoS) multidisciplinary process whereby a decision on one aspect of design may have simultaneous, multiple order effects on other aspects of the design (Australian National Audit Office, 2001). This obviously translates into operational capability and maintainability issues when there is a failure in design or even if the ship was intentionally designed for a certain limited capability only.

Design and modifications are factors raised by Dell'Isola and Vendittelli (2015) affecting operational availability of naval ships. GAO (1982) describe modifications and redesign as one of the factors impacting availability of F-15 aircrafts. For building projects Xia *et al*. (2011) explain that design is a contributing factor on complexity. Geitner and Bloch (2012) explain that faulty design is a critical issue to US plants and further explains how important for operators to operate to design. Dhillon (2002) described the design factor to engineering maintenance as a modern approach. Modification or redesign of an item was cited as a cause of shortage in 7 (16%) of the 45 parts that was analysed by GAO (1982) for the maintenance of USAF F-15 Aircrafts.

Other literatures that describe design and design change issues include Rosenberger and Pointner (2015), Papavinasam (2013), Abowitz and Toole (2010), Jonsson (1997), Dekker (1996), Pecht (2009), Coles *et al.* (2003), Smith (2005), Temple and Collette (2013), Sullivan (2011), Psenka and Elyse (2008), Stambaugh and Barry (2014), Al-Najjar (1998), Ridgway *et al.* (2009) and Pascual *et al.* (2008). Therefore, design and design change issues have been found as factors affecting downtime.

2.7.16 **Knowledge Management including Training, Knowledge and Skills**

Systems that are devised and managed by less skilled and experienced logistics personnel of the Chilean Navy (Bianchetti, 2012) results in increased time and costs for packaging, handling, transportation and storage. Training, training aids and personnel skills are factors raised by Dell'Isola and Vendittelli (2015) as affecting operational availability. Pecht (2009) explains training and skills are important prerequisites to reduce downtime. The Social Security Administration and Information Technology, Special Report (1986) describes upgrading of skills and training new staffs are crucial to reduce issues on availability. The RAN discusses in great lengths on challenges it faces for staff retention, and its action on improving skills and training through Henry and Bil (2015). Pascual *et al*. (2008) identified in his study that Operator's skills is one of the most important factors as it can have great impact on equipment performance. Nord *et al*. (1997) explained that reaching independent operator maintenance is based on starting with simple tasks and develop as the operator raises the level of competence.

Other publications and reports that describes knowledge management including training, knowledge, competency and skills include GAO (2014a), Geitner and Bloch (2012), Ross (2009), Dollschnieder (2010), Dhillon (2002), Swanson (2001), Al-Najjar (1998), Glorian and Spiegelberg (1998), Jonsson (1997), GAO (1982), Lock (2014), Goh and Yip (2014), Commission on Wartime Contracting (2011), GAO (2002),Al-Shammari and Minwir (2009), Henry and Bil (2015), Apte *et al*. (2008), Atkinson (1999), Colosi *et al*. (2010), Nepal and Park (2004), Harz (1981), Balafas *et al.* (2010), Pascual *et al.* (2008) and Bianchetti (2012). Therefore, knowledge management including training, knowledge, competency and skills are among factors affecting downtime.

2.7.17 **Availability of Original Equipment Manufacturer Support**

Availability of OEM support is a factor described by Dell'Isola and Vendittelli, (2015) affecting operational availability. The Social Security Administration and information Technology: Special Report (1986) also described problems on availability due to unavailability of OEM support. Stackley (2009) describes the importance of having OEM support on settling various contracting problems in the US Navy. For power reactor systems, OEM is listed similarly with vendors and subcontractors as external contractor in support of the facility. Other literatures on the issue is described in IAEA (2005) and Dhillon (2002). Therefore, availability of OEM support especially on complex and sophisticated equipment has proven to be a factor affecting downtime of assets.

2.7.18 **Availability of Local Vendor Support**

Dockside maintainers is a factor raised by Dell'Isola and Vendittelli, (2015) affecting operational availability. Availability of vendor support would naturally be different in accordance to the various locations of the naval vessels. The amount of resources and skills would be significantly better in modern urban cities as compared to distant suburbs. This issue is similarly faced by the PVs as the three bases where they are located are having three different levels of infrastructure and support facilities including vendors availability. The main naval base in Lumut is much greater supported when compared to the bases in Tg Gelang, Kuantan and Teluk Sapanggar in Kota Kinabalu.

Based on the study by GAO (1982) on maintenance of aircrafts, other cases involving vendors include insufficient capacity, companies going out of business and also strikes. Other literatures concerning vendor availability could be found in More (2013), Dhillon (2002), Roche and Palvia (1996), IAEA (2005), Denman (1999) and Karampelas (2013). Therefore, availability of local vendor support is a factor affecting downtime of assets.

2.7.19 **Complexity and Efficiency of Existing Contract**

Dockside contract choice decisions are central to both stakeholder management and the management of risk and uncertainty (Chapman and Ward, 2008). As a matter of comparison, Stackley (2009) listed all the contracting problems from various contracts in the US Navy.

The current PV ISS contract separates the requirement of services, spares and training as individual orders. It is a ceiling contract, on a "per repair" concept. Jobs would not be automatic, everything is subject to quotation to the customer and requires approval. The squadron has six ships located at three different bases with two ships each. Authority for submitting of quotes and approval for task order forms (TOF) are ordered independently at the three separate locations. Budgets are allocated on a yearly basis and awarded on an established quota to each base unit. Negotiations on cost verification and cost query is done with Ministry of Defence and not the ordering units. The RMN expects high availability of vessels but controls most of the maintenance scheduling through awarding of jobs.

Other literatures could be found in Xia *et al*. (2011), Pascual *et al*. (2008), Balafas *et al*. (2010), Price (2013), McNamara *et al*. (2015), Pecht (2009) and Wiggins (1985). With the explanation above, complexity and efficiency of existing contract is categorized as one of the factors for this study as it impacts downtime and operational availability.

2.7.20 **Capability of Customer performing maintenance**

Onboard maintainers and customer capability are factors raised by Dell'Isola and Vendittelli, (2015) affecting operational availability. GAO (1982) described issued faced in the maintenance of aircrafts whereby mechanics frequently remove aircraft components which they suspect are broken and send them to testing and repair. Nevertheless, some components were found to be in in good order. This may be an indication of a capability issue.

Other literatures concerning capability of customer performing maintenance could be found in Banaitiene and Banaitis (2012), Driessen *et al*. (2010), Dearden *et al*. (1999), Morris and Sember (2008), Dollschnieder (2010), Gibson (2013), Al-Shammari and Minwir (2009), Jonsson (1997), Ayyub (2000), GAO (1982), Berkok *et al*. (2013), Mokaya and Kittony (2008), Harz (1981) and Obeng-Odoom (2011). Therefore, capability of customer performing maintenance such as operator level maintenance (OLM) and some intermediate level Maintenance (ILM) onboard naval vessels is a factor impacting downtime of equipment and systems onboard naval ships.

2.7.21 Morale and Attitude of Customer involved in maintenance

Customer capability and satisfaction are factors raised by Dell'Isola and Vendittelli, (2015) affecting operational availability. GAO (1982) described issued faced in the maintenance of aircrafts, easily caused by an attitude or awareness problem, or capability issue, on both the customer who is also involved in maintenance but also vendors conducting maintenance. Based on the survey by Jonsson (1997) sent to 747 maintenance managers of various industries in Sweden, he found that attitude and communication problems between operations and maintenance are sometimes both prevalent and deep rooted and can be serious impediment to effective maintenance.

The researcher categorizes customers as internal and external, therefore this is an issue worth studying as it impacts downtime. Other literatures on the issue could be found in Banaitiene and Banaitis (2012), Driessen *et al*. (2010), Dearden *et al*. (1999), Morris and Sember (2008), Dollschnieder (2010), Gibson (2013), Al-Shammari and Minwir (2009), GAO (1982), Morris and Sember (2008), Jonsson (1997), Ayyub (2000), Berkok *et al*. (2013), Mokaya and Kittony (2008), Harz (1981) and Obeng-Odoom and Ameddzro (2011). Therefore, morale and attitude of customer is a topic to be studied in this research as they impact the downtime of equipment and systems.

2.7.22 Morale and Attitude of Contractor Involved in Maintenance

Attitude and communication problems between operators and mainteners can be serious impediment to effective maintenance (Jonsson, 1997). GAO (1982) described issues on maintenance of aircrafts whereby mechanics reflected possibility of either an attitude or awareness problem. Banaitiene and Banaitis, (2012) described the lack of experience made it very difficult to change contractors' attitude towards risk management and maintenance. Other literatures on this issue could be found in The Social Security Administration and Information Technology, Special Report (1986), Leva *et al* (2013), Geitner and Bloch (2012), Morris and Sember (2008), Obeng-Odoom and Ameddzro (2011), Attwater et al., (2014), Odeh and Battaineh (2002), Rendon (2009) andRendon and Snider (2008). Similar to morale and attitude of customer, morale and attitude of contractor involved in maintenance is also a factor impacting downtime of assets.

2.7.23 **Efficiency of Processes, Procedures and Reporting Structure**

Systems that are devised and managed by less skilled and experienced logistics personnel of the Chilean Navy (Bianchetti, 2012) results in increased time (Harz, 1981) and costs for logistics. Furthermore, unavailability of a prioritization procedure resulted in equal attention and importance be given to all spares and consumables irrespective whether it is an expensive turbine spare or a cheap valve washer.

Processes and procedures are factors raised by Dell'Isola and Vendittelli, (2015) affecting operational availability. GAO (1982) complained about inadequate and inaccurate records of maintenance for the aircrafts. The author continued to explain that there were cases where procedures were followed and processes were adhered, but priority of work was not fully thought over such as the case of a USD29,000.00 radar unit was delayed for four days because the base had run out of foam rubber to pack the items.

Other literatures that could be found discussing on this issue are Dhillon (2002), Lin *et al.* (2015), Thai and (U.S.) (2004), Burford (2012), Odeh and Battaineh (2002), Shah and Kalaian (2009), Foerst (2010), Goh and Yip (2014), McIntosh E&Y (2003), Geitner and Bloch (2012), Jardine *et al*. (1996), Sullivan (2011) and Edwards et al. (1998). Therefore, the researcher has listed the processes, procedures and reporting structure as a category of factor impacting downtime.

2.7.24 **Ship Operational and Sailing Schedule**

As ship is operational, the sailing schedule has a direct impact to maintenance, especially when maintenance activities have to be deferred. Therefore, it has been listed as one of the factors for downtime by the researcher. Popovic *et al* (2011) described that whenever possible, he found that maintenance will be deferred and performed at the convenient moment of the production process. He also explained about the effects of deferring maintenance, similar to Marais *et al*. (2013).

Marais *et al*. (2013) described that the impact of deferring maintenance to meet the warship operational requirements. The author explained that if one unit is defective and if other units are affected, either by deteriorating more rapidly or by having to work harder to compensate for the failure, those units and hence the whole system becomes unreliable. Popovic *et al.* (2011) calls this as “domino effect”. Other literatures on ship operational and sailing schedule include Keating (1996a) and House of Commons UK (2006).

2.7.25 **Non-commonality of Equipment issues**

Driessen *et al*. (2010) in the paper on “maintenance spare parts planning and control: A framework for control and agenda for future research”, has described commonality of spares and equipment as one of the factors that could increase asset availability. Nepal and Park (2004) explain the importance of having available substitute (common) equipment for construction projects. Chang (1999) describes the action of substituting parts (common) for nuclear sector. Therefore, non-commonality of equipment is one of the factors described in literatures as a factor impacting downtime.

2.7.26 Non-redundancy of Equipment issues

In general, the desired increase in availability is achieved through the implementation of redundancy strategies (Rosenberger and Pointner, 2015). Therefore, having limited redundancies would result in lesser availabilities. Rosenberger and Pointner (2015) further explained that redundancy could be implemented as a complete redundancy that requires higher cost or partial redundancy with lower costs.

Thinking of maintenance should start in the design phase of systems. The type of equipment, the level of redundancy and the accessibility will then strongly affect the maintainability (Dekker, 1996). Lack of adequate redundancy was found by Wang *et al.* (2010) as a hurdle in ship operations. Other literatures concerning maintenance could be found in Driessen *et al*. (2010), The Social Security Administration and Information Technology, Special Report (1986), Nannapaneni *et al.* (2014), Lin et al. (2015), Staub-French and Nepal (2007), More (2013), Marquez and Gupta (2005) and Pascual *et al*. (2006). As redundancy of equipment has a direct impact on the reliability of equipment and systems, as described by the various literatures above, therefore it has been considered an influential factor affecting downtime.

2.7.27 High Turnover of Maintenance Supervisors

Maintenance management roles have a high turnover, restricting the effectiveness of maintenance optimization projects (Mathew *et al*., 2006). Based on the researcher's experience, people in maintenance management roles in PV ISS seem to stay in that specific role for approximately two years before moving on. The researcher found that this situation is quite similar to the situation faced by the maintenance supervisors onboard the RMN vessels as their rotation is between one and a half to two years. This situation is consistent with Wang *et al.* (2010) that ship crew keeps changing is a hurdle to ship operations.

House of Commons UK (2008) relates the article on how Royal Navy (RN) planned to circumvent the high turnover of regular forces personnel, including improving the navy base porting policy instigated 'project fisher' to develop a system that will enable ships to be deployed as long as necessary whilst still giving naval personnel sufficient time at home with families and the stability of knowing when and for how long they will be separated.

Various literatures concerning high turnover of maintenance supervisors has convinced the researcher to include as a factor impacting downtime of assets. The other literatures include Lutchman (2008), Dhillon (2002), Tan *et al.* (1999), Lowry *et al.* (2006), Mokaya and Kittony (2008), Thomas (2013), Mafini and Dubihlela (2013), GAO (2014a), Belkhamza and Wafa (2012), Price (2013), Wang *et al*. (2010).

2.7.28 **High Turnover of Maintainers**

Similar to maintenance supervisors, ship crew involved with OLM maintenance are facing similar rotation time of two years as described by Mathew *et al*. (2006) and this high turnover has multiple implications towards the availability of the vessels (Wang *et al*., 2010). On many cases, vendors involved with maintenance of naval ships in Malaysia are also facing quite high turnovers. Lutchman (2008) describes issues of high turnover of engineers in Alberta. He researched on the impacts of a high turnover rate. The motivation level of the maintainer will be affected, skilled maintainers who are more productive will be lost, and new maintainers will need to be trained, thereby draining the already limited maintainers effort to perform maintenance tasks effectively. Research on similarity reasoning has been a subject of interest in manufacturing, biology, cognitive science, and information systems for a long time.

Mokaya and Kittony (2008) described the factors that influence high turnover of aircraft maintenance engineers in Kenya. Dvorkin *et al.* (2015) explain the strategies to improve performance at a high-turnover engineering organization. Thomas (2013) studied the causes and effects of employee turnover in construction industry. Lim *et al.* (2016) studied the mass exodus of aircraft maintenance technician from an air force and recommended to implement appropriate corrective action and initiate proactive strategies. Other literatures concerning high turnover of maintenance personnel could be found in Dhillon (2002), Tan *et al*. (1999), Lowry *et al*. (2006), Mathew *et al*. (2006), GAO (2014a), Belkhamza and Wafa (2012), Price (2013), House of Commons UK (2008), Wang *et al* (2010) and Mafini and Dubihlela (2013). Similar to high turnover of maintenance supervisors, high turnover of maintainers is also a factor impacting downtime hence operational availability of assets.

2.7.29 **Different Location of Ships**

The current locations of the PVs are distributed at 3 naval bases, hundreds and thousands of miles apart (RMN PV ISS contract, 2011). The location of the naval bases has been described in Section 2.2.1 and 2.2.3. This has an obvious impact to the support services which included spare parts inventory and warehouse, local vendor availability, facilities, tools and others. Dhillon (2002) explains the concept of centralized versus decentralized maintenance services which are impacted by the geographical area. Therefore, this is a justified factor to operational availability of the PVs and has a direct impact on downtime of the ships. Other literatures include GAO (2015c), Golding and Griffis (2003), Lu *et al.* (2010) and Skoko *et al.* (2013).

2.7.30 **Statutory Requirements**

The determinant factors on a regional basis include regulatory philosophy or statutory requirements of the countries (Glorian and Spiegelberg, 1998). Ships are exposed to various rigid prescriptive needs of multiple regulatory bodies (Wang et al, 2010). The difference between maximum and authorized capacities allowed by the government for the unit is not due to the unavailability of the unit (WEC/ UNIPEDE, 1991). New and more exigent safety and environment factors such as emerging regulations add pressure on a maintenance manager and create complexity to his function (Marquez and Gupta, 2005). Lock (2014) also identified that various regulatory authorities and other official organizations also play an important role in the success of construction projects. Other literature concerning statutory requirements could be found in Goh and Yip (2014) and IAEA (2005). As statutory requirement is mandatory to be adhered by the stakeholders of the PV ISS contract, this has an impact on the downtime of the PVs.

2.7.31 Cash Flow shortages

Financial arrangements for new plants are key factors in decision making (Glorian and Spiegelberg, 1998). Cash flow problems are listed as the top 10 overall delay factors in construction projects (Banaitiene and Banaitis, 2012). IAEA (2005) also described cash flow and lack of funds as critical factors to the maintenance of power reactors. Lock (2014) has also described the issue of cost inflation and to projects, which could turn into cash flow problem or even financial ruin. Cashflow issues between customer and ISS contractor, and between ISS contractor and vendors also greatly impact maintenance efficiency. Other literatures concerning cash flow issues are described in GAO (1982), GAO (1981), GAO (2014a), GAO (2014b) and Denman (1999). Figure 2.14 describes the relationship between availability and costs. Therefore, this is an accepted factor to operational availability through its impact on downtime.

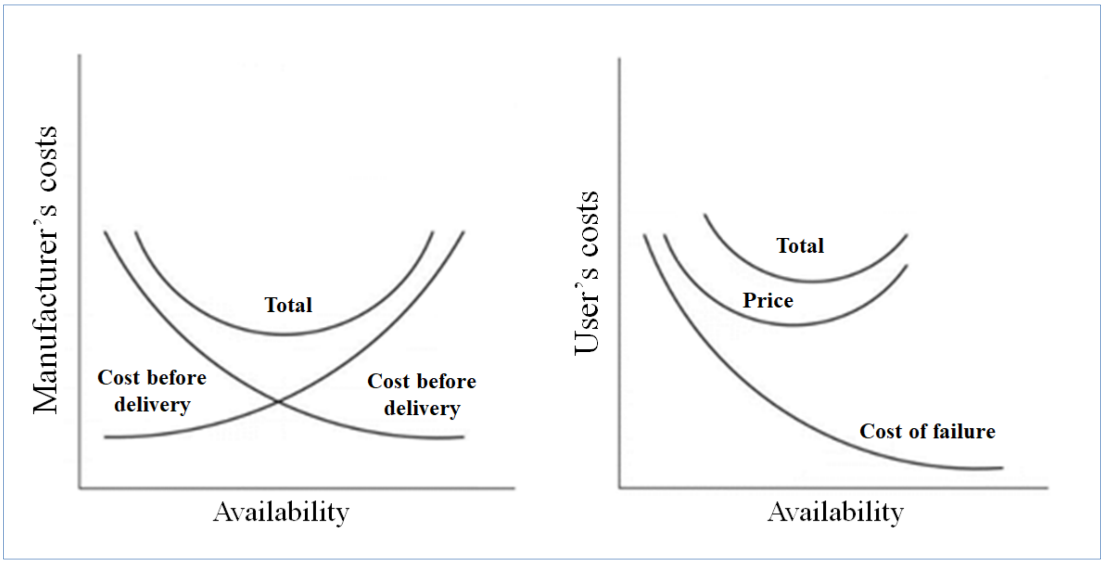


Figure 2.14 Cost to availability relationship (Fredrikkson and Larsson, 2012)

2.7.32 **Government Requirements and Policies**

The contract holder needs to confirm to all government requirements and policies such as Government of Malaysia's Offset Policy (MOF, 2011) and Government of Malaysia's Economic Enhancement Programme (TDA, 2010-2017), therefore they have an impact to the availability of the asset. Other literatures include Berkok *et al*. (2013), Bil and Mo (2013), Rendon (2009), Federal Procurement Data System (FPDS) (2010), Lee and Dobler (1971), Moe (1984), Wang *et al* (2010) and Romzek and Johnston (2002).

2.7.33 **Variation Order and Contract Change**

Banaitiene and Banaitis (2012) discussed risk management in construction projects and found that technological changes resulting in contract changes is a critical issue affecting the project. Rendon (2009) describes details on how to successfully manage contracts. Other literatures on this issue include Lock (2014), Apte *et al*. (2008), Carter (2015), Odeh and Battaineh (2002), Thai (2004), Rendon and Snider (2008), GAO (2009), Humbert and Mastice (2014), Price (2013) and Romzek and Johnston (2002). These literatures have proven that variation order and contract change have an impact to downtime, therefore shall be listed as a factor.

2.7.34 **Ageing of Equipment**

Age-based equipment retirement is outlined as one of the domains in order to obtain a comprehensive fleet maintenance management system (Colosi *et al*. 2010). Ladetto (2015) described how the Swiss are handling specific components in stored systems or ammunitions that are sensitive to ageing, where they are having them built "on demand" in order to help reduce the cost of maintenance. Chang (1999) describes aging of equipment as one of the factors to maintenance of nuclear equipment. Glorian and Spiegelberg (1998) explain the effect of ageing towards the thermal generating plant. Nepal and Park (2004) explain the effect of ageing on construction equipment.

Other literatures explaining about the ageing factor could be found in Mathew *et al*. (2006), Wang *et al* (2010), Colosi *et al*. (2010), Garel (2013), Marquez and Gupta (2005), Keller *et al*. (2002), Stambaugh and Barry (2014), Pascual *et al*. (2008), Park *et al.* (2010), Mafini and Dubihlela (2013), Davis (2014), Boonstra *et al.* (2008), Rendon (2009) and FPDS (2010). Ageing of equipment has been proven to be a factor impacting the downtime of assets (Offenbeek and Vos, 2016).

2.7.35 **Force Majeure**

In any contract nowadays, there is a provision on force majeure. Force majeure is defined by the Merriam-Webster Dictionary (Defi. Navy, 2017) as superior or irresistible force or an event or effect that cannot be reasonably anticipated or controlled. The terms of the force majeure in every contract may differ (RMN Patrol Vessel, In-Service Support Contract, 2011), but the philosophy and concept are similar. Simple example of a force majeure event is fire and flood.

Nepal and Park (2004) described force majeure force as events that are unanticipated by project participants, particularly those related to natural calamities and events. Examples include floods, vandalism, and accidents. Such events may result in delays in equipment maintenance and effect project performance. Contractors should anticipate some events, such as a heavy rainfall seasons, and take the necessary precautions to reduce their likely impact on downtime.

IAEA (2005) described the situation for power reactor, unit unavailability is defined as the status when the plant is not able to operate at its reference power. Losses may be caused by environmental issues such as frost and lightning, and unexpected embargo or restricted fuel supply. As force majeure clauses describes uncontrollable events that has happened in the past around the world, and because of the high impact it carries to the availability of the asset such as naval vessels, therefore it has been listed as a downtime factor.

2.7.36 **Accidents and Hazards**

Similar to force majeure but on a smaller scale, accident do happen which impacts the downtime of equipment and systems. Near misses and loss time due to injury (LTI) has a direct consequence to availability of assets, either impacting directly on assets or to humans which consequently impact the asset availability. Ships including naval ships have history of accidents onboard, and between ship to ship as well as ship to shore. The damages due to accidents such as fire, collision will undoubtedly result in downtime to the ship availability.

Among factors that affect equipment downtime include how well the equipment is managed and maintained (Ridgway *et al*., 2009). The operators need to be trained and competent to operate the equipment, be given all utilities and environmental support to allow equipment to operate properly and provided with the proper accessories for the equipment. Ridgway *et al*. (2009) continued by stating that subjecting any device or asset to physical stress beyond its design tolerances also is a concern. Driessen *et al*. (2010) explains that downtime could result in costly public safety hazard.

Therefore, it is a vicious circle as accidents and hazards may cause downtime and at the same time, downtime may result in hazards. IAEA (2005) explains hazards and accidents happen due to adverse environmental conditions such as storm, lightning and drought, which will result in downtime and energy losses. Sawyer (1997) explains that poor user interface design greatly increases the likelihood of error in equipment operation. Design induced errors could lead to personnel injuries and death. Operating conditions and adverse events could contribute as well. Therefore, the design should be with the user in mind. Sawyer (1997) continued to suggest that human factors should be integrated into procedures used to isolate hazardous device failures.

Soares (2014) discussed about value of downtime caused by accidents and failures of wind turbines. Reuvid (2012) explained that even small accidents, which might not trigger a claim under the company's insurance policy, can turn out to be costly. It is also easy to see how the accumulation of machinery downtime following a number of minor accidents will quickly hit overall productivity levels. Previous analyses based on past accidents suggest that reputational losses may be of the order of four times or even more of the total direct losses.

Other literatures on impact of accidents and hazards to availability of assets could be found in Twigge-Molecey and Price (2013), Banaitiene and Banaitis (2012), Bawa (2009), United States Bureau of Mines (1988), British Robot Association (1984), Mahaffey (2014), Nepal and Park (2004), Mathew *et al*. (2006), Ristic (2013), Deodatis *et al.* (2014), Berkok *et al*. (2013), Rendon (2009), Ceric (2014), Stambaugh and Barry (2014) and Rendon and Snider (2008).

2.7.37 **Extraordinary Price Escalations for Spares, Consumables, Equipment**

There are hundreds of possibilities and causes that impacts the prices of spares, consumables and equipment. Some value of contingency has been inserted by the contract holder to absorb this increase of costs before the contract was signed. However, there have been numerous cases whereby the price escalation is abnormally excessive which has gone far beyond the allocated contingency value. Insurance spares are parts that are very reliable, highly critical to system availability and not readily available in case of failure (Driessen *et al.*, 2010). Often these parts are far more expensive to procure. However, because of their high reliability, these spare parts often will not be used during the lifetime of the system.

Price escalation has been listed by Banaitiene and Banaitis (2012) as the top ten delay factors to construction projects. Lock (2014) also described the issue of cost inflation and cost escalation to projects. Due to this, issues on spares or consumables and equipment availability is obviously impacted, resulting in asset downtime and reduced availability.

2.7.38 Pilferage, Theft, Fraud and Cheat

Fraud and sabotage was listed as problems in the Social Security Administration and Information Technology Special Report (1986). Foerst (2010) described the seriousness of employee theft in the retail industry. Each year, US companies lose about USD36 billion to shrinkage. Inventory losses caused by employee theft, merchandized being misplaced or damaged and poor book keeping are part of issues listed as shrinkage. McAfee and Champagne (1994) describe this issue as a problem of employee dishonesty, a wilful perversion of the truth in order to deceive. Theft refers to taking a property without permission, in which this behaviour has resulted in considerable losses to many organizations. Many employees consider small amounts of pilferage as a fringe benefit to which they are rightly entitled. This attitude needs to be controlled and rules against it enforced.

Similar to the outside world, pilferage and theft also happen in the military including onboard navy ships. There have been several cases whereby the stolen items costed hundreds of thousands, as they are valuable military components. Loss of these items would have a significantly negative effect on availability of the naval vessel. Other literatures concerning this issue could be found in Doig (2012), Hayes (2014), Lewin and Gollan (2012), McIntosh E&Y (2003), Commission on Wartime Contracting (2011) and GAO (2015b). Therefore, pilferage theft, fraud and cheat has been listed as a factor impacting availability due to its influence on downtime.

2.7.39 Overlap of Maintenance Activities

Whenever there are overlaps of activities or tasks to be performed, there exist a few issues and risks involving human and equipment. The first is that both overlapping parties assume that the other will perform the task, and as a result, the task remain undone and in maintenance, the equipment or system is not maintained. The second issue is that there will be no ownership of the task, therefore no accountability on those people involved in maintenance. The third issue is the frequent outcome of jealousy and hostility that one’s turf is being disrespected. The fourth issue is frequently called slaps. Someone feels slapped for doing or not doing something that should or should not have been done. It is something that might have been avoided if everyone had been clear on whose job it was to make the necessary decisions associated with the neglected or overly attended task (Sword, 2010).

Deris *et al*. (1999) stated that in a squadron of ships, overlapping of maintenance activities is also a problem. Sword (2010) explains the issues that arise due to confusing roles in maintenance activities including of overlaps. The frequent outcome of overlaps is jealousy and hostility that one's 'turf' is being disrespected. This will create unnecessary risks to availability of the asset. Other literatures concerning the above-mentioned factors could be found in Xia *et al*. (2011), Jonsson (1997), GAO (1982), Henry and Bil (2015), Balafas *et al*. (2010), Ford *et al*. (2013), Crane and Livesey (2003) and Lim *et al* (2016). Therefore, overlapping of maintenance activities is considered a factor to downtime.

2.7.40 **Contract Management across Stakeholders with Conflicting Interests**

It is common knowledge that stakeholder management is an important part of contract management and project management. Stakeholders comes from various backgrounds and have their own objectives and interests. In many cases, management does not speak the same language as the staffs (Alhouli, 2011).When managing projects, project leaders encounter a range of stakeholders with different interests and varying perceptions of the project at hand (Davis, 2014). Literature has shown that project stakeholders management is critical for project success (Boonstra *et al*., 2008). During the project’s lifetime, these stakeholders will come up with issues they expect project leaders to address. Some issues may be shared by several stakeholders; others may be raised by just one. Nevertheless, many issues will seem worthy of attention, but a project management’s span of attention is limited and resources be scarce (Jepsen and Eskerod, 2009). These limitations assert additional pressure on the project managers and working level personnel as much as they do for the stakeholders themselves.

For project leaders, this raises the question of how to prioritize within the complexity of issues emerging during a project's lifecycle. There have been attempts to develop frameworks (Offenbeek and Vos, 2016) to enable a more systematic assessment, and thereby management, of the influence of stakeholder issues on a project's progress and customer. Other literature concerning stakeholder involvement is in Lock (2014), Gracht (2012), Wilkinson (2009), Chermack and Nimon (2008), Aven and Kørte (2003), Rendon (2009), Price (2013), Kwak and Smith (2009), Nasab *et al.* (2015), Seresht *et al*. (2014), Jardine *et al*. (1996), Ford *et al*. (2013), NAVSEA (2012), Lock (2014), Pogačnik *et al* (2015), Atkinson (1999), Xia *et al*. (2012), Taska and Barnes (2012) and Rendon and Snider (2008). Figure 2.15 describes Stakeholder interest adapted from Mendelow's power versus interest grid and how to include the stakeholders. Due to this, stakeholder management is a factor as the problems that arise due to their conflicting interests affects the availability of the assets.

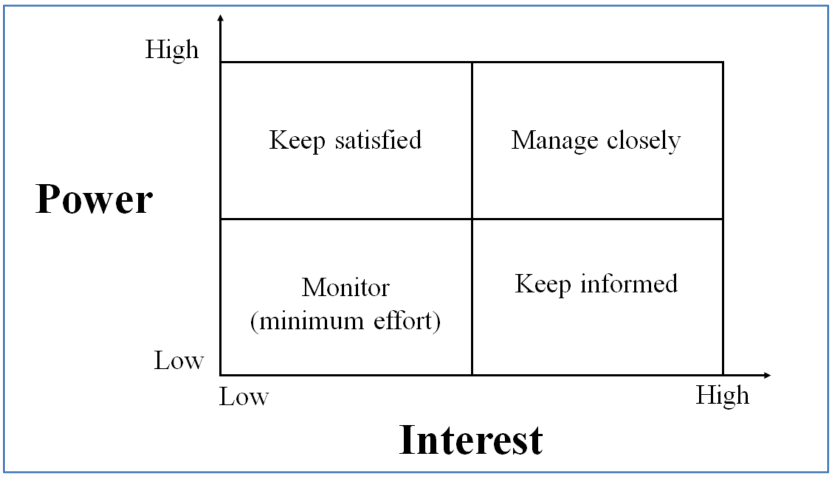


Figure 2.15 Stakeholder influence diagram (Mendelow, 1991)

2.7.41 **Impact of Parallel Contracts**

The way some contracts are implemented in Malaysia and several other countries worldwide, there can be several parallel contracts in effect at the same time concerning an asset. An example would be while the PV ISS contract is in place, some parallel contracts are awarded on the spares parts of the air-conditioning system or diesel engines to other third parties in accordance to the normal tender exercises.

When this happens, the government may decide to utilize the budget from the PV ISS contract or the equipment contract or combining both, to cater for the maintenance activities of the PVs. When this happens, there is conflict between contract managers and stakeholders as the contracts are administered by different sets of personnel. Furthermore, when the maintenance activities are combined, one contract manager may have to wait for the other contract manager to respond such as for the case of maintenance services by the PV ISS contractor who is forced to wait in the middle of a maintenance routine for arrival of spares from the equipment contract holder.

The complication is increased because the PV ISS contract holder or manager does not have access to the terms of the equipment contract and has to just rely on any statement given by the other contract holder or contract manager. However, the PV ISS contract holder has his own key performance indicator (KPI) to meet and a targeted operational availability to achieve, but he has no control of all activities in the performance of PV ISS maintenance due to the existing parallel contracts. Sahoo (2013) explains on disadvantages of several parallel contracts for process plants. Carter (2013) and Wearne (1993) describes the disadvantages of parallel contracts. Lawson *et al.* (1999) explain on definitions of traditional contracts, all things to be considered when implementing a project and also describes the disadvantages of parallel contracts. Due to this rampant issue, impact of parallel contacts has been selected by the author as a factor that influences downtime of assets especially the naval vessels.

2.7.42 **Supporting Vessel outside of Homeport**

Support of “out of area” missions is a factor raised by Dell'Isola and Vendittelli (2015) affecting operational availability. Supportability changes with location of ships and especially when the ships sail to foreign destinations. The normal support routine is now multiple times more complicated and costlier when the ships are located outside of their homeport. This obviously impacts the availability of the equipment and systems onboard, therefore has been listed as a factor to downtime (Navy Force, May 2015; Golding and Griffis, 2003; Lu *et al*., 2010; Skoko *et al*, 2013).

2.7.43 **Exogenous Factors based on Company profit margin and Admin cost**

There have been many more factors that have been found in literatures and through FGD, but they have been classified as lesser importance individually but was agreed to be pooled into a group to be considered as a possible factor to downtime. Faster, cheaper, and better has become the mantra of not only profit-making organization seeking to increase market share and profit (Darnall and Preston, 2010). These authors described the necessity to have a tool for profiling a project based on the complexity of the project and describe the different project management approach needed for the difference in project profile.

Dell'Isola and Vendittelli (2015) describe many factors related to the support of the ships such as administrative changes in the support organization and modification of the support system. Darnalll and Preston (2010) claimed that project management is complicated because project manager must understand several knowledge areas and develop a variety of tools and technique to successfully manage a project. Mathew *et al*. (2006) explains the seriousness of process issues - too much time spent on administrative issues, corrective fire-fighting environment which will impact the availability of the asset. Other literatures concerning similar factors are covered under Banaitiene and Banaitis (2012), IAEA (2005), Henry and Bil (2015).

2.7.44 **Exogeneous Factors based on Contract Concept**

Another category of factors that have been agreed to be listed belong to factors relating to type of contract. The concept of contract has also been found to be a possible factor to downtime of naval vessels. Implementation of different types of contracts such as availability-based contract (ABC) or performance-based contract (PBC) in Section 2.11, and per-repair contract in Section 2.12 would have an impact to the availability of the vessels. Dell'Isola and Vendittelli (2015) described that the FREMM is a PBC based on two availability requirements during temporary global support (TGS) period which is the initial part of ship's life cycle; and the operational availability as well as the technical availability. Similarly, another concept called class output management (COM) has been implemented by the Royal Navy (RN) which is a made up of an industry-led team structure drawn from the MoD, RN and industry for each class of vessel led by Babcock or BAE Systems, with the MoD taking the deciding role. This is also on a performance based contracting or “contracting for availability” basis (Tomkins, 2012).

2.8 Impact of Design to Maintenance Cost of Navy Ships

In the design of most naval combatants, the objective is always to try in reducing the overall weight of the vessel to achieve higher performance. For instance, the internal structure is always designed to minimize the overall weight of the vessel while meeting certain constraints introduced by minimum strength requirements or regulations and standards. This approach to design, however, does not consider the maintenance that will be necessary over the course of the vessel’s life and the costs that these repairs will cause the ship’s owner to incur. In fact, many least-weight design strategies utilized for naval combatants implicitly contain in their formulations major overhauls or repairs as part of the ship’s service life in an effort to minimize the weight of the vessel (Temple and Collette, 2013). This leads to increased frequency and complexity of maintenance, which inevitably lead not only to higher maintenance cost over the expected life of the vessel, but also large increases in cost for extending the service life or utilizing the vessel for unexpected missions. This phenomenon makes it necessary to design the structure of future naval combatants with the consequential maintenance activities and lifetime maintenance costs in mind. In simple words, to design with maintenance (CIPS, 2012) or supportability in mind (Dell'Isola and Vendittelli, 2015).

2.9 Ship Fleet-Wide Management and Naval Mission

Ships are composed of multiple heterogeneous subsystems and equipment interconnected to accomplish various missions. In civilian and naval domains, ships are usually operated as a fleet leading to mission readiness and maintenance management issues. Prognostics and health management (PHM) plays a key role for controlling the performance level of such systems, at least on the basis of adapted PHM strategies and system developments, to address monitoring, diagnosis and prognostics for health management of the underlying heterogeneous equipment/ components defining the fleet. Leger and Iung (2012) explained that large complex systems such as power plants and aircraft, similar to ships, are composed of multiple systems, subsystems, equipment and components built on different technologies (mechanical, electrical, electronic or software natures). These components follow different rates and modes of failures, for which behaviour can vary all along the different phases of their lifecycle, and maintenance actions strongly depends on this context. When they are considered as embedded in system operating as a fleet, it raises mission readiness and maintenance management issues. Figure 2.16 describes the 16 aspects that are important to gain understanding of maintenance management.

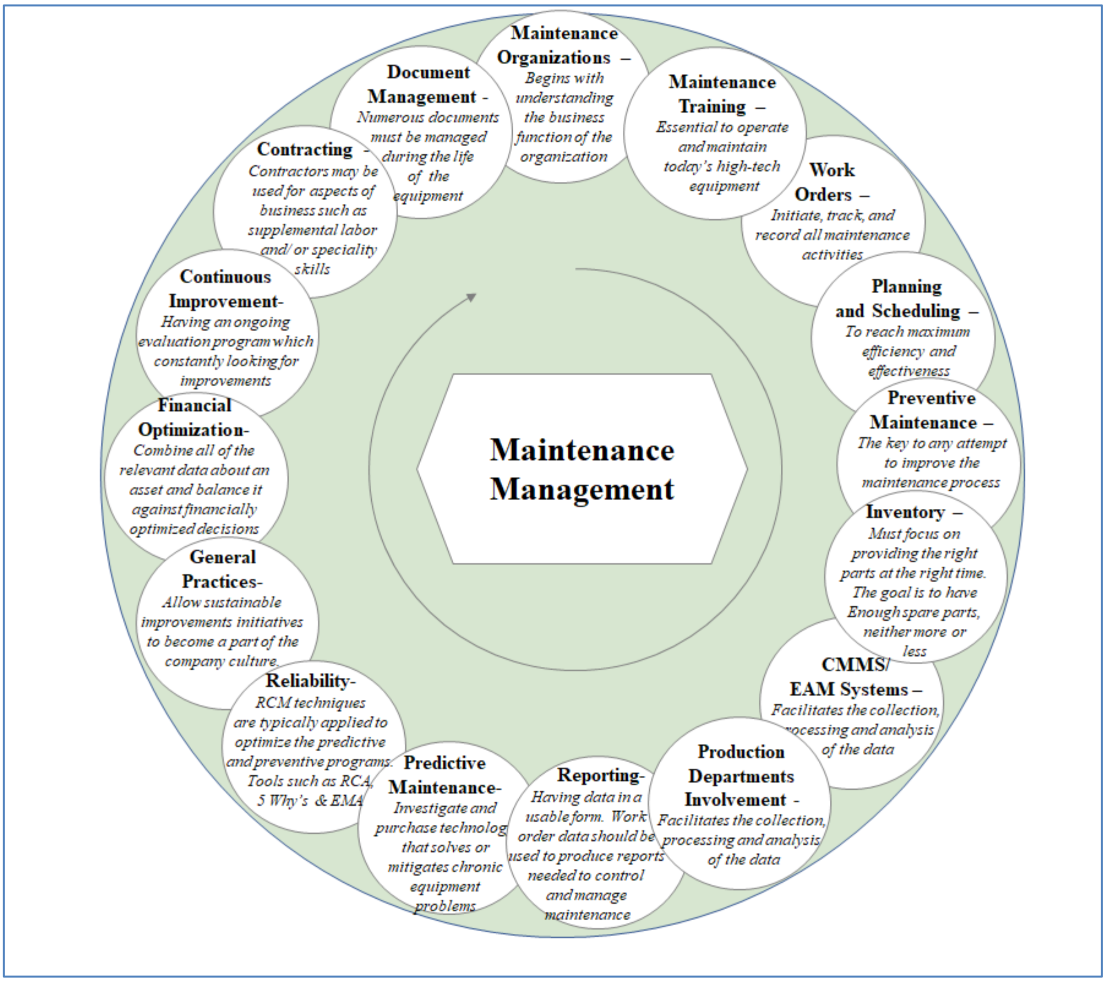


Figure 2.16 16 Aspects of maintenance management (Wireman, 2010)

Leger and Iung (2012) continued to explain that in many cases, a fleet or plant operation is optimized (in terms of production or mission planning), making system availability a primary day to day concern. Thus, PHM plays a key role to ensure system performance and requires, most of the time, to move from "fail and fix" maintenance practices to proactive "predict and prevent" strategies, as promoted by condition-based maintenance (CBM) and PHM strategy mainly based on condition-monitoring capacities. Nevertheless, even if a condition monitoring programme is in operation, failures still occur, defeating the objective for which the investment was made in condition monitoring.

Moreover, the huge amount of condition monitoring activities, coupled with limitations in setting alarm levels has led to a problem for maintenance crew coping with the quantity of alarms on a daily basis. However, proactive fleet management system is not really operational on-site because the three processes (prognostics, diagnosis, monitoring) are limited with regard to the large scale of failures and degraded states at the scale of the fleet. The design, development and implementation of such PHM system have to face up with many constraints from the very concrete technological level to organizational/ business process through information communication and technology (ICT). Proactive fleet management needs a complete guide (model, method and tool) to support the modelling and the understanding of such systems at the scale of the fleet.

The consideration of a set of complex systems operating as a fleet (e.g. military naval fleet) leads to a more complex decision making due to additional constraints that represent the fleet level in mission readiness and operation optimization. It is necessary to closely monitor each fleet element in order to keep operator updated regarding the health status of his unit and to support the unit level maintenance decision making in order to insure the overall goal of the fleet (Leger and Iung, 2012). The result of the study indicates why proactive maintenance has not been successfully implemented in the fleet of ships including on navy vessels.

2.10 Impact of Maintenance Strategies to Performance, Availability and Cost

In In order to achieve world-class performance, more and more companies are replacing their "reactive" or "fire-fighting" strategies for maintenance with "proactive" strategies like preventive and predictive maintenance and "aggressive" strategies like total productive maintenance (TPM). While these newer maintenance strategies require increased commitments to training, resources and integration, they also promise to improve performance (Swanson, 2001). The figure below describes the 3 maintenance strategies defined by the author above. The categories are easily described below in Figure 2.17.

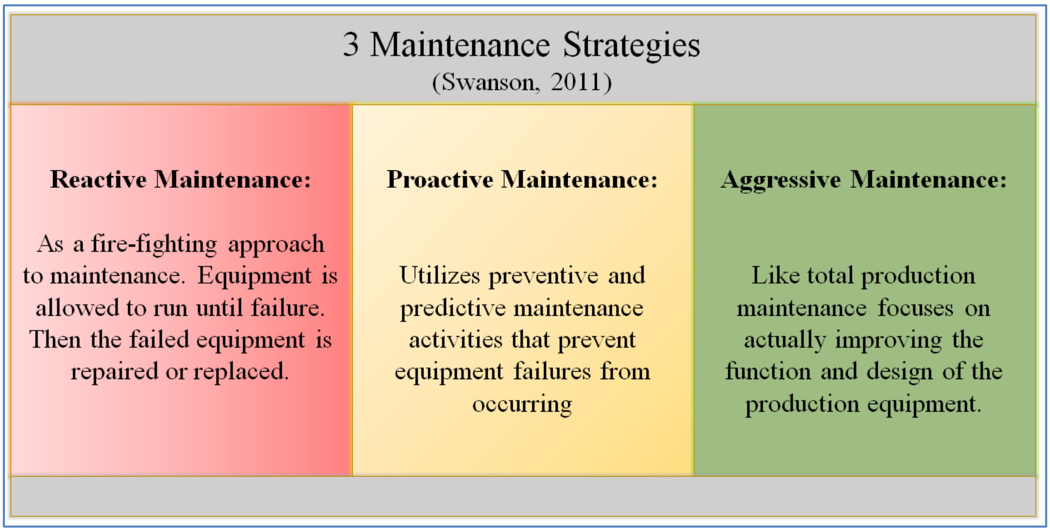


Figure 2.17 Maintenance strategies on board navy vessels (adapted from Swanson, 2001)

A proactive strategy for maintenance utilizes preventive and predictive maintenance activities that prevent equipment failures from occurring. An aggressive strategy, like total productive maintenance (TPM), focuses on actually improving the function and design of the production equipment. Reactive maintenance may be described as a fire-fighting approach to maintenance. Equipment is allowed to run until failure. Then the failed equipment is repaired or replaced (Paz and Leigh, 1994). Under reactive maintenance, temporary repairs may be made in order to return equipment to operation, with permanent repairs put off until a later time (Gallimore and Penlesky, 1988).

Reactive maintenance allows a plant to minimize the amount of maintenance manpower and money spent to keep equipment running (Vanzille and Otis, 1992). This phenomenon explains why most of companies and organizations including the navy fleets around the world mostly resort to reactive maintenance, especially when they are faced with yearly fund constraints. Small navies of the world such as the RMN and other third world countries are given tight budgets for their yearly maintenance of the navy ships. This is quite understandable but not necessarily acceptable, looking from the standpoint of reduced availability of the vessels.

Nevertheless, it is surprisingly similar to what is happening to the modern navies such as the USN that are also managing the most state-of-the-art class of vessels such as the Arleigh Burke Guided Missile Destroyers (DDG-51 Programme) consisting of 60 ships. For the DDG-51 programme, more than 80% of the maintenance performed has been corrective (Marais *et al*., 2013). The study also shows similar high percentages of corrective maintenance happening to other vessels of the USN fleet. Most importantly is to note that even USN fleets are plagued with less than expected availability and shorter than hoped lifetime, which inevitably increased the total ownership cost (TOC).

It is well known to the US government that without maintenance, long-lived systems will deteriorate due to use or age. Maintenance is especially important for costly systems that are subjected to punishing tasks, such as their naval vessels. However, they still resorted to deferring of preventive maintenance. Deferring of preventive maintenance has three main effects:

i) The system deteriorates more rapidly, bringing the time at which failures are unacceptably frequent earlier in the system's life;
ii) It increases the cost of bringing the system back to the desired reliability; and
iii) It may result in reduced performance.

Thus, deferring preventive maintenance can increase TOC and decrease expected service life. (Marais *et al*., 2013). It is also crucial to point out that deferring preventive maintenance would obviously result in an increase in corrective maintenance, especially when the systems are subjected to strenuous tasks such as the navy ships. This would result in increased lifetime cost of the vessels. Similar findings were obtained from separate studies on the disadvantages of this reactive approach, which include unpredictable and fluctuating production capacity, higher levels of out-of-tolerance and scrap output and increased overall maintenance costs to repair catastrophic failures (Bateman, 1995, Gallimore and Penlesky, 1988).

2.11 **Contracting for Availability Concept**

Since the year 2000, there has been a shift in the UK for support and maintenance logistics for complex systems which have been observed in defence and aerospace industry. Availability contracting, a new approach in this area, is replacing traditional service procurement practices. The premise behind availability-contracting is summarized in the official UK Ministry of Defence (MoD) guidelines (UK MOD, 2007).

"Contracting for availability (CfA) is a commercial process which seeks to sustain a system or capability at an agreed level of readiness, over a period of time, by building a partnering arrangement between the MoD and Industry."

Erkoyuncu *et al*. (2009) stated that under availability-based contracting, the supplier offers a fixed-price to the customer whilst assuming responsibility and risk that, if they underestimate the number of tasks involved in maintaining the asset at the given contracted availability, profitability may be reduced with a possibility of loss. Erkojuncu *et al.* (2009) continued by saying under the traditional contract arrangements, suppliers are typically paid according to the throughput of spares and repairs and other transactions. The throughput is under the customer's control and will normally manage their demand rate within internal budgetary constraints.

According to Dell'Isola and Vendittelli, (2015), one of latest development is on FREMM Frigate Programme implementing CfA which is synonymous to availability-based contracting (ABC) or performance-based contracting (PBC). Even though this effort will increase the probability of the affected systems to have constantly high availability, there is no doubt that it will be at the expense of additional costs involved. However, when the decision was taken by Ministry of Defence (MOD) UK to move towards CfA, there was not enough research done on cost.

The study concluded that there was no previous literature on any study on cost estimation on availability type contracts. Nevertheless, the challenges identified in costing of availability type service contracts are: too much reliance on expert opinions might limit innovative thinking of uncertainties and risks, uncertainties of customer's contribution to availability performance, reliability of data supplied by user or assumptions regarding equipment failure, difficulty of not using bottom up cost estimates in every case, communication problems with the customers, prediction of maintenance activities in future (10-15 years), inability to understand cost impact of customer focused risks (Dattaa and Roy, 2010).

At this point of time it remains unexplainable as to why MoD UK (RDS, 2012), Australia (Henry and Bil, 2015), France and Italian Navies (Dell'Isola and Vendittelli, 2015) have shifted to implementing CfA to increase the availability of their strategic assets; whilst on the other hand the USN and most of the navies of the world have continued to remain with the traditional service procurement approach, even though the USN has not been satisfied with the availability of their naval ships. Furthermore, USN and the US Armed Forces in general have implemented CfA for certain systems such as weapons systems (Keating, 1996), therefore giving the researcher an impression that the CfA has not been successful in meeting the US military's objectives, and otherwise we would be seeing a rapid change of concept of maintenance of all US military assets to CfA.

Keating (1996a) was of the opinion that CfA depends on well informed contractors who understand the repair costs and failure patterns of the related system. Therefore, this sort of approach would seem better suited to mature rather than experimental systems. Another simple assumption by the researcher is that possibly the increase of cost would be too high based on the finding by RAND (Keating, 1996b) that an increase to 100% availability would cost more than three times the cost for 50% availability. Nevertheless, the aim of availability-based contracting is always to be available to devise, negotiate and deliver the contract that are both affordable to the customer and remain profitable to the supplier (Erkoyuncu *et. al*, 2009).

2.12 Per-repair Contract Mechanism

In accordance to Keating (1996b) the US government has typically used "per-repair contracts". With per-repair or traditional contracts, the contractor receives compensation that is a direct function of the number of items the contractor repairs. One version of a per-repair contract is a requirement contract in which the contractor receives a specified fee per unit repair without a guaranteed minimum workload. Time and material contracts are also a version of a per-repair contract. With a time and materials contract, the contractor is paid for whatever labour time and materials are required to fix broken items. Also, Keating (1996a) and Keating (1996b) stated that in the category of per-repair contracts, the government sometimes uses fixed price contracts where a fixed number of items are guaranteed to be entering the repair process. Keating (1996a) also stated that historically, the common approach to weapons systems repair and maintenance is by per-repair contracts.

Keating (1996b) goes on to state that per-repair contracts have been criticized for not providing contractors with good incentives. For example, because the contractor gets paid additionally each time a piece of equipment needs to be repaired, the contractor lacks obvious incentive to do high-quality repair. Keating (1996a) stated that simulation suggested that per-repair contracts tend to induce low repair quality. However, Keating (1996a) admitted that modelling and simulation exercises of the sort they were doing were fundamentally an abstraction from reality. They provide suggestions and possible insights, but ultimate proof requires real-world implementation.

2.13 Spares and Logistical Support affecting Maintenance

Various studies have been conducted for many years on this subject. An interesting study was done in 1996 on the significant negative impact of the long delivery period of certain spares onto the maintenance activities of RMN ships (Raof, 1996). Some spares have long lead times in excess of six months as stipulated in the contract of purchase at the point of when the research was conducted in 1996, and now the lead times of spares have increased to a year or more. This is very predominant on corrective maintenance activities whereby the spares requirement was only known when the equipment became defective, or order placed upon completion of survey following dismantling of the equipment. In fact, some major work during refits or extended maintenance routines were further delayed from their original planned completion date even when just a small number of spares were not available in time. The non-availability of spares was found as the major contributor towards the delay of ship refits in the RMN then, and it still remains unsolved to this very day.

A study for depot level maintenance (DLM) of the Chilean Navy (Bianchetti, 2012) also found issues on spares and consumables whereby improving inefficiencies could positively improve up to 55% of asset availability. Another interesting study was on analysing operational availability of Brazilian navy and Argentinian Air force A4 fleets (Rodrigues and Karpowicz, 1999). The study has shown that the operational availability of the aircrafts could be raised when a consolidated spares inventory is shared between both organizations.

Therefore, the concept of a consolidated spares inventory is workable, and similarly the concept of "commonality or standardization" by having common types of equipment onboard different types or aircrafts or ships is also an attractive method in increasing the operational availability of the ships or aircrafts. The findings obtained also indicated that reducing spares transportation time has managed to increase the operational availability figures for the A4 Skyhawk aircrafts from the combined squadron by as high as 7%. Using a rapid and responsive shipping mode, such as air mode, reduces the spares item required in the system inventory to achieve a specific operational availability. The transportation time reduction generates savings in the 23 to 43% range in total cost over a 10-year period. Although the air mode cost is more expensive than the sea mode, this additional expense is offset by the reduction in system inventory costs, thereby reducing the total system cost.

Requirements of the correct amount, quantity, quality and delivery of spares impacting maintenance has been presented by many other authors across various industries including McNamara *et al*. (2015), The Social Security Administration and Information Technology, Special Report (1986), Banaitiene and Banaitis (2012) and Driessen *et al*. (2010).

2.14 Past Studies on Availability of Equipment and Systems

In general, there have been various previous researches on availability of equipment and systems from various disciplines, most of which were done on a component or equipment basis. There have been many literatures from various disciplines discussing about downtime of equipment of systems therefore impacting availability, which included Al-Najjar (1998), Papavinasam (2013), Odeyinde (2008), (GAO, 1981), Korshidi *et al.* (2013), WEC/ UNIPEDE (2001), WEC/UNIPEDE (1991), Glorian and Spiegelberg (1998), Lazakis *et al.* (2010), Rosenberger and Pointner (2015) and Nepal and Park (2004). Details have been explained in Section 2.6.1.

Studying availability for a complex system made up of several equipment running in series and parallel is far more complicated compared to conventional systems, resulting in very limited studies being done to date. Many simulations have been performed including production of conceptual models (Keating, 1996; Dell'Isola and Vendittelli, 2015), studies on a selected portion of the system (Rosenberger and Pointner, 2015), improving availability by improving scheduling (GAO, 1981), promoting a "design for availability" approach (Jazouli and Sandborn, 2010, Jazouli and Sandborn, 2011), even various methods of calculating availabilities (Dell'Isola and Vendittelli, 2015).

Several studies have been done on availability of naval vessels, they are generally similar to the types of studies applied by the other disciplines. Most of these researches focused on a selected area of study, such as spares assessment, while implying that any proven improvement would result in an obvious improvement to the availability of the ship. This natural tendency has been explained in the book called Engineering Design – A Systematic Approach by CIPS (Contract Management Guide, Oct 2012) that it is often useful to divide problems, tasks and functions into subproblems, subtasks and subfunctions and to solve individually, also called factorization method. However, CIPS Contract Management Guide (Oct 2012) stated that once the solutions for subproblems, subtasks and subfunctions are available, they have to be combined to arrive at an overall situation.

The past researchers mostly conclude their study by creating a link to the end but refrain from consolidating all solutions for a complete solution, which is absolutely the most difficult objective. CIPS Contract Management Guide (Oct 2012) also reiterated that it is also a problem in the selection of the most technically and economically favourable combinations of principles from the large field of theoretically possible combinations. An example is a study on the spares and consumables for depot level maintenance in the Chilean Navy (Bianchetti, 2012) concluded that late requests affect their working plan and decreased assets availability by a slippage of 53 days. Raof (1996) also found significant negative impact of the long delivery period of certain spares onto the maintenance activities of RMN ships. Similar studies have been done by Rodrigues and Karpowicz (1999) for the Brazilian and Argentinian Air Force and by Moon (2010) for the South Korean Navy.

The most recent and interesting study on availability of warships is titled Operational Availability (Ao) of Warships – A complex problem from concept to in service phase by Dell'Isola and Vendittelli (2015). They attempted to initiate more studies on naval ship availability by introducing to the world that warships are complex, and availability studies on warships would require encapsulation of all factors from concept to in-service phase.

The author described the need of a new design approach, based on operational availability for warships and associated support system, in order to achieve the best balance between operational availability and life cycle cost (LCC) along the whole operative life. Several key factors were given as examples, and various types of contracts involving naval ships were presented including those that are "availability-based" which are being implemented for the FREMM Programme of the French and Italian Navy. Figure 2.18 describes an example of LCC Tree.

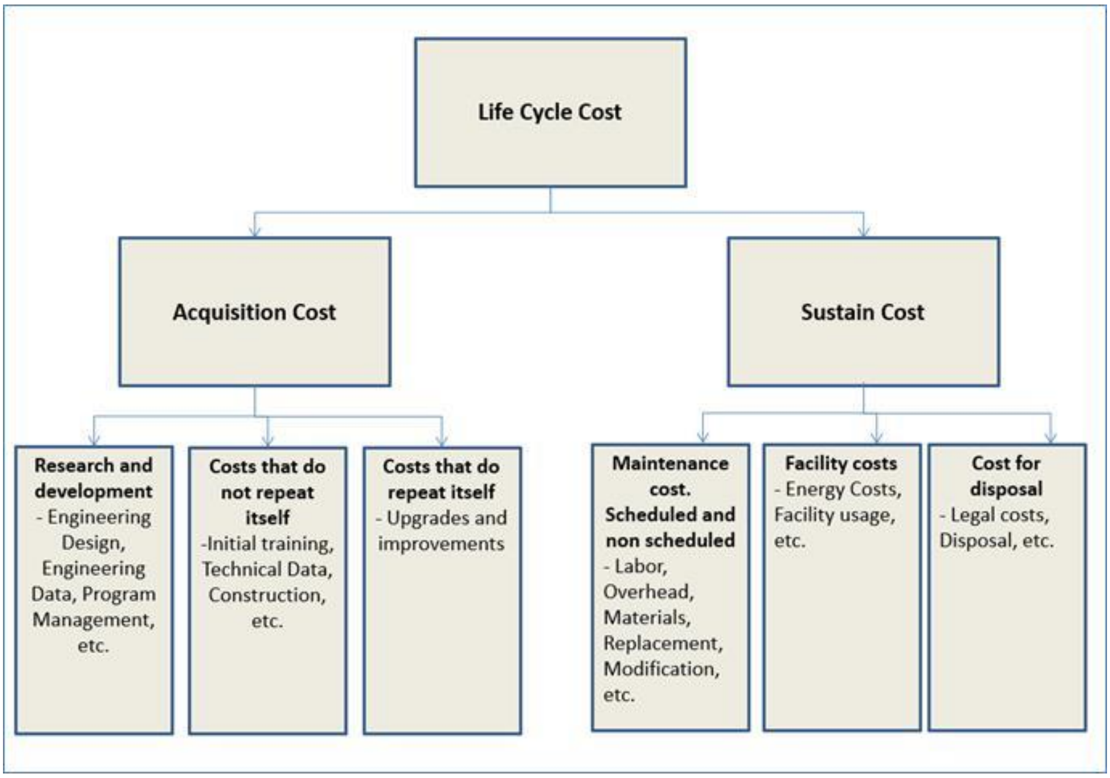


Figure 2.18 Life cycle cost tree (Dell'Isola and Vendittelli, 2015)

To achieve their goals, Dell'Isola and Vendittelli (2015) described the importance of utilizing the proper design processes, methods, models and tools. As an indication that the research area is still 'green and untapped', the authors did not refer their paper to any previous naval ship availability researchers.

2.15 Project Management and Contract Management "Iron Triangle"

Lock (2014) in his book called The Essentials of Project Management stated that the success of a project manager will usually be judged according to how well they achieve the three main objectives of project management; namely:

i) Project completion within the approved budget – cost
ii) The project finishes on time – time or schedule.
iii) Good performance, satisfying the given specification and benefits – scope / performance.

In accordance to the Australian Contract Management Better Practice Guide (2001), the objectives of contract management are to ensure:

i) goods or services are delivered under contract according to the time, cost, quantity and/or quality standards specified in the contract; and

ii) the organization has sufficient information to enable it to decide regarding succession arrangements to the conclusion of the term of the contract.

Proper contract management is crucial in the pre-award stage, and especially during the post award phase. In accordance to the Chartered Institute of Purchasing and Supply, Contract Management Guide (CIPS, Oct 2007) organizations in both the public and private sectors are facing increasing pressure to reduce costs and improve financial and operational performance. New regulatory requirements, globalization, increases in contract volumes and complexity have resulted in a rising recognition of the importance and benefits of effective contract management.

The growing recognition of the need to automate and improve contractual processes and satisfy increasing compliance and analytical needs has also led to arise in the adoption of more formal and structured contract management procedures and an increase in the availability of software applications designed to address these needs.

The foundations for effective and successful post-award contract management rely upon careful, comprehensive and thorough implementation of the upstream or pre-award activities. During the pre-award stages, the emphasis should be focused on why the contract is being established and on whether the supplier will be able to deliver in service and technical terms. However, careful consideration must be given to how the contract will work once it has been awarded. The organization's high-level requirements should be carefully researched so that there is clarity of purpose from the outset. This will help to ensure clarity in all aspects of the procurement process.

2.16 Contract and Project Management relationship with Ship Availability

There is a clear relationship between project management and contract management, 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 and Preston (2010) describes that project management 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, project management 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 (time, cost, quality and scope) which are basically in accordance with the contract. Contract management is focused at ensuring that terms and commitments agreed in the contract are adhered to. Contract manager's 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. According to ITSL (2019), in addition to the ILS elements there are other disciplines associated with ILS including contract management.

The International Association for Contract and Commercial Management (IACCM) conducted a survey in the year 2012 highlighting that the average scale of loss is 9.15% impact to the bottom-line performance resulting from weaknesses in contract management (IACCM, 2012). The industry variations and scale of loss in percentage are exhibited in Figure 2.19

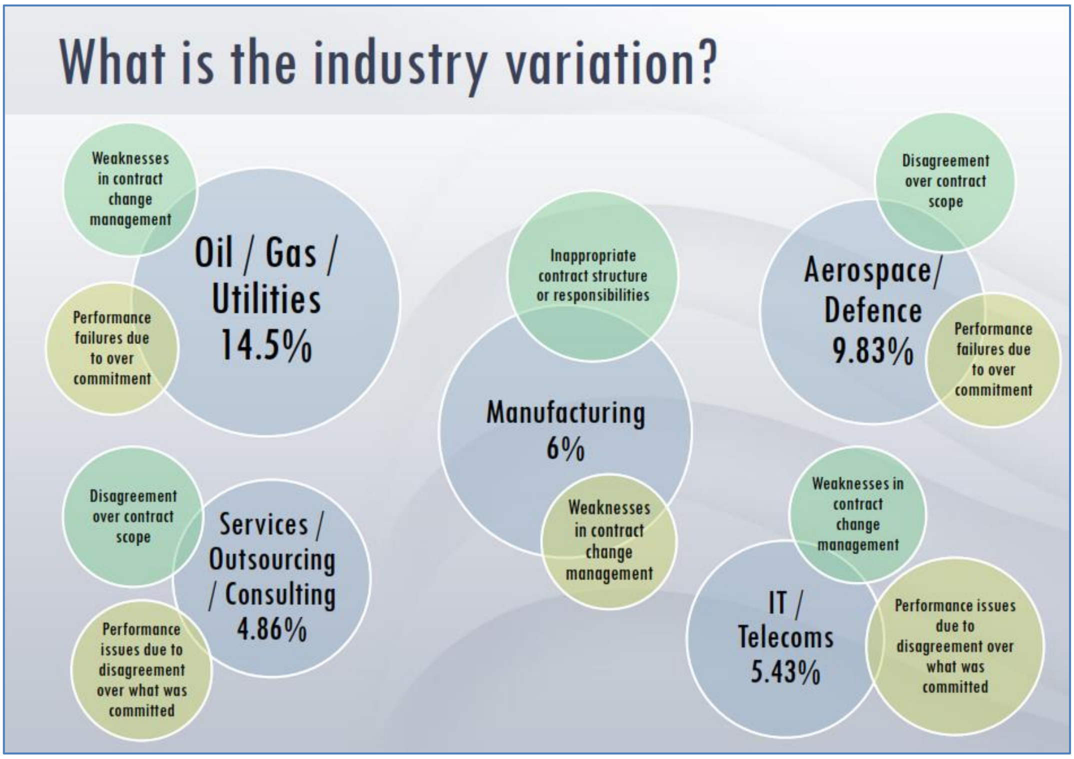


Figure 2.19 The value of contract management by industry (IACCM, 2012)

From Figure 2.19 it can be seen the major factors stated for the negative impact in aerospace and defence are “performance failures due to over commitments” and “disagreement over contract scope”. In addition, the survey results were displayed by countries. Based on the findings of the IACCM survey it can be stated that in Asia the average loss is higher than in other parts of the world and that the main causes for this discrepancy is due to “inappropriate contract structure or responsibilities” and due to “performance issues due to disagreement over what was committed”. The main causes stated for negative impact to the bottom line are directly linked to both project and contract management areas.

2.17 **Risk Management and Risk Analysis**

Risk management is one of the nine knowledge areas propagated by the Project Management Institute (PMI) (PMBOK, 2013). PMI defines a project risk as "an uncertain event or condition that, if it occurs, has a positive or negative effect on at least one project objective". Since there are many possible risks that could impact negatively on the project or leading to project failure, it is crucial to identify all risk factors. Raz *et al.* (2002) stated that too many project risks as undesirable events may cause construction project delays, excessive spending, unsatisfactory project results or even total project failure.

A reduced demand and shortage of orders in the international market dramatically increases competition between companies competing for projects. This increases pressure to improve quality, productivity and reduce costs, and creates the need for project strategies and management that can appropriately and effectively manage project risks (Banaitiene and Banaitis, 2012). The Royal Navy (RN) has also developed a risk-based maintenance policy in 2012 (Cdr C New MOD, 2012) for the RN ships and submarines to meet the operational needs.

Banaitiene and Banaitis (2012) also described that the benefits of the risk management process include identifying and analysing risks, and improvement of project management processes and effective use of resources. They continue to indicate that risk management may probably be the most difficult aspect of project management. Managing risks in projects has been recognized as a very important process in order to achieve project objectives in terms of time, cost, quality, safety and environmental sustainability (Zou *et al.*, 2007). Carbone and Tippet (2004) conducted project risk management using the project risk FMEA, using the developed risk factors.

Risk analysis and management techniques have been described by many authors internationally. A good typical risk management process is described by Wysocki (2009) as follows:

i) Risk identification
ii) Risk assessment
iii) Risk mitigation
iv) Risk monitoring

Risk management helps the key project participants – client, contractor or developer, consultant, and supplier – to meet their commitments and minimize negative impacts on project performance in relation to cost, time and quality objectives. Banaitiene and Banaitis (2012). Risk mitigation and risk response development is often the weakest part of risk management (Hillson, 1999). The proper management of risks requires that they be identified and allocated in a well-defined manner. This can only be achieved if contracting parties comprehend their risk responsibilities, risk event conditions, and risk handling capabilities (Perera *et al.*, 2009).

According to Zaghloul and Hartman (2003), there is no possibility to eliminate all the risks associated with a specific project. All that can be done is to regulate the risk allocated to different parties and then to properly manage the risk. Contract choice decisions are central to both stakeholder management and the management of risk and uncertainty (Chapman and Ward, 2008). In accordance with a survey conducted in 2011, Banaitiene and Banaitis (2012) explained the results that 97% of the respondents answered that the risks must be managed at the early stages of the project. 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 stated in equation 2.3

$$\text{Risk} = (\text{Probability of Incident/Accident}) \times (\text{Losses per Incident/Accident}) \qquad (2.3)$$

The probability and impact (losses) matrix illustrates a risk rating assignment for individual risk factors. It shows the combination of impact and probability that in turn yields a risk rank or risk priority. The likelihood of occurrence and consequences of scenarios Wiggins (1985) as the result of their pairing is called a risk assessment matrix. An example of a risk matrix is described in Figure 2.20.

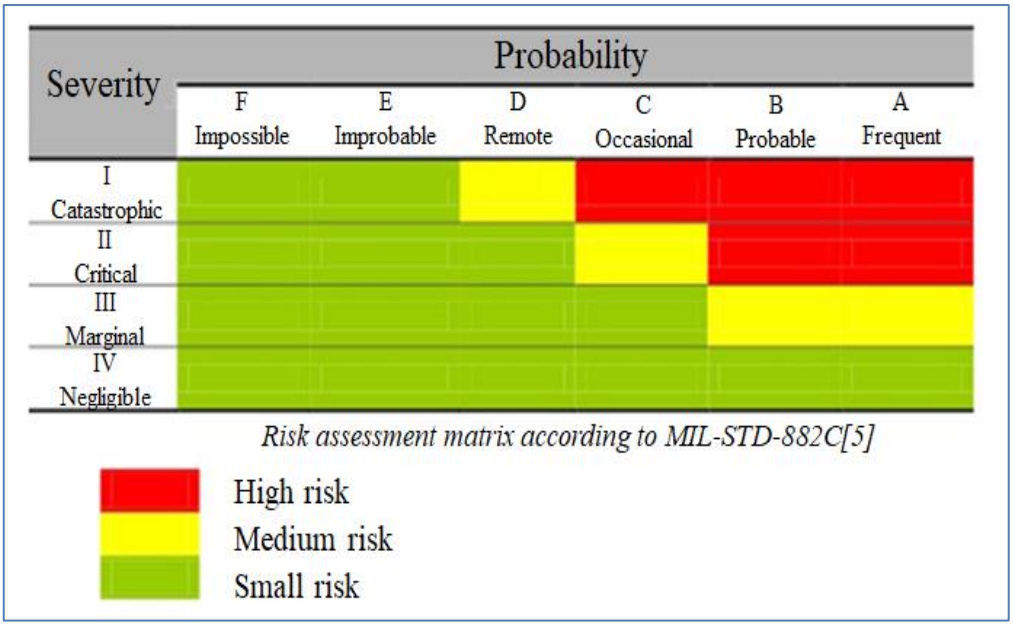


Figure 2.20 Example of risk assessment matrix (Ristic, 2013)

Typical risk assessment matrices vary with organizations. Referring to Ristic (2013), the example of the ranges for categories of likelihood and consequences are as illustrated in Table 2.6.

Table 2.6 Example of risk assessment matrix by organisation (Ristic, 2013)

Organizations	**Risk Assessment Matrix**
US Department of Defense MIL-STD-882C	6 x 4
US Department of Defense MIL-STD-882B	5 x 4
OHSAS standard recommended by the European Agency for Occupational Safety and Health	3 x 3
US Department of Veterans Affairs for Patient Safety	4 x 4
Regulation on Chemical Risk and Environmental Pollution Assessment RS No 60/94, 63/94	5 x 3

The US National Aeronautics and Space Administration (NASA) had used risk assessment matrices to avoid the problem of managers treating the values of probability and risk as absolute judgments (Wiggins, 1985). The US Department of Defence offers the use of risk assessment matrices as a tool to prioritize risk (Ceric, 2014). Based on Ristic (2013), both the levels of occurrence and consequences may be based on expert-opinion elicitation.

2.18 Research Gap

Operational availability of naval vessels, that reflects the number of days ships are available for operational tasking in a year, is a complex problem (GAO, 2015c, Dell'Isola and Venditelli, 2015, Ng *et al.*, 2009). High operational availability of naval vessels remains a challenge to many navies worldwide despite increasing and novel approaches to availability (Paik, 2014, van Donkelaar, 2017, Marais *et al.*, 2013). The number of days the ships are able to spend in an area of operations reveals the vital sustainability of the naval force in showing of presence and deterrent capability (GAO, 2015c). Downtime or unavailability of assets need to be minimized, as they are very costly (Driessen *et al.*, 2010).

There have been numerous literatures proposing the calculation of downtime through mean time between failure (MTBF) and mean time to repair (MTTR) to obtain availability value (Peiravi 2010; Oliveto, 1999) and concepts of availability optimization (Pan *et al.,* 2012). However, there has been very limited literatures pinpointing to the root cause of the various downtime, called downtime influence factors (DIFs) for naval vessels. Availability has over time been continuously associated with component failures, but according to Weibull (2017), there are also other contributing factors such as time-to-repair distributions, maintenance practices, crews and spares availabilities, logistics delays, etc.

In practice, even though it is normally assumed that loss of availability is caused by component failures, there exist other incalculable influences caused by external factors or sources that could not be taken into consideration when calculating availability (Rosenberger and Pointner, 2015). To the researcher, this may be caused by the inability to identify and quantify the DIFs influence on availability.

The limited literatures on DIFs of naval vessels are further restricted in the study of a single factor such as obsolescence (Sandborn, 2013) or spares availability (Moon, 2010), or two or three factors at most (Pahl *et al.*, 2007). In reality however, the DIFs encompass a wide range of human and equipment related factors that most researchers have not attempted to study. The situation is further complicated by issues of equipment and component redundancies as well as possible interdependencies between each DIFs (Driessen *et al.*, 2010, Rosenberger and Pointner, 2015, Nannapaneni *et al.*, 2014). It appears that there has never been a holistic research into the combined human and equipment root causes inducing downtime. As a result, previous improvement efforts could not be placed precisely by organisations in controlling specific DIFs which greatly impact them.

Even though asset availability optimisation concepts have been studied in a multitude of industries including the defence industry for a few decades, nowadays continued budget and regulatory restrictions increase the burden for all stakeholders (Button *et al.*, 2015). Most concepts developed are applied to systems that do not have many interlinked and parallel operating sub-systems. For war ships, its complexity is higher than other assets due to their floating and movable condition. Furthermore, they have cross-functional capability to meet different roles and missions depending on time and conditions and political scenarios (Olivier and Ballestrini-Robinson, 2014). Unlike other commercial assets, the complexity increases rapidly as the naval ships are expected to be able to deploy quickly and change their roles in an extremely short turn-around-time depending on situations (Directorate of Maritime Strategy Canada, 2001).

To date and based on the literature review, it appears no generic framework or model on availability-oriented contract management has been developed for war ships that is universally applicable. A key drawback is that historically, proposed efforts remained placed on complex mathematical calculations and estimates, which required not only sophisticated programmes but also limited the understanding to a few highly skilled professionals able to implement them (Jardine *et al.*, 1996, Wang *et al.*, 2010). This has never been appealing to most practitioners as well as the majority of stakeholders who continuously complain about the gap between theory and practice. There is a need for a research aimed at simplifying the complexity surrounding naval ship availability.

There is a lack of a handy tool to assist contract managers to efficiently and continuously track, manage and control ISS contracts. Contracts could be managed better if relevant stakeholder especially contract managers are provided with a tool consisting of information as close to real time, with the necessary feedback and recovery information to ensure faster decision making, as opposed to routine scheduled progress reporting. This tool could also be used as a mechanism to compare contract performance and for the evaluation of contract compliance on scope, time and quality.

According to Keller *et al.* (2002), while the nature of the clauses may differ considerably among different contracts, the general structure of all different contracts remains the same. This implies that there is a possibility to come up with a unified contract model, which can be applied to a multitude of bilateral customer/provider relationships. The researcher has embarked on developing a generic framework or model that would be generally applicable and beneficial globally and assist the contract manager in managing the contract efficiently. Figure 2.22 illustrates the research gaps identified.

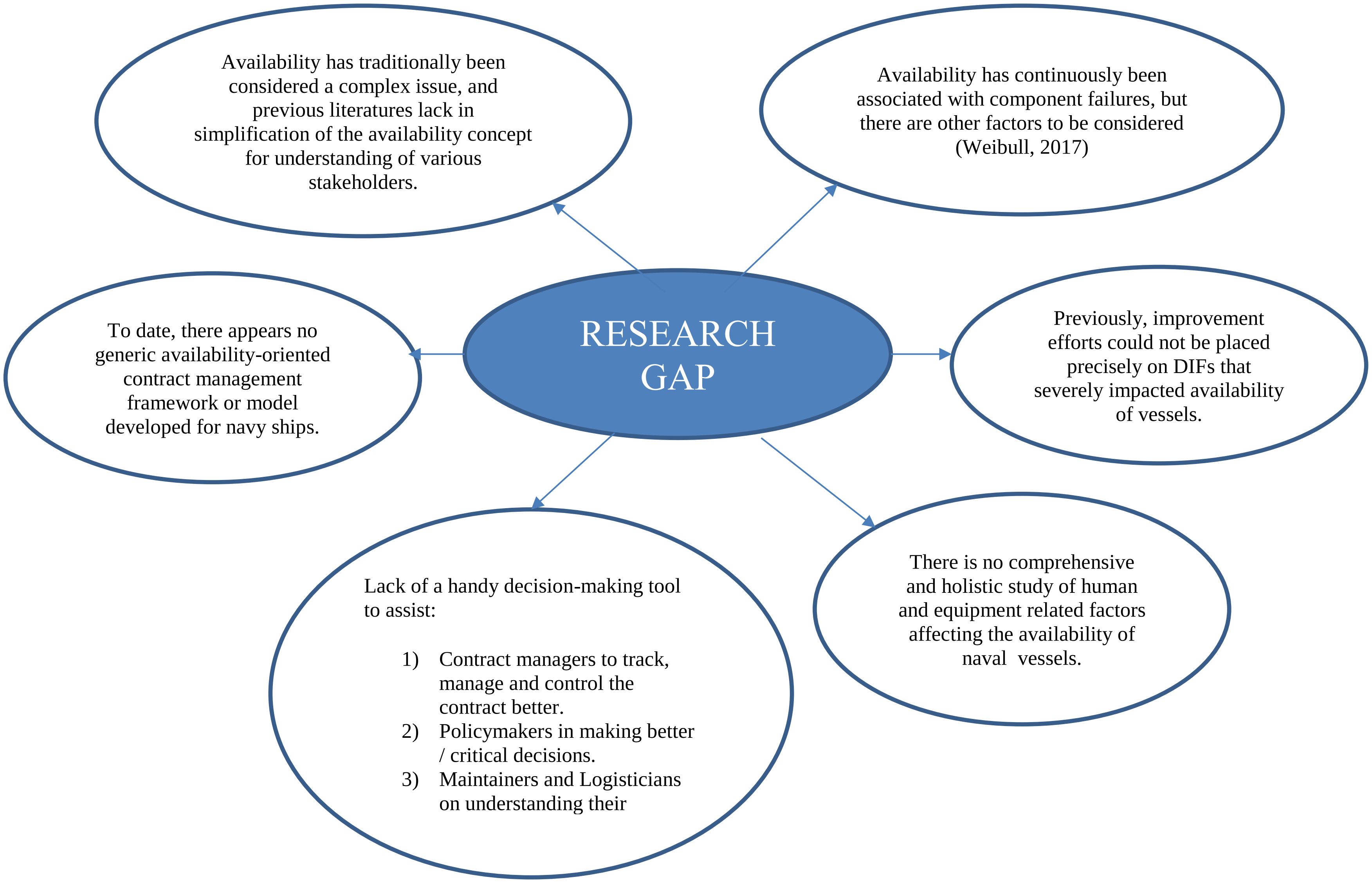


Figure 2.21 Research gap

2.19 **Summary**

In the past, availability has continuously been associated with only component failures, but there are also other contributing factors such as time-to-repair distributions, maintenance practices, crews and spares availabilities, logistics delays, etc. (Weibull, 2017). The literature review has identified a multitude of downtime factors affecting availability gathered from various other engineering disciplines as there has been limited holistic research concerning human and equipment related factors on naval ship availability. Non-existence of this holistic study created ambiguities and uncertainties on responsibilities and accountability between stakeholders involved in the PV ISS contract. Furthermore, the factors have been gathered, naturally treated with equal standing, as they have never been ranked and prioritized previously. This is especially interesting when concerning which factors would severely impact the naval ships. The complexity of the naval ship, the complex mission scenarios, and the complexity of factors affecting operational availability created perplexity as the various stakeholders are uncertain of their individual contribution towards improving ship availability. This has then naturally led the researcher to the research aim and objectives which are explained in the next chapters.

This chapter also summarized the background of the PV ISS contract, the relationship between various stakeholders involved, the previous issues and efforts taken on naval ship availability, relationship between uptime and downtime to availability, relationship between availability to contract and project management, other contracting methods concerning availability and previous literatures concerning the Delphi technique. The chapter also captured literatures concerning the RMN's mission and vision reflecting the expectations of the current Chief of Navy on the future of the fleet such as the "15 to 5" transformation programme. The challenge therefore has been for the researcher to develop an availability-oriented contract management model which considers the gathered factors through the literatures as summarized in the research gap in Figure 2.22.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter contains the methodology of the complete study. It describes the research design and research methodology applied in fulfilling the research aim and objectives in Chapter 1, as well as the overall structure of the research methodology and research approach. It explains in detail the activities in each research phase with justification and background of the chosen panellists.

Following the introduction, Section 3.2 presents the process to determine the appropriate research approach. Section 3.3 discusses the Delphi technique from its origin to its selection as a research tool. Section 3.4 elaborates on the steps taken in the study. This section contains the research design, explains the best methodology adopted in this research and elaborates on ethical consideration in conducting the research. Sections 3.5 describes the process of determining the research variables, Section 3.6 explains the development of the conceptual model and framework. This is followed by Section 3.7 on the development of the model algorithm. Section 3.8 discusses on the data collection and analysis including population of study, sample size, sampling technique as well survey questionnaire development. Discussion on validation of the developed model is explained in Section 3.9. Finally, Section 3.10 summarizes the chapter.

3.2 Determination of the appropriate Research Methodology

This section describes a review of research philosophy, methodology and common research approaches. It provides explanations and justifications on why some approach and methodology is more suitable than others depending on type of research.

3.2.1 Review of Research Methodology, Design and Strategy

The research philosophy and methodology could be derived from understanding the definition of research itself as a 'detailed and careful investigation into some subject or area of study with the aim of discovering and applying new facts or information.' (Chambers 21st Century English Dictionary) and 'studious inquiry or examination; especially: investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new or revised theories or laws.' (Merriam-Webster Dictionary). The Cambridge advanced learner's dictionary (2003) defined research as 'a detailed study of a subject, especially in order to discover (new) information or reach a (new) understanding'.

Research is defined as study and investigation, especially to discover new facts. It may also concern confirmation of existing facts. As an example, studies or experiments with controversial results may be repeated by other scientists in order to validate the credibility (Terblanche and Boshoff, 2003). The purpose of research design is to create a link between the research questions and the empirical data which has been collected. Moreover, research design also involves the tools and procedures used to answer the research questions (Punch, 2000). Selection of an appropriate research strategy is a significant initial stage prior to the determination of the study design (Irianto, 2005).

3.2.2 Research Philosophy and Research Approaches

The research approach includes the types of evidence to be collected and the sources of such evidence, as well as the process of interpretation used to obtain satisfactory answers for the questions being posed (Easterby-Smith *et al.*, 2002). This section covers the definitions of research philosophy, research approaches and research techniques. To obtain an understanding of the meaning of research methodology and its elements, the adapted 'nested' methodology in Figure 3.1 demonstrates it holistically. In summary, the outer ring of the nested research methodology represents the overall encompassing research philosophy, which influences the inner research approaches and research techniques. Research approaches further influences the research techniques which comprise of data collection mechanism.

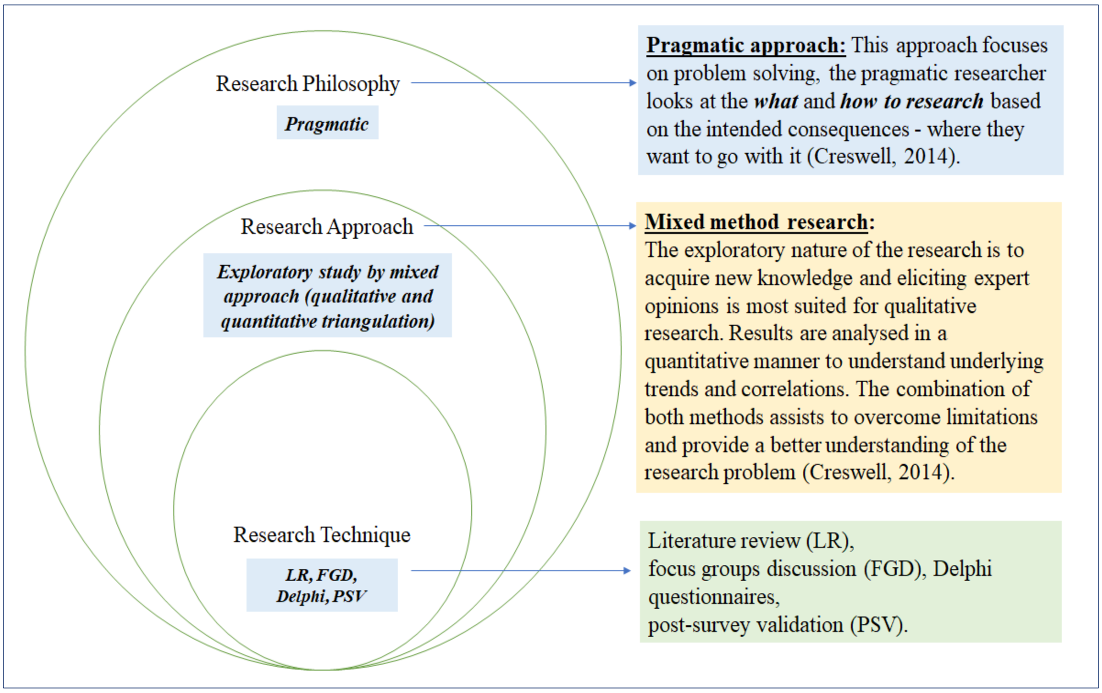


Figure 3.1 The nested research approach (adapted from Kagioglou, 1998)

The approach to be adopted for conducting research depends on the type of investigation, data and information that are required and available (Naoum, 1998). There are recommendations of the types of research approaches best suited for different types of research. The research approach taxonomy from Galliers *et al.* (2007) adapted by Fathi (2009) can be seen as illustrated in Figure 3.2. As can be seen, it would appear that some approaches are more appropriate than others given the topic under study. A combination of several approaches may also be used to undertake research.

Research Approach: An Outline Taxonomy (adopted from Galliers et al., 2007)

Object of study	Interpretive Approach					Positive Approach		
	Laboratory Experiment	Field Experiment	Survey	Case Study	Forecast/ Future Research	Simulation	Reviews	Action Research
Society	X	X	XXX	XX	XXX	XX	XXX	XX
Organisation/ Groups	XX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
Individuals	XXX	XXX	XX	XX	XX	XXX	XXX	XX
Technology	XXX	XXX	XXX	X	XXX	XXX	XX	XXX
Methodology	X	XX	XXX	XXX	X	XXX	XXX	XXX

XXX Most applicable **X Least applicable**

Figure 3.2 Research approach : An outline taxonomy (Fathi, 2009)

Creswell's (2014) pragmatic research philosophy is most suited in assisting the researcher to answer the research questions since both, qualitative and quantitative assumptions can be drawn from liberally with a freedom to choose research methods, techniques and procedures that best meet the research need and purpose. Creswell and Clark (2011) highlights that the core argument for a mixed method design is that the combination of both forms of data provides a better understanding of the research problem than either quantitative or qualitative data by itself. Creswell (2014) provides a mixed method format example which the researcher has used as a guideline. Creswell (2014) contains the updated mixed method procedures including the detailed explanations of mixed method research (a) convergent, (b) explanatory sequential, (c) exploratory sequential. The researcher has opted for the exploratory sequential mixed method as illustrated in Figure 3.3.

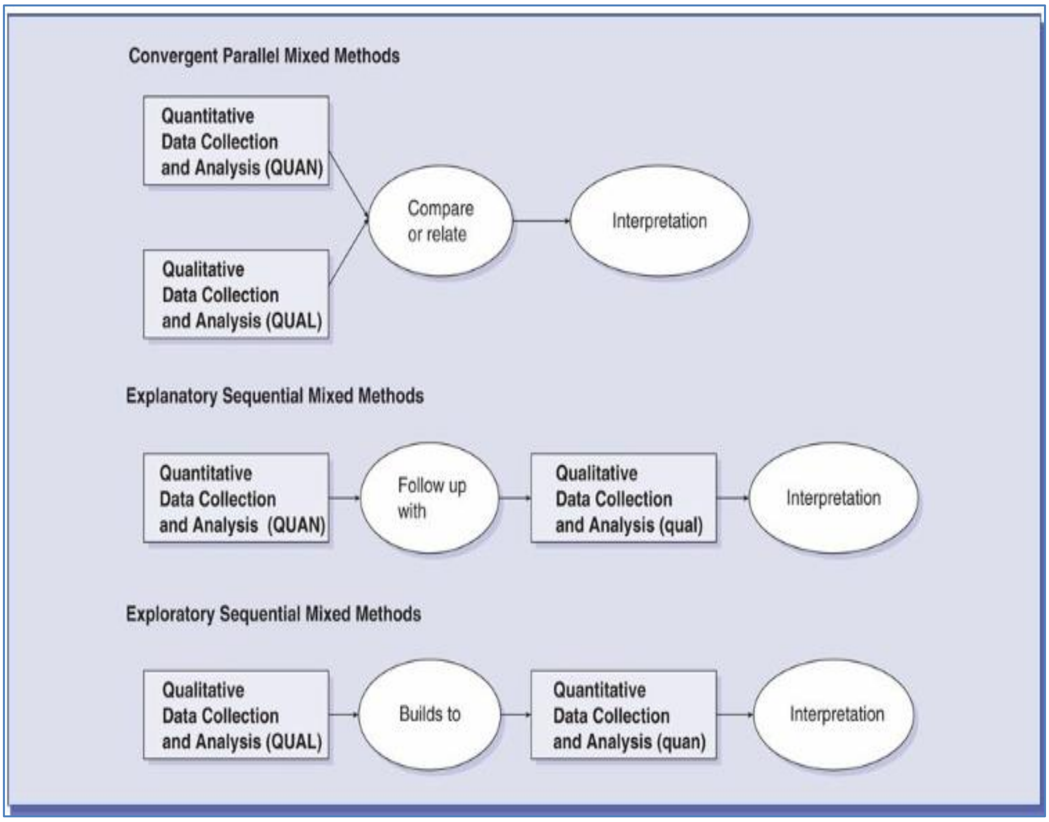


Figure 3.3 Three basic mixed method research design (Creswell, 2014)

There are a multitude of literatures by various authors that support the concept of mixed methods in order to produce greater results to the study. Ford *et al*. (2013) specifically mention that to obtain optimum results in naval surface ship in-service information exploitation a combination of information sources that are “subjective” typically qualitative data and “objective” typically quantitative is recommended. Similarly other authors argue that combining quantitative and qualitative approaches in research design and data collection should be considered whenever possible (Abowitz and Toole, 2010) . The use of multiple research methods is beneficial in better understanding adequately an activity, process or object (Wynekoop and Russo, 1997). The contribution of triangulation to enhancing validity is one of the key rationales for using mixed methods (Creamer, 2018).

The application of the exploratory sequential mixed method as the research methodology for this thesis is based on the realisation that new knowledge needs to be acquired and is further expanded in Figure 3.4.

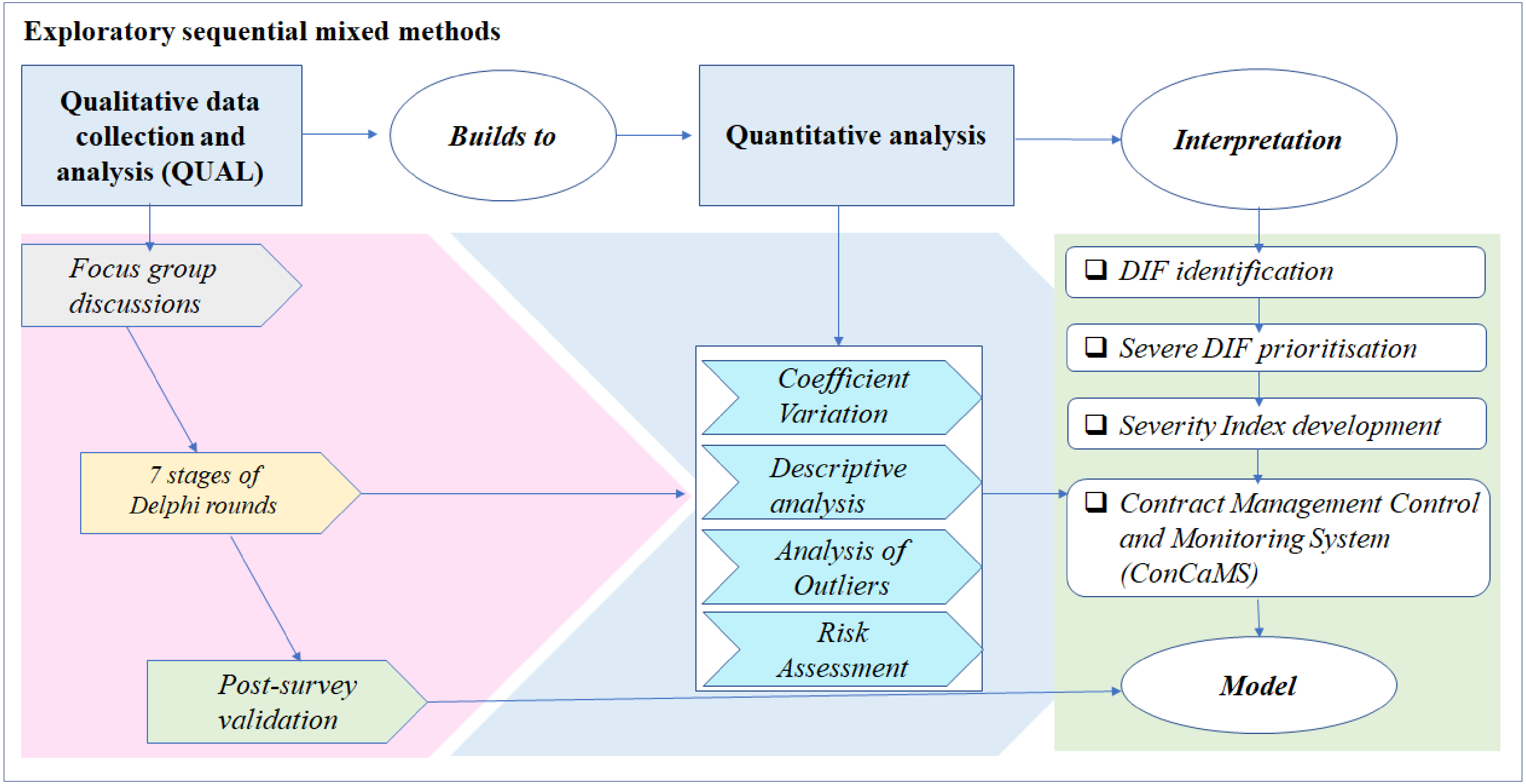


Figure 3.4 Exploratory sequential mixed method concept for thesis research

Figure 3.3 highlights the various research techniques that will form part of the exploratory sequential mixed method approach. Focus group discussions (FGD), Delphi technique and post-survey validation are research tools mostly classified as qualitative. The analysis of the Delphi results is however done in a quantitative manner by ensuring the experts opinion converge round upon round with the use of coefficient variation, descriptive analysis is used to better understand underlying trends in demographic and analysis of outliers is applied to further explore relationships. Further risk assessment analysis is introduced to prioritize and rank the downtime influence factors (DIFs). Only upon combination of both approaches the research objectives can be met. A post-survey validation is the final step to validate the produced model.

Creamer (2018) argues that the value added of a fully integrated mixed method research that combines quantitative and qualitative elements is the potential to strengthen explanatory power. The researcher has selected to elicit experts' opinions that are traditionally considered for qualitative research, nevertheless the sample size consisting of a large majority of all available ISS contract experts in Malaysia would warrant for a quantitative approach. Further, Creamer (2018) highlights that the greatest potential to enhance explanatory power through mixing is to employ a recursive or iterative approach to analysis, have interlinked qualitative and quantitative research questions. The researcher applies a combination of typically qualitative open ended and typically quantitative closed-ended questions throughout the FGD, iterative Delphi rounds and post-validation survey pinpointing that a mixed method is the most compatible approach. Creamer (2018) also states that most mixed methods studies use more than one sampling procedure. The researcher selected purposive sampling as well as snowball sampling for the various stages of this research. Since both qualitative and quantitative research approaches are seamlessly integrated throughout the complete study it appears justified to be designated as mixed-method research (MMR).

3.3 The Delphi Technique

This section explains the determination of the appropriate research methodology. This section contains the origin and application of Delphi, the forms of Delphi technique, the Delphi process, explaining Delphi as the selected research tool and culminating with the sequential Delphi process applied.

3.3.1 The Origin and Application of Delphi

The Delphi method or technique if by far the most known method for eliciting and synthesizing expert opinion (Ayyub, 2000). The original intent of Delphi was as a forecasting technique, developed by RAND Corporation designed to predict the likelihood of future events to study the impact of technology on warfare in 1950s using expert judgment. Olaf Helmer and Norman Dalkey at the RAND Corporation during the 1960s (Dalkey and Helmer, 1963, Helmer, 1968, Dalkey, 1969) developed the method for the collection of judgment for such studies including the military. However, Dalkey (1968) states that the name "Delphi" was never a term with which either Helmer or Dalkey (the founders of the method) were particularly happy. Dalkey argued that the term implies "something oracular, something smacking a little of the occult", whereas, as a matter of fact, precisely the opposite is involved. It is primarily concerned with making the best you can of a less than perfect kind of information.

The Delphi method is a flexible research technique that has been successfully implemented in many areas of study. It is well suited as a research instrument when there is incomplete knowledge about a problem or phenomenon. The Delphi technique works especially well when the goal is to improve our understanding of problems, opportunities, solutions, or to develop forecasts (Skulmoski *et al.*, 2007). The technique has since been widely accepted throughout the world in many industry sectors including healthcare, defence, business, education, information technology, transportation and engineering (Skulmoski *et al*, 2007). In accordance to the comparative studies by Giannarou and Zervas (2014), 32 Delphi studies between 1975 to 2013 in the fields of management and business were discussed.

In the last several decades Delphi has been more frequently used for facilitating group communication for decision making and planning (Shelton and Creghan, 2014). It allows researchers to maintain significant control over bias in a well-structured academically rigorous process using the judgment of qualified experts (Hallowell and Gambatese, 2010). Besides nursing and healthcare, business and education where the majority of the Delphi study resides (Shelton and Creghan, 2015) over the past 50 years, the Delphi has also been used in societal policymaking, industry, and psychology (Linstone and Turoff, 2002) and (Moriarty and Honnery, 2012). Studies on quality management based on Delphi method was done by Iñaki (2006) and quality assurance by Gracht (2012). A Delphi study involving risk analysis on soil studies was done by Webler *et al.* (1991) and on construction engineering and management (Hallowell and Gambatese, 2010).

On multi-stakeholder scenarios, Delphi was used by Wilkinson (2009), Curry (2007) and Chermack and Nimon (2008) to help contrast constructive disagreements between stakeholders which often do not share common vision or underlying set of value. Delphi method for risk analysis can be referred to RainerJr *et al.* (1991), Tummala and Burchett (1999), Schmidt *et al.* (2001) and Addison (2003). A study by Skulmoski *et al*. (2007) captured at least 280 dissertations and thesis that use Delphi method in their research. Grisham (2009) quoted that a search of academic search premier alone in May 2008 yielded 476 articles, so the use of Delphi in research is an accepted practice. Landeta and Barrutia (2011) found 677 scientific articles on Delphi in the period between 2004 and 2010.

Márquez (2007) provided a basic definition of the Delphi technique by stating that it is a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem". Rieger (1986) stated that Delphi is continuing to be a much-used tool in the search for answers to normative questions, especially in education areas, but also in other fields. The Delphi technique is preferred as a problem solving or policy making tool when knowledge about a problem or a phenomenon is incomplete and is used with the aim of obtaining the most reliable group opinion (Adler and Ziglio, 1996).

Dalkey *et al.* (1972) described Delphi as a procedure that is a rapid and efficient way to cream the tops of the heads of a group of knowledgeable people. He further stated that a well-designed and properly managed Delphi could be a highly motivating environment for respondents. Grisham (2009) referred to Delphi as appropriate for researching complex issues where larger scale quantitative hard data fails to unearth richness in tacit knowledge to help the research understand subtle expert opinion. He continued to state that it also provides a scientific methodology that is well suited to issues that require the insights of subject matter experts.

The Delphi technique is also described as a method for finding and evaluating solutions in the engineering field, especially in fundamental studies for long term developments. Goldberg *et al.* (1994) further states that the Delphi Technique is best performed for conceptual trade studies, concept definition and deployment of product and performance validation. On the question of validity and reliability of the technique, Helmer (1967) supported it as an acceptable method of data collection from an identified group. He also stated that Delphi is efficient in both group decision making situations and in other areas where order of magnitude estimates are required. Helmer (1967) further described Delphi as a technique frequently used for eliciting consensus from within a group of experts that has application in reliability and has many advantages over other methods of using panel decision making. Marquez (2007) agreed with Helmer (1967) on the application of Delphi, and both found that one of the major advantages of using Delphi as a group response is that consensus will emerge with one representative opinion from the experts.

3.3.2 **Forms of Delphi Technique**

Several names have been given to types of Delphi over the years, associated with the objectives of the research. Dailey (1988) called it as an exploratory Delphi. VanDijk (1990) described it as a conventional Delphi. Yousuf (2007) stated that the process of Delphi is essentially the same, however the purpose of a study determines the type of Delphi used.

Linstone and Turoff (2002) explained that a policy Delphi is one which seeks to generate the strongest possible opposing viewpoints on a policy issue from an expert panel. The emphasis is on identifying differing opinions and divergent responses through a process of debate carried out through the rounds of Delphi. Policy Delphi is also sometimes called focus Delphi and decision Delphi (Hsu and Sandford, 2007). A normative Delphi focuses on establishing what is desirable in the form of goals and priorities (Sutherland, 1975). Most Delphi studies in educational settings are normative and are perceived as particularly useful. There are also several extensions and modifications of the Delphi technique (Riggs, 1983).

3.3.3 Process or Steps of Delphi

Theoretically, the Delphi process can be continuously iterated until consensus is determined to have been achieved. Hsu and Sandford (2007) and Delbecq *et al.* (1975) suggest that a two or three iteration or stage Delphi is sufficient for most research. Cyphert and Gant (1971), Brooks (1979), Custer *et al.* (1999) pointed out that three iterations are often sufficient to collect needed information and reach a consensus in most cases. In accordance to Helmer (1968), the basic Delphi technique consists of the following steps:

i) Selection of issues or questions and development of questionnaire.
ii) Selection of experts who are most knowledgeable about issues or questions of concern.
iii) Issue familiarization of experts by providing sufficient details on the issues on the questionnaires.
iv) Elicitation of experts about the issues. The experts might not know who the other respondents are.
v) Aggregation and presentation of results in the form of median values and inter-quartile range.
vi) Review of results by the experts and revision of initial answers by the experts. This iterative re-examination of issues would sometimes increase accuracy of results. Respondents who provide answers outside the inter-

quartile range need to provide justifications or arguments on the second cycle of completing the questionnaires.

vii) Revision of results and re-review for another cycle. The process should be repeated until a complete consensus is achieved. Typically, the Delphi technique requires two to four cycles or iterations.

viii) A summary of the results is prepared with argument summary for out of inter-quartile range values.

The responses on the final iteration usually show less spread in comparison to spreads in earlier iterations. The median values are commonly taken as the best estimates for the issues or questions. There are many variations of the steps but most of them cover the essential elements of Delphi. A flowchart of the typical Delphi process by Riggs (1983) is described in Figure 3.5.

A Flowchart of the Typical Delphi Process

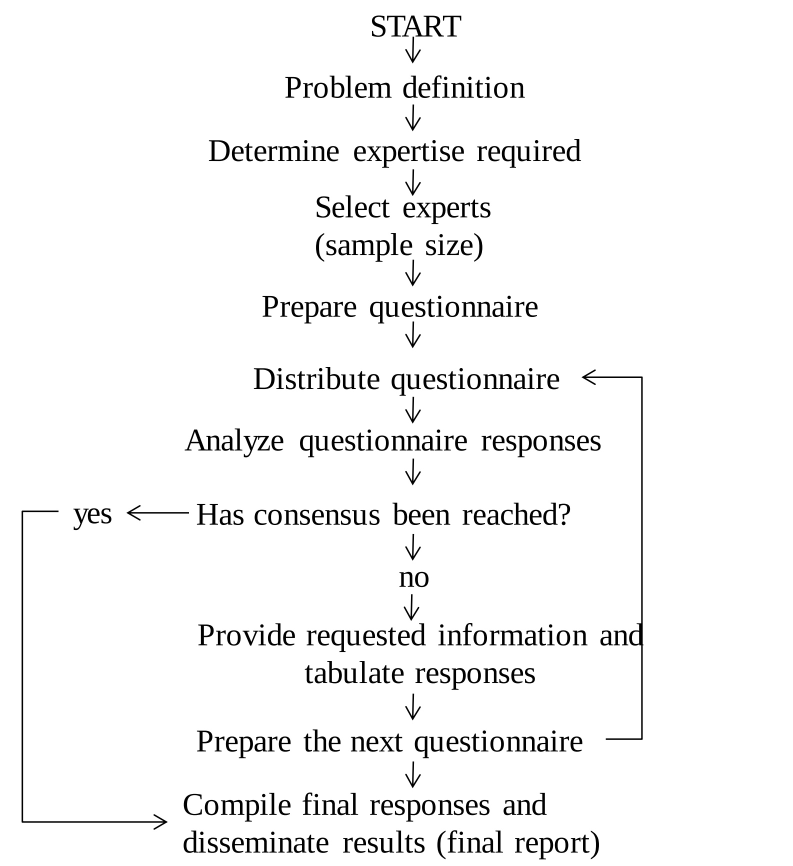


Figure 3.5 A typical flow of Delphi process (Riggs, 1983)

3.3.4 **Delphi as the selected Research Tool**

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 author have explored the usage of many methodologies for this research, however Delphi was chosen as the most suitable research tool 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 and 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. Furthermore, in accordance to (Button *et al.*, 2015), even though the RN has implemented the SURFMEPP system for collecting ship-level detailed data which should prove valuable in determining factors impacting ship maintenance, in many cases however, understanding why a particular availability escalated in cost would require on-site interviews with ship's personnel, maintenance supervisors, and the overall chain of command.

It is also well agreed among researchers that Delphi technique is preferred as a research instrument for incomplete knowledge about a problem or phenomenon (Skulmoski *et al.*, 2007, Adler and Ziglio, 1996, Czinkota and Ronkainen, 1997, Linstone and Turoff, 2002) or in the case of limited experts in the field are available (Cuhis, 2003, Skulmoski *et al.*, 2007). Grisham (2009) emphasized that the method is appropriate for researching complex issues where larger scale quantitative hard data fail to unearth richness in tacit knowledge to help the research understand subtle expert opinion. The scientific methodology provided by the Delphi is well-suited to issues that require the insights of subject matter experts. Whilst Delphi technique is generally used with the aim of obtaining the most reliable group opinion (Adler and Ziglio, 1996), it is also useful for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with the complex problem (Márquez, 2007). The method works especially well when the goal is to improve the understanding of problems, opportunities, solutions or to develop forecasts (Skulmoski *et al.*, 2007). It is continuing to be a much-used tool in the search for answers to normative questions (Rieger, 1986) such as policy making (Adler and Ziglio, 1996).

On the implementation and enhancement of the Delphi technique, Rowe and Wright (2011) presented a framework for conducting the necessary Delphi research and how to enhance the usage of the Method including improving expert recruitment via snowballing and other methods of retention over Delphi rounds. Specifically, Baker and Edwards (2012) recommended guidance and advice on sampling size for qualitative interviews based on a set of succinct "expert voice" contributions stating that saturation is central to qualitative sampling depending on the methodological and epistemological perspective. Meanwhile, Adler and Adler (2011) advised sample pool sizes and a mean of 30 though later confirmed that the best answer is simply to gather data until empirical saturation has reached since some qualitative researchers argued that as little as one expert opinion can add value to the area of research. Among various issues based on cost, time and resources available considered in preferring the Delphi approach are outlined as follows:

i) Identification of factors affecting the downtime and therefore naval ships availability have not been itemized previously due to the complexity while identification of the most critical factors requires a Risk Analysis.
ii) Limitation of current literatures relevant to availability of naval vessels encouraged the need for rich data collection hence allows the understanding of the stakeholder's experiences as well as requirements.
iii) Requirement in addressing the presence of 'objective' and 'subjective' data as it spans across equipment/system and human related issues.
iv) Limitation in the number of people who have access to ISS contract, knowledgeable and experienced in dealing directly with the implementation of ISS in Malaysia.
v) Requirement on end result presentation as an availability-oriented Contract Management model.
vi) Various roles of participants/experts, nature of expertise, expert recruitment and retention over during the study.

Even though the main component of the current research approach is the Delphi procedure, to strengthen the study, other methods are integrated appropriately at various stages of the Delphi study including focus group discussion (FGD) as the initial expert validation of the DIFs identified via literature study, and also the qualitative risk analysis method. The main component of this study is the Delphi technique. Nevertheless, the Delphi technique which is normally done in two or three stages only, has been increased in the number of stages in this research and combined with other methods to further strengthen and increase the rigor of the study. Skulmoski *et. al* (2007) stated that there are many varieties of Delphi ranging from qualitative to quantitative, to mix-method Delphi. In the Schmidt *et al.* (2001) study, participants from three countries took part in a brainstorming session prior to the Delphi rounds.

Creswell and Clark (2011) emphasized that irrespective of the mixed method research chosen ethical issues were especially important throughout the research process, but particularly during the data collection and writing and disseminating of reports. The authors emphasized that confidentiality of participant responses needed to be protected, along with minimizing links between data respondents and participants. The proposed method of assigning IDs linked to a response was applied by the researcher since Creswell and Clark (2011) stated this practice to be an effective means of protecting individual identity. The authors highlighted that researchers have the obligation to destroy survey instruments after the conclusion of the study. This last step will be followed by the researcher but can only take place upon successful conclusion of the research. Further, Creswell (2014) provides recommended guidelines on how ethical issues are to be addressed in the research design process. The author's recommended guidelines were incorporated throughout the 7-stage Delphi procedure. The researcher adhered to ensure that religious, gender, cultural and other differences to be respected were appropriately addressed during the research design process and the research instrument development. The questionnaires were designed in order to avoid questions that would require the panellist to disclose sensitive information. The panellists had been thoroughly briefed on the procedures prior to the participation in the various phases and they were assured that their privacy and anonymity would be respected throghout the Delphi study. Further, the use of unbiased language throughout the various questionnaires was respected. The implemented diagram of the 7-stage Delphi procedure is reflected in Figure 3.6.

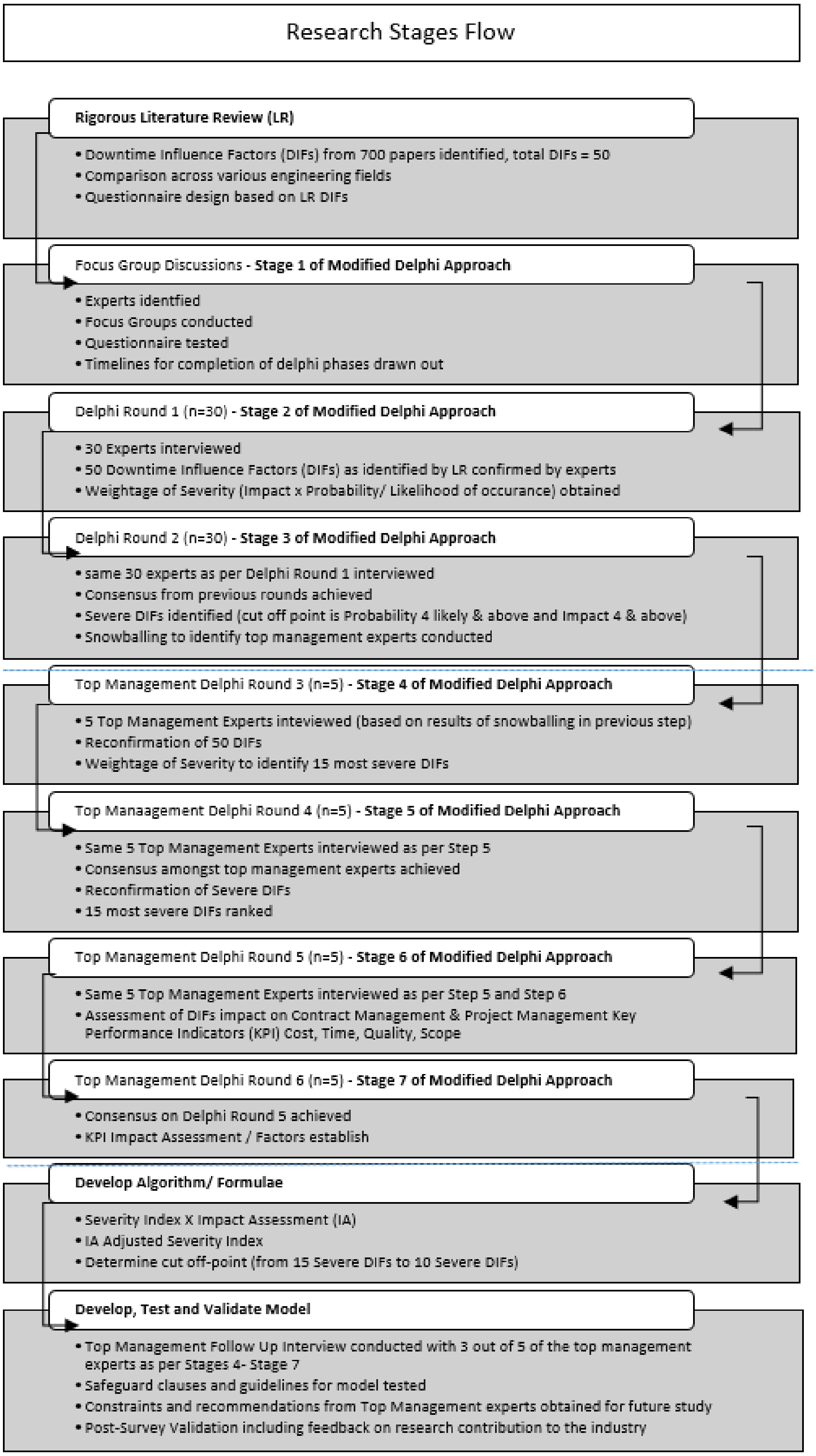


Figure 3.6 Seven stage sequential mixed method Delphi research design

3.3.5 **Sequential Delphi Process**

The 7-stage modified sequential Delphi approach, as exhibited in Figure 3.3 was selected with the objective to discover and better understand the unavailability causes and to highlight as well as to prioritize the areas of improvement. A panel of 30 professionals directly involved in naval ship maintenance was selected and their expert opinion was sought via various questionnaires. In a subsequent stage, five top management experts as proposed via snowballing technique in earlier rounds were used to validate and confirm the total as exhibited in Figure 3.7.

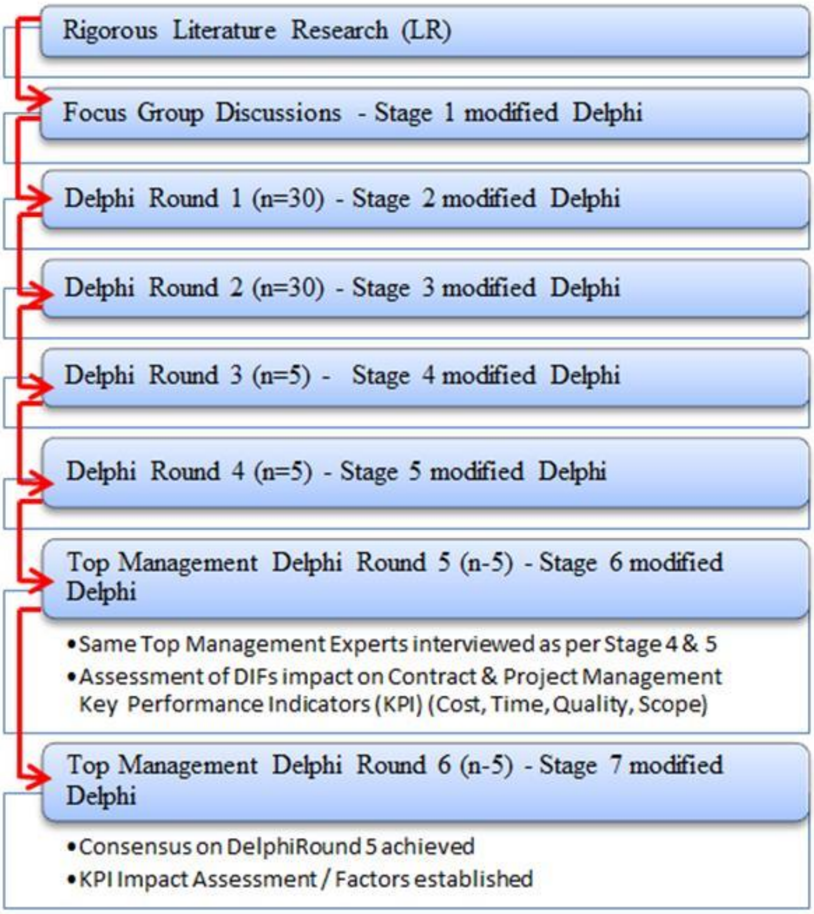


Figure 3.7 The Delphi rounds

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 and 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 and 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 one 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 and Ziglio, 1996).

3.4 Research Steps

The research steps encompassing the research flow and the research objectives depicting their relationship in various stages of the research is described in Figure 3.8. The figure illustrates the relationship between research objectives, research flow and the 13-Step availability-oriented approach. The diagram reflects how each interlinked phase is mapped.

The first underlying horizontal arrow in yellow represent the progression throughout the "conceptual stage" that lays the foundation of the research and enables the subsequent phase. The second underlying horizontal arrow in light blue represent the "realisation stage" that contain the critical activities to be performed to successfully culminate the research. The green horizontal frames align each research flow activity to the corresponding availability-oriented contract management approach steps. As such the determination of research variable is aligned to Steps 1 to Step 4 of the availability-oriented contract management approach. The development of a conceptual model is aligned to Steps 5 and Step 6 of the said approach. The development of a model algorithm and the data collection & analysis are performed in Steps 7 to Step 12 of the said approach. The final research flow activities of evaluation and validation are covered in Step 13 of the availability-oriented contract management approach. The post-survey validation exercise commences after Step 12 and is an independent follow up questionnaire to validate the previous stages of the Delphi methodology applied.

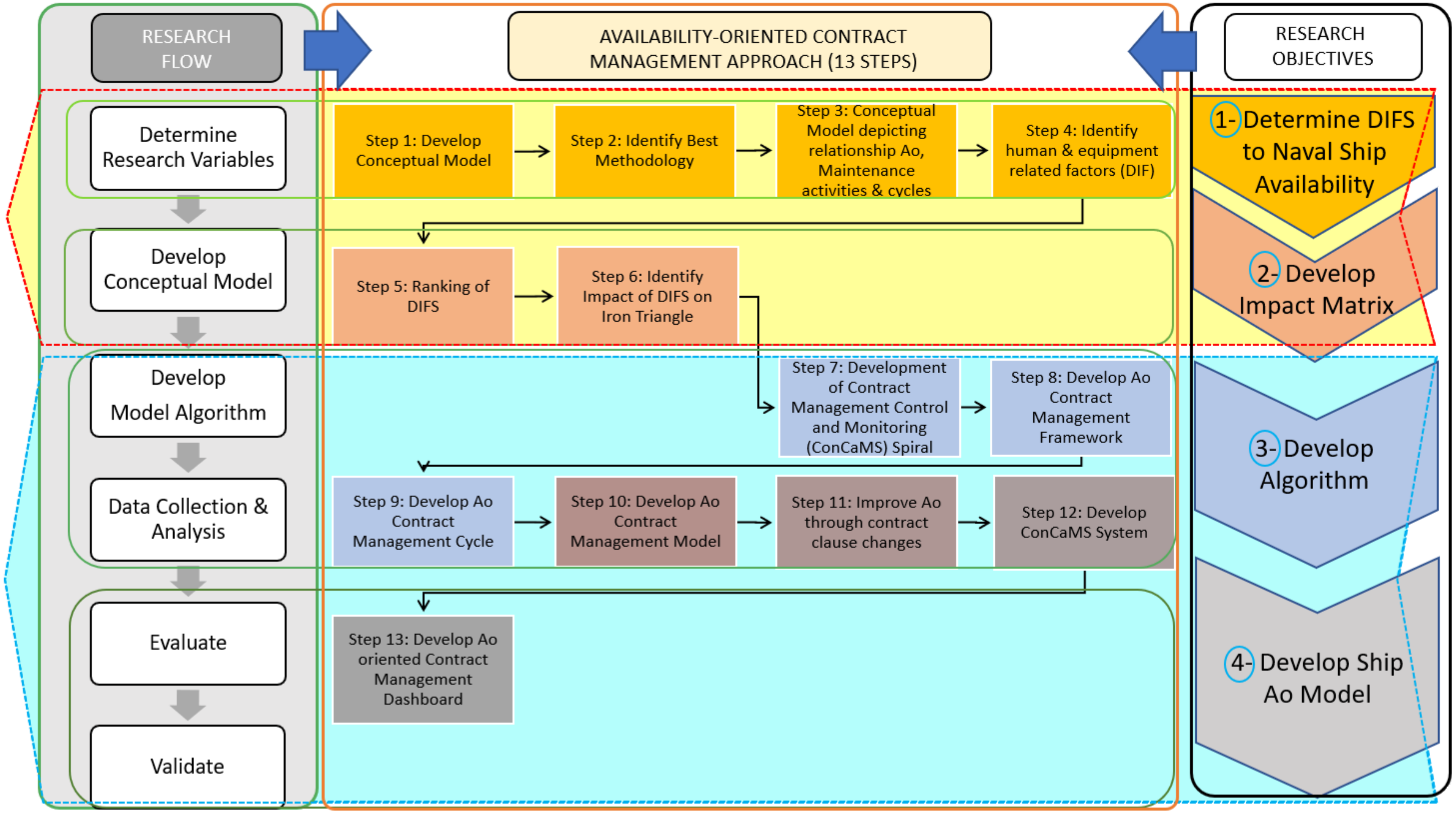


Figure 3.8 Methodology flowchart

In order to pave the way towards this uncharted area of knowledge the researcher has established a 13-step approach to be undertaken in this research, as indicated in Table 3.1.

Table 3.1 13-Steps availability-oriented contract management approach

Steps	**Description**
Step 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.
Step 2	Identification of the best methodology to approach the study.
Step 3	Development of a conceptual model depicting the relationship between operational availability (Ao), maintenance activities and maintenance cycles.
Step 4	Identification of human and equipment related downtime influence factors (DIFs) affecting Ship operational availability.
Step 5	Ranking of the DIFs from most severe to least severe.
Step 6	Identifying the impact of DIFs from contract and project management perspectives, especially on cost, time, quality and scope.
Step 7	Development of a contract management control and monitoring system spiral.
Step 8	Development of an availability-oriented contract management framework.
Step 9	Development of an availability-oriented contract management cycle.
Step 10	Development of an availability-oriented contract management model.
Step 11	Improving availability through change in contract clauses – a suggested mechanism.
Step 12	Development of an availability-oriented contract management control and monitoring system (ConCaMS).
Step 13	Development of an availability-oriented contract management dashboard

3.5 Determination of Research Variables

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, the identification of research variables begins with a thorough review of over 700 literatures concerning downtime elements that affects the availability of naval vessels, and downtime of equipment and systems from various fields of research. Subsequently a further literature review was conducted in determining other relevant data to the study from various stakeholders including copies of the ISS contract, historical records of vessel condition, home base of vessel (location), vessel operations area, mission schedule, availability of maintenance support facilities, availability of spares support, logistical support, infrastructure, availability of Original Equipment Manufacturers (OEM) and specialists, availability of special tools and test equipment, funding approval period, budget and cash flow status and management organization structure, etc.

All pertinent information relevant to the scope of the current ISS contract includes planned maintenance or preventive maintenance, corrective maintenance, provision of spares, computer support, engineering support, training and integrated logistics support (ILS) were collected. Other relevant information beyond the ISS contract but relevant during the implementation of ISS activities such as the RMN administrative order for the execution of ISS, was also collected for study. The generic list of variables consisted of close to 100 variables, most of which were believed by the researcher to be similar in meaning and interpretation. This is consistent with Goosens (2015) that seemingly unimportant criteria that are nonetheless needed to understand the problem should be included, only later unimportant criteria will be eliminated by the judgement process. In order to reduce the list and pool into a more manageable number of groups with relevant terms for better understanding for future stages, a focus group discussion (FGD) was conducted.

The objective was obtained by several steps in preliminary stage and stage 1 to stage 5 in mixed-method modified Delphi. In the preliminary stage, the involved steps were aimed to identify the research variables and develop the research questionnaire and the detail of the steps as presented in Figure 3.9.

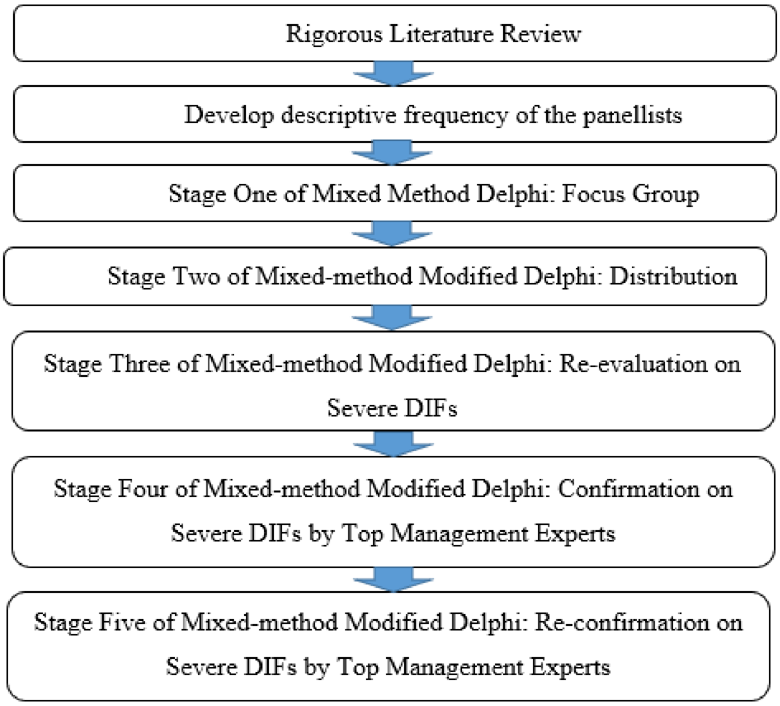


Figure 3.9 Steps in identifying DIFs as key variables to ship availability

Identification of the current research variables commenced from a detailed literature review concerning down time elements that affect the availability of naval vessels and downtime of equipment and systems from various fields of research. All pertinent information relevant to the scope of the current ISS contract and other data from various stakeholders relevant to the study were gathered as well. A generic list of variables comprised of close to 100 possible factors were compiled and pooled in groups as the initial reference and basis of the study.

The list of variables that have been generated was used during the subsequent brainstorming session and FGD with 30 experts from the PV ISS maintenance organisations and the RMN to reconfirm and pool the variables into relevant groups. The method in identifying the variables is reflected in Figure 3.10. The summarized list of DIFs from the relevant literatures can be viewed in Appendix A. Addressing the first stage of the modified Delphi approach, FGD by expert group was designed to confirm and screen the identified variables into relevant terms with more manageable numbers.

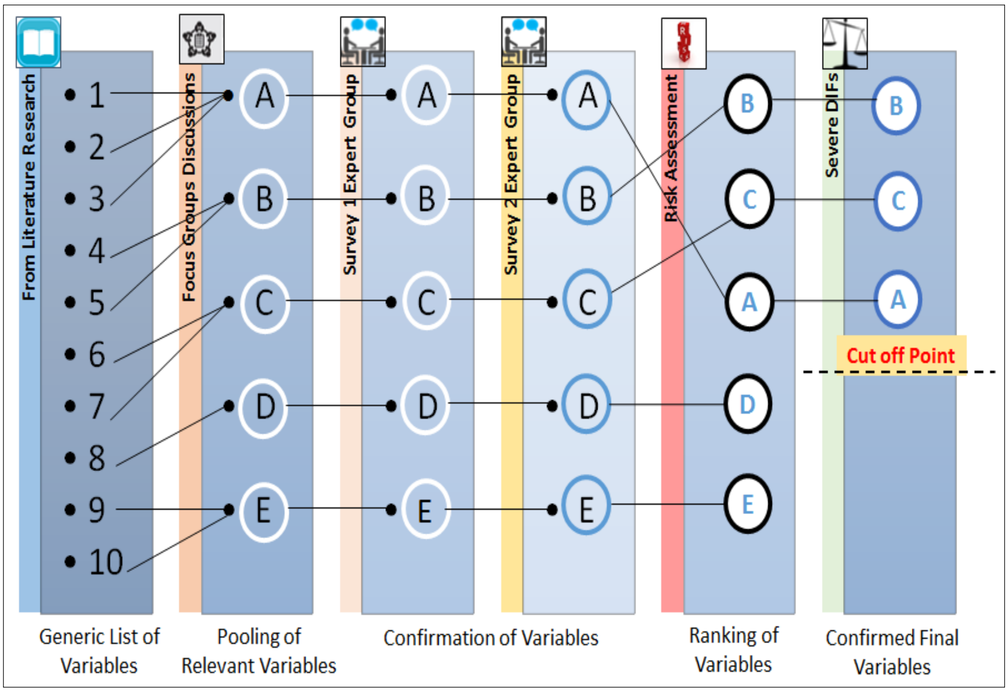


Figure 3.10 Method of identifying key variables

Consolidations of different interpretations, cross-referring of various definitions as well as pooling similar variables into agreed categories were carefully executed during the session. The next steps were confirmation of variables through Delphi round 1, with expert opinion convergence in round 2. The ranking of variables was performed according to risk assessment methodology, whereby DIFs were ranked from most to least severe. The most severe DIFs were define based on a pre-selected cut off point of "high and above" impact and "likely and above" probability.

3.6 Development of a Conceptual Model and Framework

An availability-oriented contract management model was developed after taking consideration of all available INPUTS from prior research steps and having inserted all requirements for the PROCESS as well as the expected OUTPUT, based on the McGrath (1984) IPO model as described in Figure 3.11. Subsequently a conceptual framework was produced as per Figure 3.12. The availability-oriented contract management model was further developed after completion of the seven-stage exploratory mixed-method Delphi study covered in detail in Chapter 4.

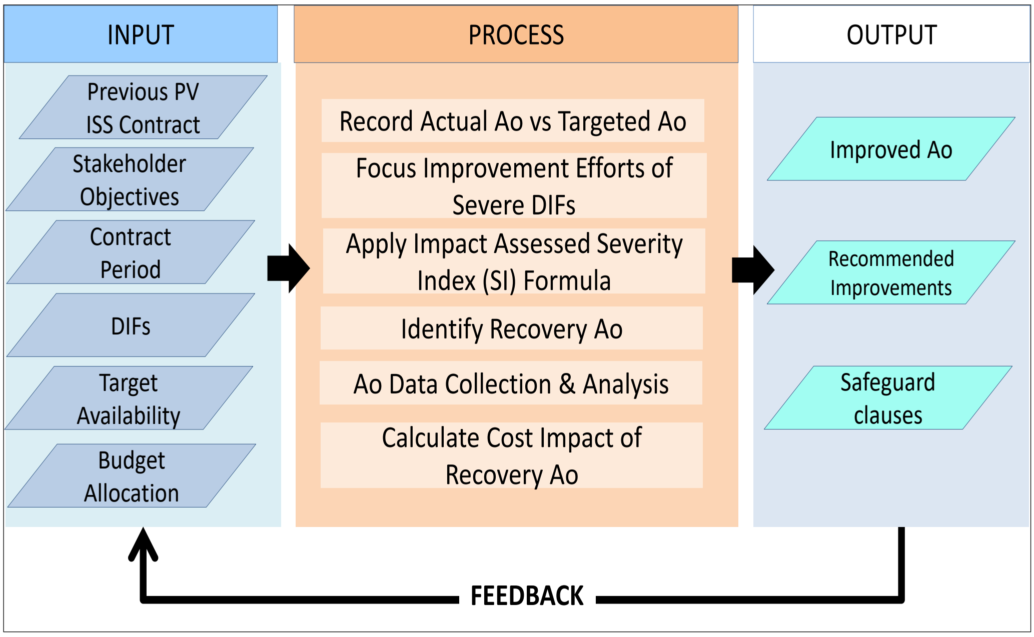


Figure 3.11 IPO model for ISS ship availability-oriented

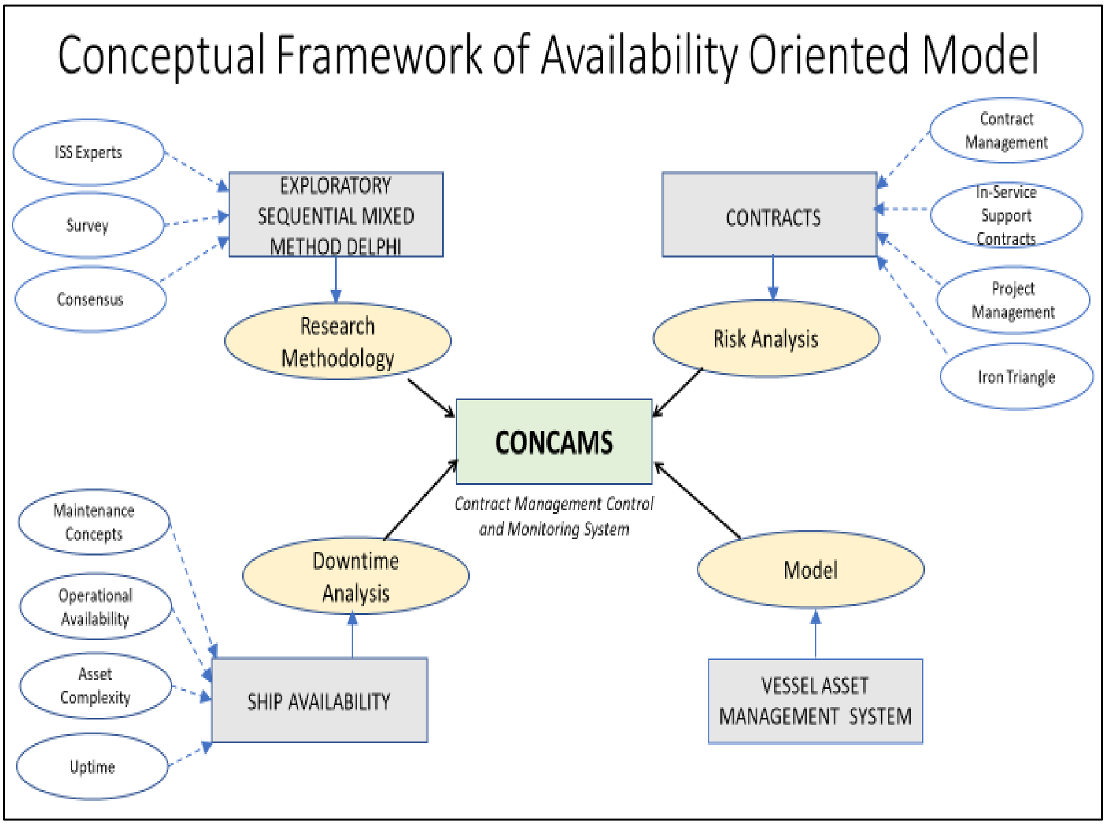


Figure 3.12 Conceptual framework of availability-oriented model

3.7 Development of the Model Algorithm

This section contains the development of the model algorithm. The determination of the weightage of severity via risk assessment, the development of the DIF impact matrix, the development of the mathematical formula, the determination of the DIF severity index, the calculation of Pearson's correlation matrix, the determination of an impact assessment adjusted severity index and the conceptual development of a management dashboard are described in the following subsections.

3.7.1 Determine Weightage of Severity via Risk Assessment

A questionnaire was developed for the usage in this mixed method research regarding the importance of each DIF towards the ship availability. The questionnaire is constructed in structured questions which consisted of closed, dichotomous questions and Likert scales. The questions which contained the 50 DIFs produced by the FGD were brought forward to this stage for evaluation by the Expert Group of its relevancy to ship operational availability.

The questions which contained the 50 DIFs produced by the FGD were brought forward to the next stage for further identification by the expert group. Based on the recommendations to improve question formulation for Delphi studies as summarized in Rowe and Wright (2011), the researcher emphasized on the use of easy-to-answer questioning mostly involving closed ended questions. Finally, a subset of the FGD participants undertook the exploratory workshop or questionnaire pilot test identified to refine the questionnaire provided in the first round of Delphi.

Risk analysis methodology was further conducted to ascertain the severity of each DIF, by obtaining feedback from the panel members on the probability against the impact of the various DIFs. Each expert member was asked to select the DIFs that have impact on ship availability. The variables were ranked in accordance to its severity. The following step was to set a cut-off point for the severity of the variables, and the result was a list of critical variables or DIFs that severely impact availability of the naval vessels. The most appropriate risk assessment matrix for the study was as a 5x5 matrix, with a 5-points Likert scale on the impact of the DIFs onto the ship availability for the ISS contract and five degrees of DIFs probability occur throughout the contract duration employed for the rating. The list of 50 DIFs from first stage was provided to the panel members for their reference. The questionnaires that were provided to the panel members to provide rating for each of the DIFs are as follows:

i) Questionnaire 1: In your expert opinion, which of the following criteria have an impact on ship availability?

ii) Questionnaire 2: For those relevant boxes marked applicable by yourself, please indicate the following:

Impact of the DIF onto availability of the naval vessels for the ISS contract would be measured using the following 5-point Likert scale:

Extreme:	5
High:	4
Medium:	3
Low:	2
Negligible:	1

The probability of DIF occurring throughout the contract duration would be measured using the following 5-point Likert scale:

Almost Certain:	5
Likely:	4
Possible:	3
Unlikely:	2
Rare:	1

Based on the given rating, a 4x4 cut-off point is employed in defining the severity of the DIFs. Hence, a DIF with a total value of 16 and above that possesses "high" impact and "likely" probability of occurrence shall be considered as important and labelled as "severe" will remain to be evaluated in later stages. Consequently, any results below 16 in total or combinations of "medium" or lower impact and "possible" or lower occurrence were considered as "not severe" and taken out from further evaluation. Only the severe DIFs are regarded as important and remain for the re-evaluation in stage three.

Delphi round 2 was conducted using the refined questionnaire with aim to begin the process of building the consensus among the panellists regarding the importance of each DIF. The panellists were asked to re-assess their severe DIFs ratings in the light of the consolidated results obtained from stage 2. A new questionnaire was issued for their feedback to refine the result. Further computation to compare results from Delphi round 1 and previous results from Delphi round 2 was performed by exploiting a coefficient of variation (CoV) parametric statistical methods. A small CoV value would indicate that the data scatter or variation compared to the mean is small and vice versa.

In any case, the 'knowledgeable persons' could be identified either through literature research or recommendation from institutions and other experts, demanding techniques of purposive and snowballing sampling (Giannarou and Zervas, 2014). stage 4 commenced with the "snowballing method" of recommending the next level of top management experts by the current level of experts. The 30 experts from Delphi stage 1 to stage 3 were requested to list down the top management expert from either RMN or Prime Contractor that have extensive experience in ISS contract management. The snowballing results were vetted as per Figure 3.13 based on Delbecq *et al*. (1975) criteria.

Snowball Sampling for Expert Selection

Question:
In your opinion following the consolidation of results of the questionnaire you have participated in, who would you recommend to be the panel members of experts to provide the best feedback on the subject matter?

Note:

1. **Title of the study**:
   Ship-availability based Contract Management model for In Service Support Contracts on Maintenance of Naval Vessel.

2. **Experts should possess the following qualities**

Qualities	Delphi Qualities	References
a) Experts are truly knowledgeable in their field. b) Experts have vast experience in their field. c) Experts truly understand the In Service Support Background, T&C, Implementation and Contract Clauses.	Have pertinent info to share	Delbecq *et al.* (1975)
d) Experts are expected to be busy but will most likely participate positively to ensure the research is successfully completed, due to his or her passion on the subject matter.	Motivated to participate Feels personally involved	
e) Availability of the Experts administratively and logistically.	Availability of the Experts administratively and logistically	
f) Senior position with clear bird's eye view to discuss on policy level issue but knowledgeable and detailed enough to understand the issues at ground level.	Qualified if top management decision makers who would utilize the study for	
g) Truly interested not just on the subject matter, but also truly believes that his or her contribution along with other experts shall assist in a successful research being done, of which the result would be of good use to himself or herself and the industry.	Feel that the aggregation of judgments of a respectable panel, which they too value to which they would not otherwise have access	

Figure 3.13 Criteria for expert selection using snowball sampling method

There were seven shortlisted top management experts and all were approached. Nevertheless, only five could participate in the survey. All the top management experts confirmed the list of 50 DIFs are valid. The results of stage 3 were provided to the group of five top management experts to confirm their agreement to the list of 50 variables that influence ship's downtime. The respondents were aware that 50 DIFs were identified due to their direct impact to the ship's availability.

The five respondents were then given the list of the 15 most severe DIFs resulted from stage 3 and asked to confirm their agreement to the DIFs listed as the most severe factors that impact the RMN ship's availability. This included providing their feedback on the impact of the DIFs onto availability of the naval vessels under ISS contract, using the same five-point Likert scale to assess impact and their feedback on the probability of DIFs occurring throughout the contract duration using the same five-point Likert Scale to assess probability as per stage 2 and stage 3. All the experts confirmed the list of 15 DIFs via risk assessment of probability and likelihood.

The summarized results from stage 4 were presented and the respondents were asked to reconsider the ratings of the 15 most severe DIFs. Results from Delphi round 4 and previous results from Delphi round 3 was compared by exploiting a coefficient of variation (CoV) parametric statistical methods. Then the level of concordance or agreement between experts was calculated using Minitab or Statistical Package for the Social Sciences (SPSS). The risk assessment matrix for each DIFs would be used as an input to determine the severity index (SI) and would be a direct input in the development of the algorithm.

3.7.2 **Develop the DIFs' impact matrix for ISS contract**

The objective was obtained by several steps in Stage 6 and 7 of mixed-method modified Delphi. The involved steps were aimed to re-assess the ratings of DIFs according to the link between the 15 severe DIFs to the project management constraints and contract management objectives. The detail of the steps as presented in Figure 3.14.

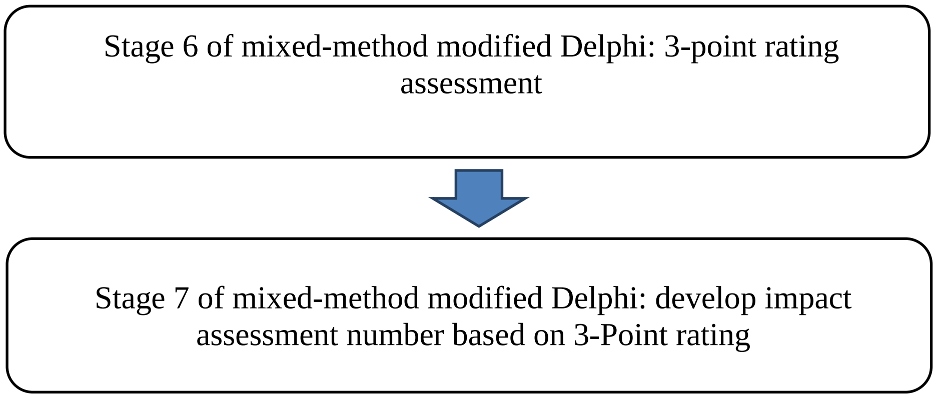


Figure 3.14 Steps in Determining DIF's impact matrix on ISS Contract

In Stage 6 of the Delphi study, the contract management experts were asked to establish the link between the 15 severe DIFs to the project management constraints and contract management objectives. The constraints of "cost", "time", "quality" and "scope" were identified as key performance indictors (KPI) as established in many project and contract management references as elaborated in Section 2.6.1.

The ISS contract duration of three years and the administrative burden of any contractual changes during the execution period deeming the possibility of scope changes practically out of the question. Therefore, the assumption was made that within this period, the "scope" is fixed. Scope has been fixed in accordance to the current terms and provisions of the PV ISS contract. The participants were asked to answer the following question and a 3-point rating scales for the effect on each KPI was provided as shown in Table 3.2.

"If the objective is to improve the ship availability by reducing a DIF, how does the improvement of the identified severe DIFs impact the project management constraints (iron triangle) of cost, time, quality and scope and the contract management objectives of time, cost and quality?"

Table 3.2 Three-point rating scales for the effect on the constraints of "cost", "time", "quality" and "scope"

Cost	**Time**	**Quality**	**Scope**
No Impact Lower Higher	No Impact Shorter Duration Extended Duration	No Impact Better Reduced	Fixed

The result was filled as in Table 3.3 for assessment with listing of the 15 selected severe DIFs. A Kendal's coefficient of concordance was calculated in SPSS to determine the level of agreement. Subsequently, the expert's answers were quantified to better understand if the impact of reducing the severe DIFs has an overall "negative", "positive" or "neutral" effect on the contract management and project management constraints.

Table 3.3 Assessment of the severe DIFs

			Top Management Experts				
S/No	**Severe DIFs**		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
1		**Cost**					
		Time					
		Quality					
		Scope	Fixed	Fixed	Fixed	Fixed	Fixed
	15 Severe DIFs	**Cost**					
		Time					
		Quality					
		Scope	Fixed	Fixed	Fixed	Fixed	Fixed

In stage 7, the summarized table of the effect of DIFs on project management and contract management KPI which was produced based on the feedbacks in stage 6 was presented the five top management experts. Their feedbacks were considered and they were given chance to change their feedback. An observation was expected on which DIFs would have an impact on "cost", as the researcher believes that not all DIFs reduction would have a negative impact on "cost". Another observation would be to see whether reduction of DIFs would have a positive or negative effect on "time" and "quality".

3.7.3 **Develop the Mathematical Formula for DIFs' Severity Index**

The objective was obtained by several steps aimed to develop the algorithm for the availability factors of naval vessels based on Severity Index. The detail of the steps as presented in Figure 3.15 is explained.

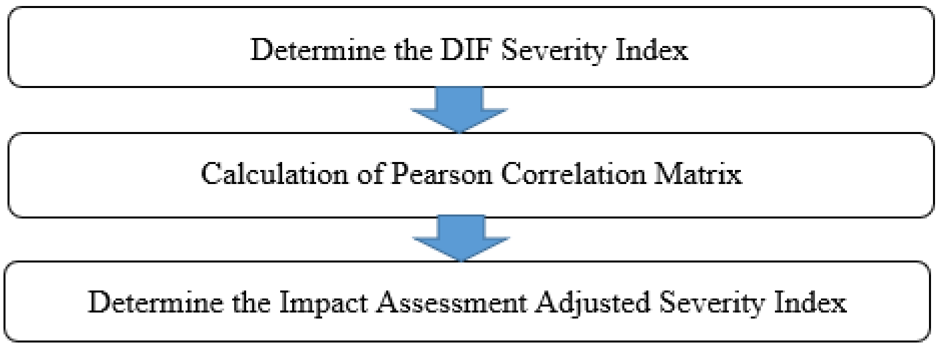


Figure 3.15 Steps in developing a mathematical algorithm on severity of DIFs

3.7.4 **Determine the DIF Severity Index**

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. Therefore, the mean scoring was considered from stage 3 (n=30) and stage 5 (n=5) of the Delphi study. A preliminary series of weighted severity measures (SM) was developed based on the mean ratings advocated by all the respondents. The weighting for each of the top DIFs was computed using the equation (3.2).

$$W_{SMi} = \frac{M_{SMi}}{\sum_{1}^{15} S_{SMi}} \tag{3.1}$$

Where:

W_{SMi} represents the importance weighting of particular severe DIFs

M_{SMi} represents the mean rating of particular severe DIFs

$\sum S_{SMi}$ 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 formula in Equation (3.3). Once the severity index had been defined, the project management and contract management KPI score was quantified for each of the severe DIFs.

$$\begin{aligned} SI = \; & W_{SM(DIF1)} + W_{SM(DIF2)} + W_{SM(DIF3)} + W_{SM(DIF4)} + W_{SM(DIF5)} \\ & + W_{SM(DIF6)} + W_{SM(DIF7)} + W_{SM(DIF8)} + W_{SM(DIF9)} \\ & + W_{SM(DIF10)} + W_{SM(DIF11)} + W_{SM(DIF12)} + W_{SM(DIF13)} \\ & + W_{SM(DIF14)} + W_{SM(DIF15)} \end{aligned} \tag{3.2}$$

3.7.5 Calculation of Pearson Correlation Matrix

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. Though it seems more sophisticated to use a non-linear model to fit the data obtained, over-fitting is a common problem with non-linear models especially when the sample size is not sufficiently large (Neter *et al.*, 1996, Weisberg, 2005).

A guide as provided by Cohen and Manion (1994) was referred to interpret the linear correlations. The suggested size of coefficient was given as in Table 3.5. Pearson correlation matrix was calculated and analysed for the algorithm development in this study using SPSS to ascertain the linear correlation.

Table 3.4 Interpretation of the size of coefficient for linear correlations (Cohen and Manion, 1994)

Size of coefficient	Interpretation
0.20-0.35	Slight relationship
0.35-0.65	Useful for limited prediction, usually bivariate relationship
0.65-0.85	Good prediction result from one variable to other
0.85 and above	Two or more variables are related

The Pearson's correlation coefficient which obtained in SPSS was referred to determine the linear relationship between weightage of severity (WOS) whether it is statistically significant. A statistically significant relationship between two or more WoS gives a challenge and requirement to adjust the severity index (SI) algorithm to consider the multiplier effect between these factors.

3.7.6 Determine the Impact Assessment Adjusted Severity Index

The weighting for each of the top DIFs and Impact Assessment weighting of the severe DIFs were then combined into a KPI Impact Adjusted Severity Index formula as per Equation (3.4) to obtain the Adjusted Severity Index for DIFs.

$$SIAdj_i = W_{IAi} \, X \, W_{SMi} \qquad (3.3)$$

3.7.7 Development of a Management Dashboard for ISS Ship Availability-Based Contract

The dashboard for ISS ship availability-based contract was developed based on the adjusted severity index for DIFs algorithm and severity coefficient was produced. The null hypothesis is that contract managers for ISS for naval vessels in Malaysia can improve ship availability by only focusing on the identified severe DIFs which have been measured based on the specific impact assessment adjusted severity index. The mathematical algorithm validity shall be tested in various iterations of simulated data. The main limitation is however that for the severity coefficient to function in formulae that specifies days the minimum amount of downtime days to be improved must be 30 days.

From the mathematical algorithm and an impact assessment (IA) number assigned for each DIF from stage 7, a ship availability-oriented contract management dashboard was produced reflecting relevant clause changes required in improving ship availability. The robustness of the model was tested with simulated data to ensure that the algorithm sensitivity is understood. It was the researcher's intentions to use a subset of data collected from previous ISS contract for PV of RMN and apply the algorithm with hindsight in the alternative models. The data is simulated with the proposed safeguard clauses and guidelines to estimate the availability.

3.8 Data Collection and Analysis

This section contains the data collection and analysis phase of the research. The Delphi sample size, the expert selection process, the data collection and analysis of data are explained in detail in the following subsections.

3.8.1 Delphi Sample Size

The sample does not need to comply to quantitative research as the results will not be analysed in view of inferential statistics but with the view to better understand the problem areas based on expert opinions in the field. This type of sampling can also be referred to as non-probability sampling (Lavrakas, 2008). The minimum number of participants to ensure a good group performance is somewhat dependent on the study design. There are still unclear guidelines on the best panel size for Delphi studies and the recommended "small" or "large" samples (Akins *et al.*, 2005, Miller, 1993). It seems that the decision about panel size is empirical and pragmatic, taking into consideration factors such as time and expense. However, Akins *et al*. (2005) claimed more than 16 experts in the second round of the Delphi questionnaire survey are considered acceptable.

Skulmoski *et al*. (2007) argues that a smaller sample might be used, with results verification conducted with follow-up research. A single Delphi study is considered sufficient for master thesis but the Delphi result is usually verified with a follow up study for a PhD dissertation. The authors also argue on the number of rounds. Fewer than three rounds may be sufficient to reach agreement, theoretical saturation and sufficient information if the objective is to understand nuances and the sample is homogeneous. Good results can be obtained even with a panel as small as 10-15 individuals with a homogeneous group of experts (Adler and Ziglio, 1996).

Size of sample and the appropriate number of experts was decided according to Baker and Edwards (2012) who provide guidance and advice on sampling size for qualitative interviews based on a set of succinct "expert voice" contributions. Baker and Edwards (2012) further advised that the number of people required to make an adequate sample for a qualitative research project can be in the broad range of between a dozen and 60, with 30 being the mean considering the difficulties of this type of research. Meanwhile, Adler and Adler (2011) advised sample pool sizes and a mean of 30 though later confirmed that the best answer is simply to gather data until empirical saturation has reached since some qualitative researchers argued that as little as one expert opinion can add value to the area of research.

Due to the limited number of experts available in Malaysia and the relative homogenous sample the Delphi process to identify DIFs and their severity measures for naval ship maintenance in Malaysia was designed in seven stages with participation in line with the research objectives requirements and decreasing the sample size from 30 expert participants for Stage 1 to Stage 3 to five top management experts for stage 4 to stage 7.

3.8.2 Expert Selection Process

Other researchers have similarly used expert opinions to study maintenance downtime distribution which reflects availability of systems (Hussin and Hashim, 2011). The role of participants and experts, nature of expertise, expert recruitment and retention over Delphi rounds were referred to Rowe and Wright (2011) who provide a framework for conducting the enhanced Delphi technique including improving panellist recruitment via snowballing and other methods of retention over Delphi rounds. The 'knowledgeable persons' could be identified either through literature research or recommendation from institutions and other experts, demanding techniques of purposive and snowballing sampling (Giannarou and Zervas, 2014).

Similar to the application of the Delphi technique in Australia (Skulmoski *et al.*, 2007), the experts consist of personnel who have access to the ISS contract, knowledgeable and experienced in dealing directly on the implementation of ISS in Malaysia. The experts were classified as those individuals fulfilling all four of the following criteria;

i) Directly involved in contract management of ISS contracts.
ii) Personnel of either RMN, prime contractor or other participating shipyards.
iii) Minimum of 3 years working experience with either of these organizations
iv) Vast experience in the RMN or dealing with the RMN.

The minimum number of working experience years was selected as 3 years, as this was determined to be the minimum number of years for any junior employee to have until they are able to perform their tasks on PV ISS maintenance activities at their job description with minimal supervision. It is the minimum number of years considered at Boustead Heavy Industries (reflecting the industry) that the junior employee's feedback and recommendations were deemed to be acceptable for consideration by the top management. The selection of members or panellists is important because the validity of the study was directly related to this selection process. According to the criteria, 30 expert members who are working directly on ISS Contract and other relevant organizations with sufficient working experience or knowledge in the ship maintenance field from contractor and the customer's organizations were selected to populate the variables based on their knowledge and experience Table 3.5 summarizes the criteria for stages 1 to stages 3 for the 30 expert panellists. Table 3.6 points out the criteria of fulfilment for stages 4 to stage 7 for the five top management experts. The list of panel members and their positions for stage 1 to stage 3 of Delphi study is as reflected in Table 3.7. The summary of positions of the top management experts is reflected in Table 3.8.

Table 3.5 Panel members fulfilment criteria for stage 1 to 3 of Delphi

Stage	Criteria to be fulfilled
1 to 3	i) Having sufficient working experience or knowledge in the ship maintenance field; and ii) The requirements of the Royal Malaysian Navy Patrol Vessel In Service Support (ISS) Contract requirements.
	Working in relevant organizations in the naval ship maintenance field.

Table 3.6 Five panel members fulfilment criteria for stages 4 to7 of the Delphi

Stage	Criteria to be fulfilled
4 to 7	Having extraordinary working experience or extraordinary knowledge in the ship maintenance field; and the requirements of the PV ISS Contract.
	Working in relevant organizations in the naval ship maintenance field.
	Stakeholder at a reasonably senior position, with interest on the subject matter, and would like to utilize the result for future work in the field.

Table 3.7 List of the panel members for stages 1 to stage 3 of Delphi study

Type of Organization	Number
ISS Contractor at Ship Location 1	12
ISS Contractor at Ship Location 2	4
ISS Contractor at Ship Location 3	1
Shipyard 1	5
Shipyard 2	1
Shipyard 3	1
Shipyard 4	2
Customer – Navy Senior Officers	4
Total	**30**

Table 3.8 List of the panel members for stages 4 to stages 7 of Delphi study

Type of Organization	**Number**
ISS Contractor Top Management	1
Shipyard Top management	1
Navy Admiral (Engineering)	3
Total	**5**

The categories of these participating expert panels were analysed by using univariate frequency analysis before conducting the steps of Delphi stage 1, including the designation, working experience, working area, location, their organization or company, qualification and gender. This was performed to identify the aspect that influenced the result of research and to estimate the pattern of raw data. The criteria of the experts according to the categories were set as the variables. The frequency distribution of the data variables was obtained and analysed by the statistical software SPSS.

3.8.3 **Data Collection**

Regarding the Delphi rounds, Ludwig (1997) and Custer *et al.* (1999) pointed out that three iterations are often sufficient to collect needed information and reach a consensus in most cases. Furthermore, the responses on the final iteration usually show less spread in comparison to spreads in earlier iterations and median values are commonly taken as the best estimates for the issues. However, Yousuf (2007) stated that the payoff usually begins to diminish quickly after the third round but it can be extended for several rounds after that. The process of data collection in Delphi can be continuously iterated until the consensus achieved (Hsu and Sandford, 2007).

Data of the research was collected through survey (questionnaire) and expert opinion solicitation in the seven-stages of Delphi method with 6-rounds questionnaire. Details of both methods have been explained in Chapter 2. A good questionnaire which is brief and designed as to make sound analysis and interpretation possible, helps to directly achieve the research objectives, provides accurate information and easy for both interviewers and respondents to complete (Lavrakas, 2008). The development of the Questionnaires was in line with the sequential mixed method modified Delphi Design type and was included in the combination of the mixed method approach of Creswell (2014) and the guidelines of Delphi study in Section 3.3. The questionnaire was constructed in structured questions which consisted of closed, dichotomous questions and Likert Scales. Table 3.9 summarizes the design elements according to Survey Research Methods by Lavrakas (2008) that were considered in the development of the questionnaire.

Table 3.9 Design elements in the questionnaire development process

Survey Design considerations	Stage 1, Stage 2, Stage 3	Stage 4 and Stage 5	Stage 6 and Stage 7
Determination of goals, objectives and Research Question	Research Objective 1 Identify DIF that Impact Ship Availability and Identify the severe DIFs.	Research Objective 1: Identify Impact based on Risk Assessment of DIFs.	Research Objective 2: Confirm the DIFs that impact ship availability, provide risk assessment and KPI impact assessment.
Definition of key concept	Downtime Influence Factor, Ship Availability	Impact of DIF on Ship Availability, Risk Assessment	Validation of results
Generation of hypotheses and proposed relationships	Identify severe DIFs and their relationship.	Severe DIFs Impact Assessment, DIF interrelationships.	Refine Impact Assessment.
Choice of survey mode	Face to Face, printed questionnaire		
Question construction	Structured (closed questions or dichotomous questions and Likert Scales).		
Sampling	30 experts	Five experts	Five experts (as per snowballing)
Questionnaire administration and data collection	Administered by Interviewer. Anonymity of responses for summarizing finding back to experts is required for Stage 2 and 3		Administered by Interviewer. Anonymity of responses for summarizing finding back to experts is required.
Data summarization and analysis	Quantitative Analysis (SPSS)		
Conclusions and communications of results	Conclusions are summarized and re-validated in subsequent stages.		

3.8.4 **Analysis of Data**

Statistical analysis can ensure that opinions generated by each subject in a Delphi study are well represented in the final iteration and that each subject has no pressure either real or perceived, to conform to another participant’s responses. The tools for statistical analysis allow for an objective and impartial analysis and summarization of collected data. Quantitative analysis of the statistical software SPSS was employed in this research to summarize and analyse the collected data and results are validated in subsequent stages.

The collected data from the questionnaire were processed through a descriptive study including data cleansing, data coding and data preparation. The collected data by means of questionnaires was cleansed and this step included checking of spellings, confirmation of qualifications, confirmation of locations of panellists, and the names of panellists. All paper questionnaires were coded in a standard manner with view to prepare for data input into SPSS which initially administered via Excel spreadsheets as a means of data preparation. The data integrity was checked prior to upload into SPSS. The data was then structured in a manner that will allow analysis with identifiers for the data set and variables structured into columns and observations into rows. The data were imported to SPSS and thereafter formatted.

In the earlier stage of Delphi, the data were analysed by means of descriptive statistics including Univariate Frequencies, Bivariate Cross Tabulations, One Way Anova and scatterplots. Descriptive statistics enable the researcher to understand the nature of responses by the panellists and analyse if there are any positive or negative relationships between variables. The descriptive frequency of the panellists was prepared and analysed based on the means plot of the Weightage of Severity (WOS). The WOS was obtained by multiplying the impact assessment by the Likelihood assessments. The means graphs provide a better understanding of possible relationships between the DIFs and the sample characteristics.

Bivariate analysis was performed by means of Pearson’s Chi Square test with the help of SPSS. Bivariate analysis is a type of simultaneous analysis with two variables or attributes. The concept of relationship between two variables was applied to determine the existence of dependence aspect between each other, the differences between two variables and the significance of these differences. The value of Pearson's correlation coefficient, p was evaluated whether it is above or below 0.05 to determine whether the DIFs varied by the variables or not. The analysis helps to understand whether there is any evidence in the WOS relationship between DIFs. All DIFs WoS were cross tabulated with the help of SPSS to obtain the evidence of relationship.

The analysis was proceeded with One Way Anova analysis to identify if any relationships could be found in the collected data for those variables with more than two groups and more than three observations per group. The pairwise comparison analysis was performed as a post hoc test to obtain better understanding on the relationship of those variables per group. The assumption of homogeneity of variances was tested using Levene's test. The null hypothesis which was decided for the DIFs would be rejected if there were differences between the variances in the population. This was identified if the p-value from the Levene's test is less than some significant level, typically 0.05. For obtaining the p-value, post hoc comparison was conducted using Tukey Honestly Significant Difference to evaluate the pairwise differences amongst group means.

Further computation to compare results from Delphi round 2 and previous results from Delphi Round 1 was performed by exploiting a coefficient of variation (CoV). Parametric statistical methods such as the CoV and F-test have been used in Delphi studies with samples below 50 as stated in (Shah and Kalaian, 2009) . The CoV which defines ratio of standard deviation (SD) of a competency area to its corresponding means (AVG) among the Expert members was formulated as Equation 6. Accordingly, an absolute difference was calculated by subtracting the CoV of the current and previous stage. A small CoV value would indicate that the data scatter or variation compared to the mean is small and vice versa as stated in Equation (3.5):

$$CoV = SD/AVG \qquad (3.4)$$

Kendall’s coefficient of concordance was calculated in SPSS to determine the level of agreement between the panellists for the response given in stage 5 and 7.

3.9 Validation of Developed Model via Post-Survey Validation

The major risk as in all foresight processes in this research was to regard the results as facts because they were presented in the form of data. The existed tools and the gathered information about the future cannot accurately predict the future and the unexpected result would be existed. Agumba and Haupt (2014) claimed good iterative nature of Delphi method provided a structure within which important statements or indicators were validated and then discussed. There are several ways in which validity can be measured including content, construct and criterion, each of which highlights different aspects of rigour testing. Content validity, similar to face validity, assesses if an instrument provides adequate coverage of a topic under investigation; construct validity, whilst subjective, assesses the theoretical foundations of a scale or measurement and the adequacy of the test in its measuring

The reliability of the Delphi Study and the result validation was decided according to Keeney *et al.* (2011). The validation aimed to address the methodological rigour of the mixed method modified Delphi and Delphi result interpretation. A few Delphi authors believe that the term trustworthiness is more appropriate than reliability and validity to gauge the effectiveness and appropriateness of the Delphi. Nevertheless, it is recommended that measures of rigour for both qualitative and quantitative be applied to each Delphi study as well as its findings to be confirmed and verified. The researcher opted for content validity since the results of the Delphi method of research are already validated by two sets of expert panels initially 30 experts and subsequently five top management experts via multiple iterative rounds. In addition to estimate reliability, the approach of internal consistency of the results as described in Keeney *et al.* (2011) was applied and the consistency of results across items within a test were assessed. Given that the coefficient of variation has been improved from round to round, it was possible to deduce that reliability of results had been achieved. To evaluate and validate the proposed availability-oriented contract management control and monitoring system (ConCaMS) the researcher enlisted the assistance of an independent group of maritime leaders. The methodology adapted for this stage has been consistent with Ramasamy (2017) who also used post-survey expert validation to confirm the final thesis framework in her thesis. Judgmental sampling was applied to identify the best suited experts for the study.

The sample does not need to comply to quantitative research as the results will not be analysed in view of inferential statistics but with the view to better understand the problem areas based on expert opinions in the field. This type of sampling can also be referred to as non-probability sampling (Lavrakas, 2008). Other researchers have similarly used expert opinions to study maintenance downtime distribution (Hussin and Hashim, 2011). Size of sample and the appropriate number of experts was decided according to Baker and Edwards (2012) who provide guidance and advice on sampling size for qualitative interviews based on a set of succinct "expert voice" contributions. Adler and Adler (2011) advised that the best answer is simply to gather data until empirical saturation has reached since some qualitative researchers argued that as little as one expert opinion can add value to the area of research. The criteria to be fulfilled by the Post-Survey Validation Experts was defined as follows:

(i) In excess of 20 years of working experience, having similar or higher position than Top Management Experts in earlier rounds of Delphi.

(ii) Stakeholders at very senior position, with interest in the subject matter and who would benefit from results in their work field in the future.

(iii) Recognized as leading maritime experts in In-Service Support (ISS) and naval ship maintenance.

Since the ConCaMS was developed with inputs from 35 experts and top management experts from the niche field, there was only a limited balance of Top Management Experts qualified to take part in the Post-Survey Validation. The participants were selected from shipyards, MMEA and RMN based on their most recent and remarkable contributions to the maritime and defence industry in Malaysia, categorically recognizing them not only as leaders but also as subject-matter experts. Table 3.10 summarises the participant's demographics.

Table 3.10 Post-survey validation questionnaire participant's demographic

No	Organisation Type	Years of Experience	Title/ Designation	Contribution to Naval Industry
1.	RMN	>20 years	Rear Admiral	Ground breaking Strategic Planner
2.	RMN	>20 years	First Admiral	Director of Engineering
3.	Award winning Shipyard	>20 years	Executive Director	Recognized by MMEA and other government agencies as expert in the field
4.	Award winning Shipyard	>20 years	Chief Executive Officer	Recognized by MMEA and other government agencies as expert in the field
5.	MMEA Academia	>20 years	Rear Admiral	Head of MMEA OPV Project. Formerly Commanding Officer of RMN PV

The questionnaire administered was divided into the following sections:

i) SECTION A: Demonstration and explanation of the model (25 minutes).
ii) SECTION B: Feedback on the demonstrated model and implementation considerations (10 minutes).
iii) SECTION C: Any further feedback (5 minutes).

3.10 Summary

This chapter has reviewed, described and presented the research philosophies, research methodologies and research techniques available to address the research problems. After thorough consideration of the advantages and disadvantages of the various methodologies and taken consideration of the existing constraints concerning the subject matter, the mixed method modified Delphi was selected as the chosen research methodology. The combination of the FGD, the rigorous 7-stage exploratory sequential Delphi with snowballing technique and the follow up independent questionnaire further strengthens the expected findings and the applicability and acceptability of the results.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The results and discussions in Chapter 4 are divided into Section 4.1 introduction, Section 4.2 contains the results of a complex problem simplified, Section 4.3 describes the results of the seven stages of mixed method sequential Delphi procedure, Section 4.4 explains the identification of DIFs and severe DIFs that impact operational availability. Section 4.5 describing the establishment of the DIF's impact matrix on contract and project management elements of the 'iron triangle of cost, time, quality and scope'. Section 4.6 describes the development of model algorithm, Section 4.7 containing the development of an availability-oriented model. Section 4.8 explains the validation of the model and Section 4.9 contains the discussion on meeting the research objectives.

This chapter presents all vital results of the study from the 13 steps of the availability-oriented contract management approach detailed in Chapter 3 and continues with the results presented in accordance with the research objectives (RO) as summarized in Table 4.1. The table assists to summarize each section of the chapter to the corresponding research question (RQ) matching the research objective.

Table 4.1 Summary of research objectives and research questions

<table>
<tr><td colspan="6">Research Aim: The aim of this research is to demystify the complex naval ship availability issue through the development of a decision-making model in improving naval ship operational availability especially for the in-service support (ISS) contract. It could be achieved by meeting the following research objectives (RO) and research questions (RQ):</td></tr>
<tr><th>Code</th><th>Research Objective (RO)</th><th>Code</th><th>Research Question (RQ)</th><th>Results</th><th>Discussion</th></tr>
<tr><td rowspan="2">RO1</td><td rowspan="2">To determine the Downtime Influence Factors (DIFs) to Naval Ship Availability.</td><td>RQ1a</td><td>What are the human and equipment related downtime influence factors (DIFs) affecting ship availability?</td><td rowspan="2">Section 4.4</td><td rowspan="2">Section 4.91</td></tr>
<tr><td>RQ1b</td><td>How can the DIFs affecting ship availability be-ranked and prioritized?</td></tr>
<tr><td rowspan="3">RO2</td><td rowspan="3">To develop the DIF’s impact matrix on contract and project management elements of the “iron triangle of cost, time, quality and scope”.</td><td>RQ2a</td><td>How do the DIFs impact the contract and project management elements of the “iron triangle of cost, time, quality and scope”?</td><td rowspan="3">Section 4.5</td><td rowspan="3">Section 4.92</td></tr>
<tr><td>RQ2b</td><td>Is it possible to improve ship operational availability by improving DIFs?</td></tr>
<tr><td>RQ2c</td><td>What areas can be improved when faced with budget constraints, if RQ2b is positive?</td></tr>
<tr><td>RO3</td><td>To develop the Severity Index as the mathematical algorithm to the model</td><td>RQ3</td><td>Is it possible to develop an index based on ranking of the DIFs to indicate the severity of the DIFs?</td><td>Section 4.6</td><td>Section 4.93</td></tr>
<tr><td>RO4</td><td>To develop a “ship availability-oriented model” for ISS contract</td><td>RQ4</td><td>Is it possible to develop a new model to assist stakeholders to better understand the availability concept and assist contract managers to monitor and control the contract better?</td><td>Section 4.7</td><td>Section 4.94</td></tr>
</table>

To answer the research questions and following the methodology laid out in Chapter 3, the research timelines of the research stages encompassing literature review, brainstorming sessions, focus group discussions, 7-stage Delphi methodology and post-survey validation are laid out in Figure 4.1

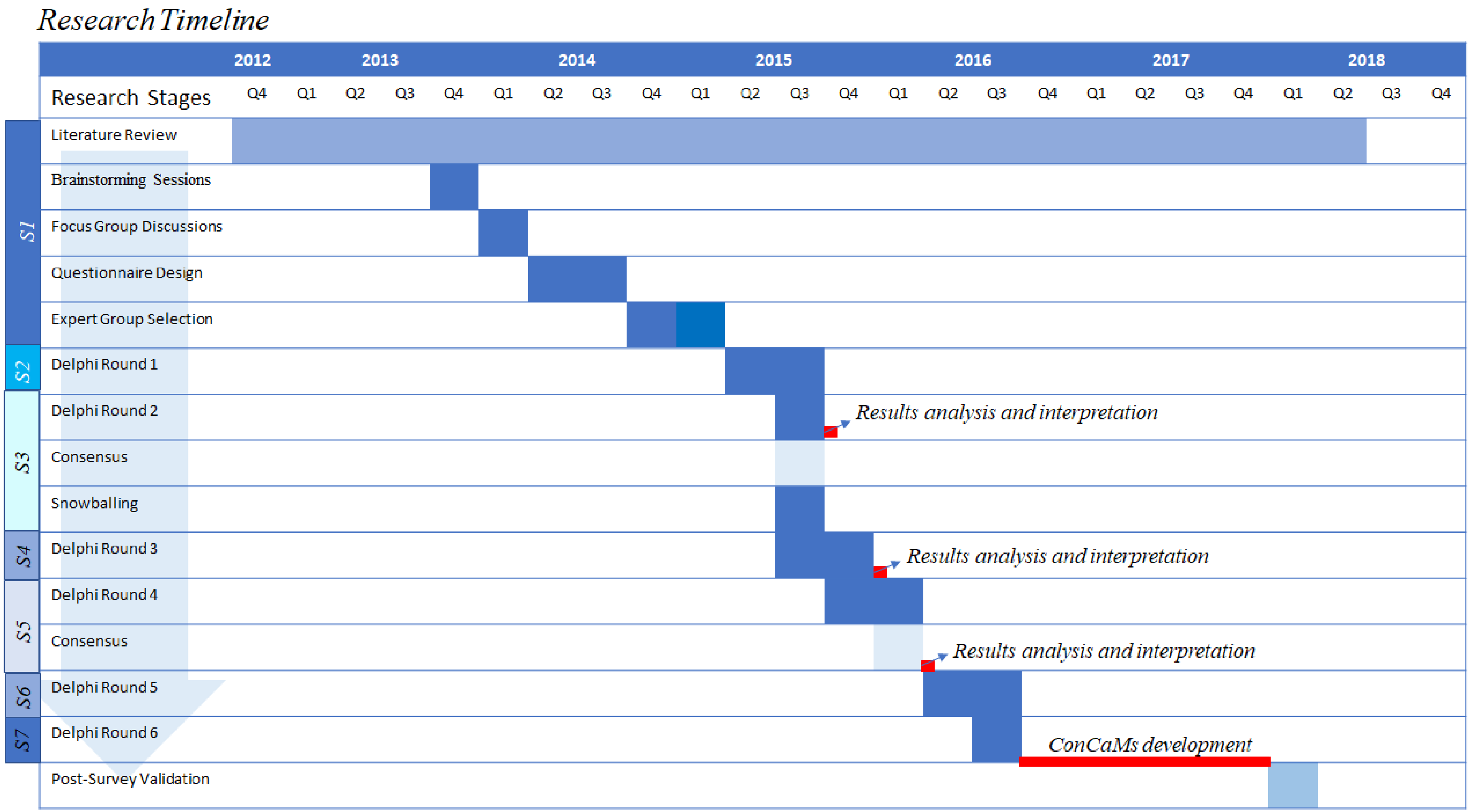


Figure 4.1 Research timelines for the various research stages

4.2 A Complex Problem Simplified

The new concept that the researcher introduced in this study began with the crucial effort in simplifying the complex situation surrounding naval ship operational availability for better understanding of the various levels of stakeholders. Stakeholders of the ISS Contract realized that they concentrated mostly on day-to-day operations and kept busy in "everyday fire-fighting culture'. In summary, they had never been able to record relevant data and analyse the past to improve the situation in the future. Urgencies superseded importance, and problems became crises. A key drawback was that historically, proposed efforts remained placed on complex mathematical calculations and estimates, which required not only sophisticated programmes but also limited the understanding to a few highly skilled professionals able to implement them.

This has never been appealing to most practitioners as well as the majority of stakeholders who continuously complained about the gap between theory and practice. This same gap has been the motivation behind the study on Royal Netherlands Navy vessels by Goosens (2015) on finding practical approaches to maintenance decision making. Many of the stakeholders agreed that an in-depth research was necessary before a concerted effort could possibly be placed in improving the implementation process in future as they are currently blind and clueless to the root causes as well as the recommended solutions. Therefore, the researcher developed a systematic approach towards managing these real-life and legacy issues by simplifying the complex situation surrounding naval ship operational availability for better understanding of the various levels of stakeholders.

4.2.1 Improving Ship Availability Concept simplified - through Availability See-Saw

Ship Availability is defined by Inozu (1996) and Blanchard and 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 formulated as one minus downtime or known as unavailability, with the resulting mathematical implication that the more unavailability or "downtime", the lesser the availability achieved. The relationship between reduction of downtime and improvement in uptime or ship operational availability is displayed diagrammatically in Figure 4.2. availability See-Saw. The See-Saw concept was chosen as a means to communicate the perceived convoluted operational availability concept to all levels of stakeholders in a clear and easy manner to understand.

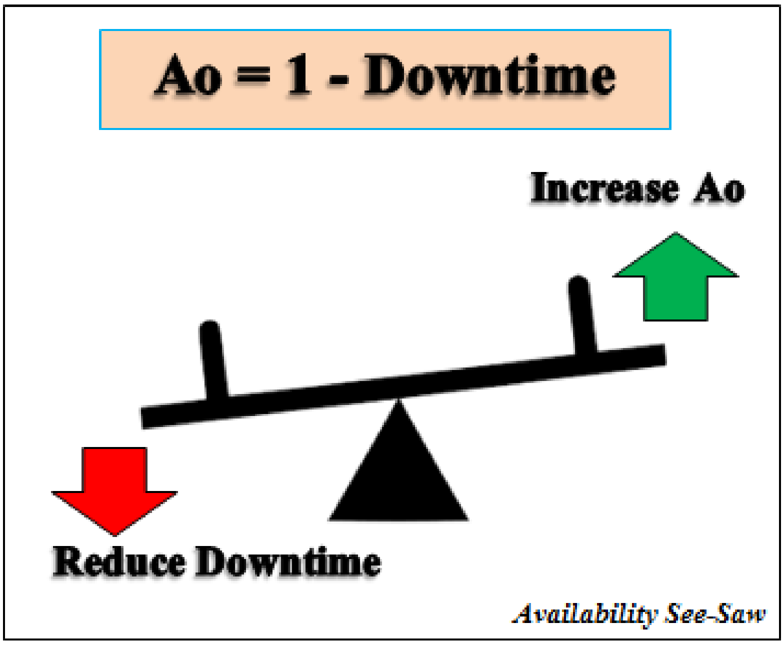


Figure 4.2 Availability See-Saw

Ship operational availability is also described as the number of days the warships are available for operational tasking in a year (GAO, 2015c). Therefore, for easy understanding of all levels of stakeholders, the objective in achieving high operational availability can only be attained by reducing the impact of all factors that create downtime or unavailability.

4.2.2 **Improving Ship Availability Concept simplified - DIF Conceptual**

The DIF conceptual diagram as shown in Figure 4.3 portrays the relationship between uptime, downtime and availability, as well as the various DIFs that make up the downtime, for the benefit of all levels of stakeholders in a simplified way. Nevertheless, the sizes of the individual DIFs would vary depending on the DIF severity. This new perspective introduced by the researcher demonstrated that by reducing downtime through either reducing the number of DIFs or reducing the size of the DIFs, the availability (uptime) will consequently be increased.

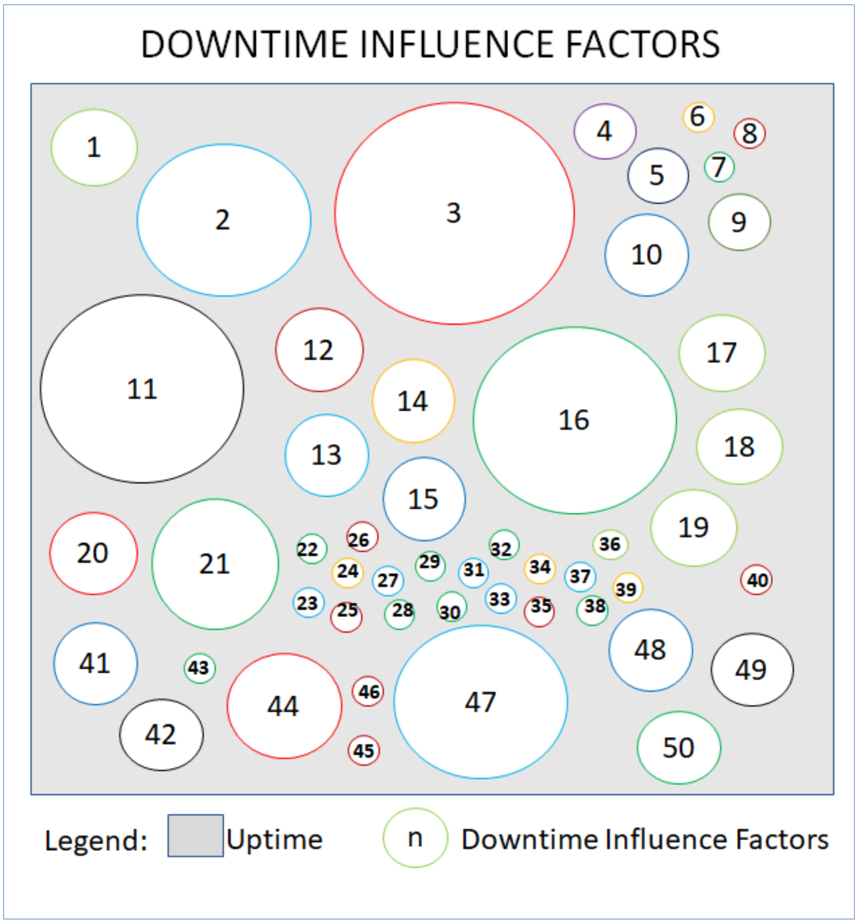


Figure 4.3 Conceptual diagram of DIFs

Once quantified and ranked, the severe DIFs would appear as the various colourful spheres illustrated in Figure 4.4. The illustration depicts the improvement in uptime by showing an increase of the grey coloured area. This could be achieved by the various stakeholders through focusing on reducing the size of severe DIFs.

Figure 4.4 Illustration of reduction of DIFs

The first illustration exhibited in Figure 4.5 tackles improvement efforts for severe DIF “availability of spare parts”. Improvement of the severe DIFs “availability of spare parts” in Figure 4.5 could be achieved by focusing on resolution of key problem areas within these DIFs. The illustrations are to exemplify how the improvements could be tackled.

As the first step, the severe DIFs area to be improved including empirical data is discussed with the stakeholders tasked with the severe DIF improvement. At the next step, a list possible improvement effort tailored to the particular severe DIF is presented. For DIFs concerning spare parts, improvement efforts would include:

i) purchase of spares based on projection
ii) imposing minimum stock levels for routine spares
iii) sharing of spares between agencies.

All the improvement efforts shall be based on better practice. Since numerous studies on each DIFs have been conducted by various researchers in the past as covered in Chapter 2, stakeholders should refer to these literatures as references for improvement on the individual subject area. Subsequent to the proposed improvement efforts, the improved availability as a result of actions taken is displayed. The improvement includes:

i) critical spares are available prior to maintenance therefore downtime is reduced.
ii) routine spares are available prior to maintenance therefore downtime is reduced.
iii) sharing of spares between agencies ensured spares are always available therefore reducing downtime

Supporting these actions are the relevant stakeholders that will be responsible for the severe DIF improvement. Similarly, the second illustration in Figure 4.6 demonstrates a possible approach to improving severe DIF “facilities”.

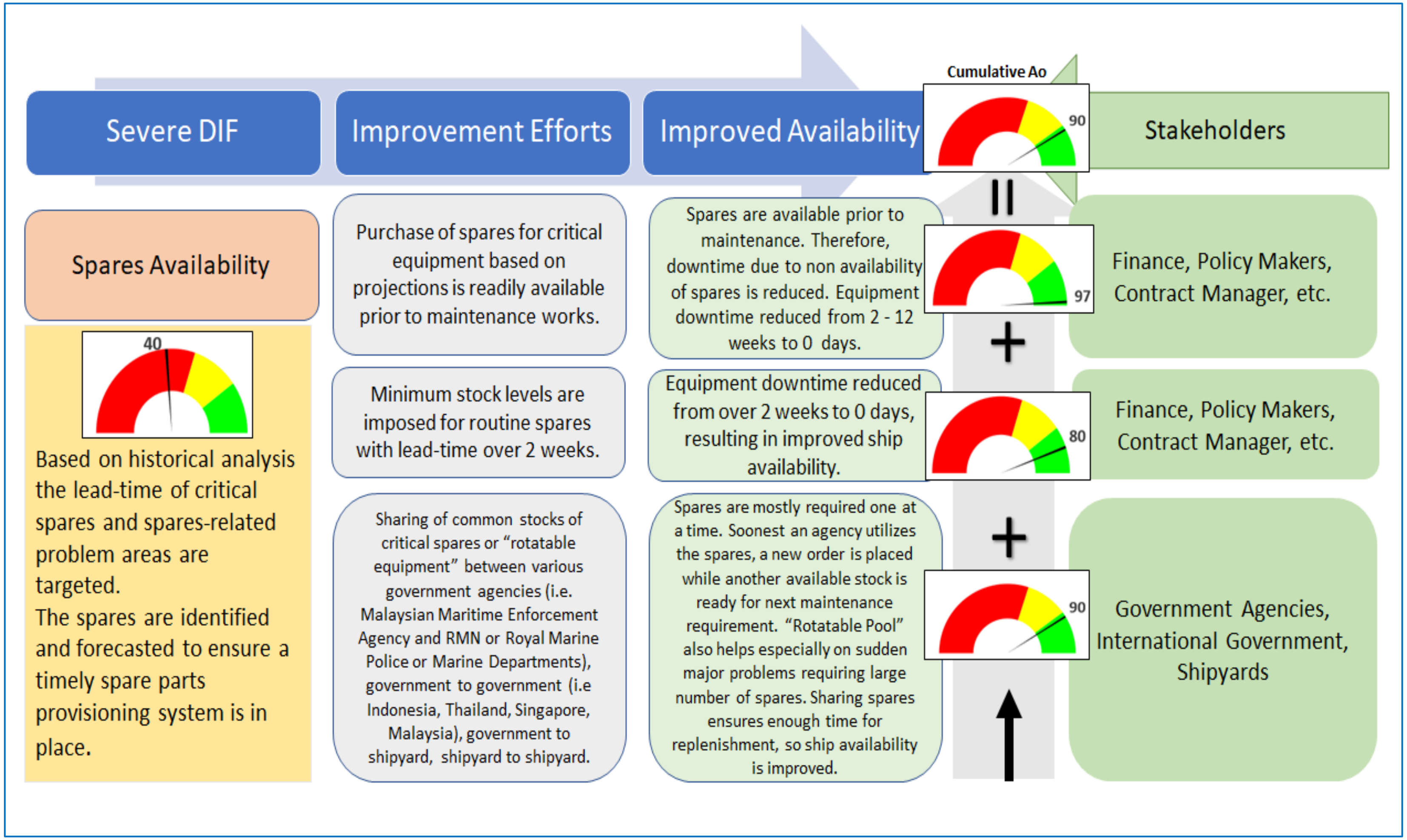


Figure 4.5 Illustration of reduction of DIFs (Spares availability)

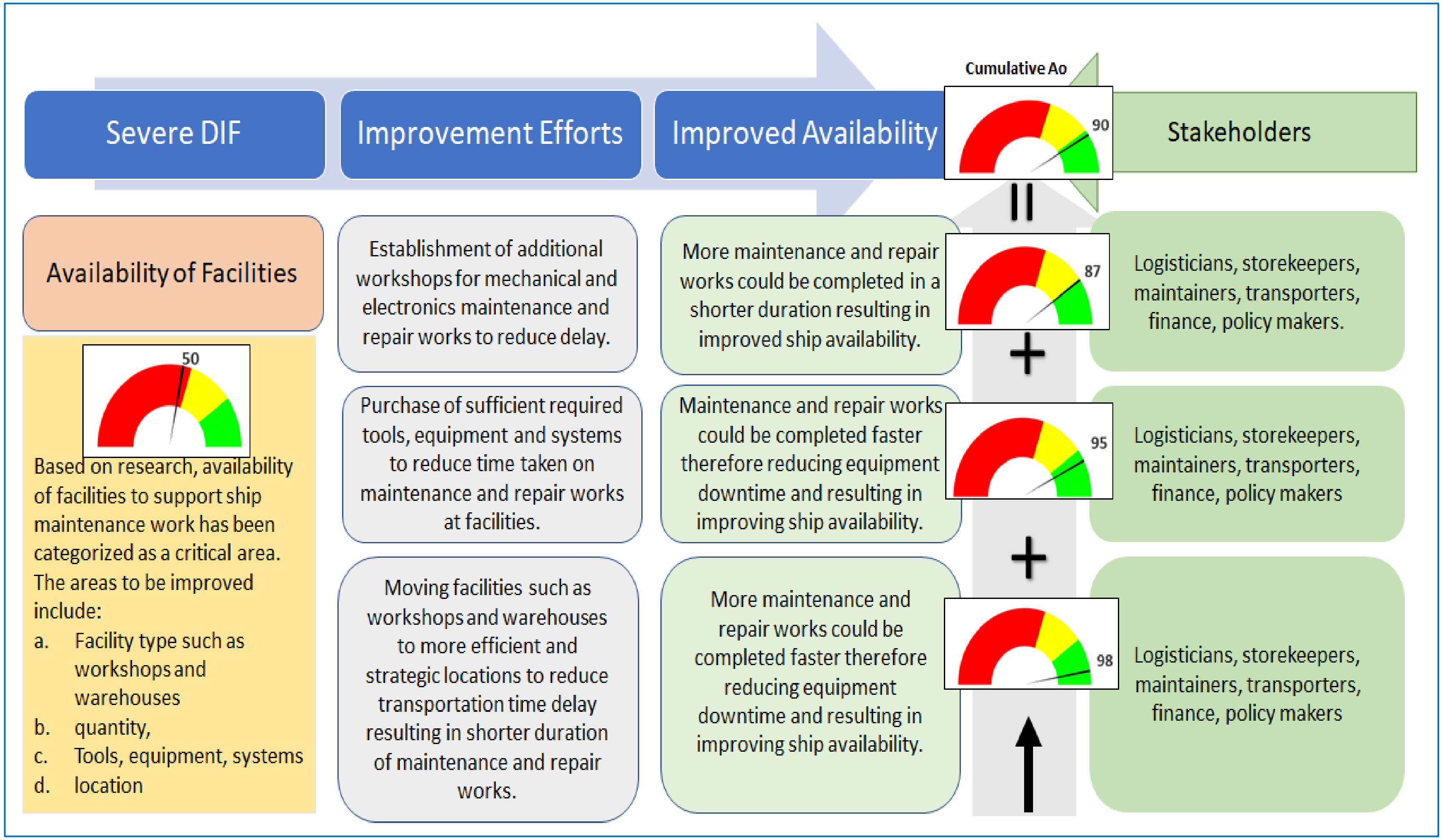


Figure 4.6 Illustration of reduction of DIFs (Facilities)

4.2.3 Relationship between Human and Equipment Factors to Availability - Simplified

High failure rates for diesel engines threaten ship availability and mission readiness. Nevertheless, the failure was not caused by manufacturing or latent defects but as a result of other non-equipment related factors including insufficient training, change in inspection process, shift in maintenance process, increase complexity of control systems and wrong choice of lubrication.

For the initial PV ISS contract some data related to equipment and spares factors had been captured as part of a contractual requirement to monitor the start and end of defects reports and the ordering and delivery of spares. Nevertheless, all PV ISS stakeholders realized that there were other factors impacting availability, but they were uncertain of the factors and the issue, hence no other data has been collected.

The range of factors related to human and equipment that affected the availability of the vessels over the contract period had not been holistically covered in any existing procedures or books or references of the RMN, or even covered extensively in any publications worldwide. Nevertheless, once the DIFs had been identified as described in step 1 in Chapter 3, it was possible to display diagrammatically a simplified relationship between human and equipment factors and availability as shown in Figure 4.7.

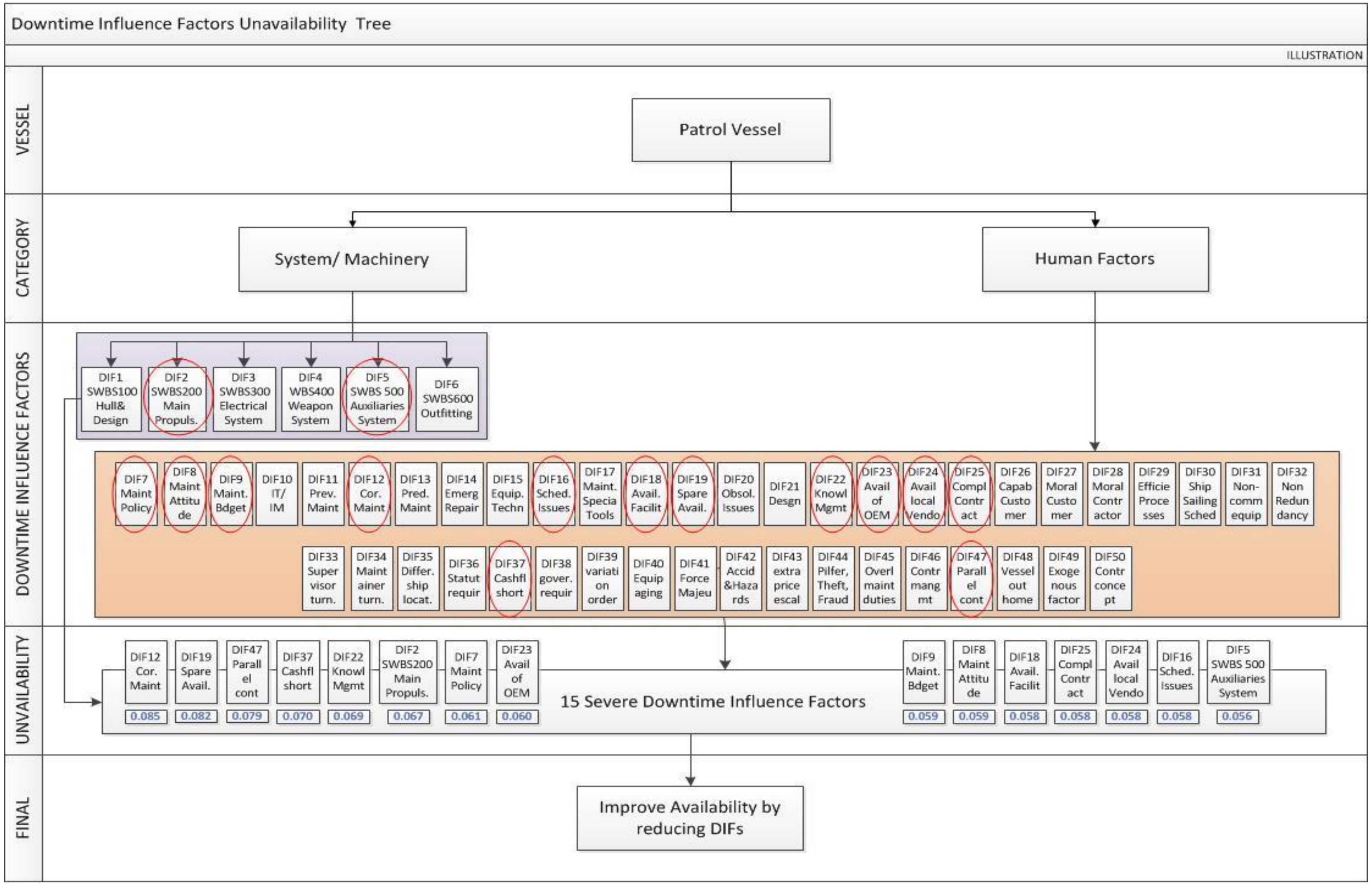


Figure 4.7 Relationship between human and equipment factors to availability

4.2.4 Simplified Maintenance Contract Preparation and Implementation

The overall process of the preparation and implementation of the PV ISS maintenance contract depicting uptime, downtime and operational availability measurement has been simplified in Figure 4.8 and Figure 4.9.

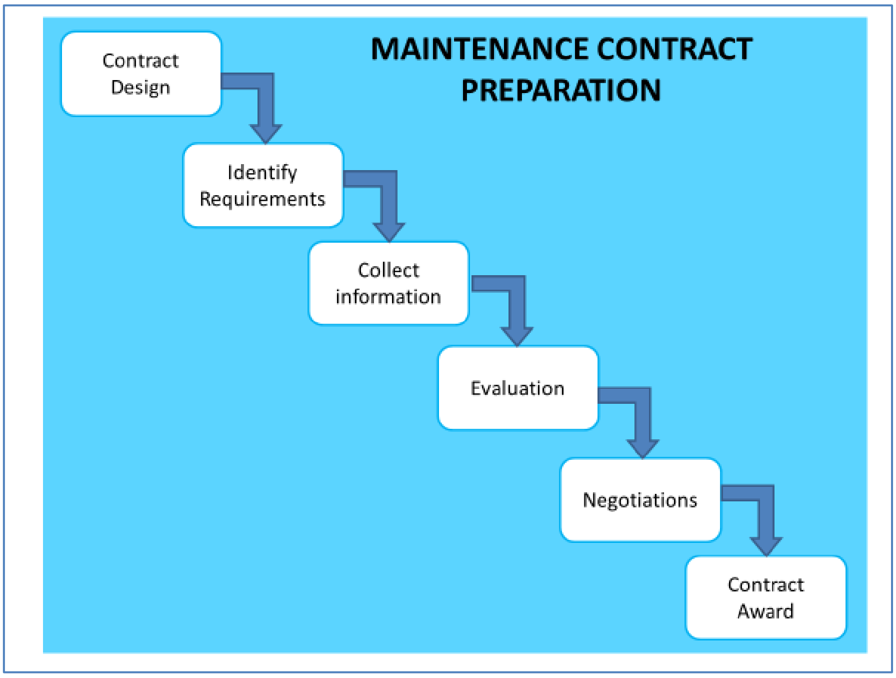


Figure 4.8 Maintenance contract preparation

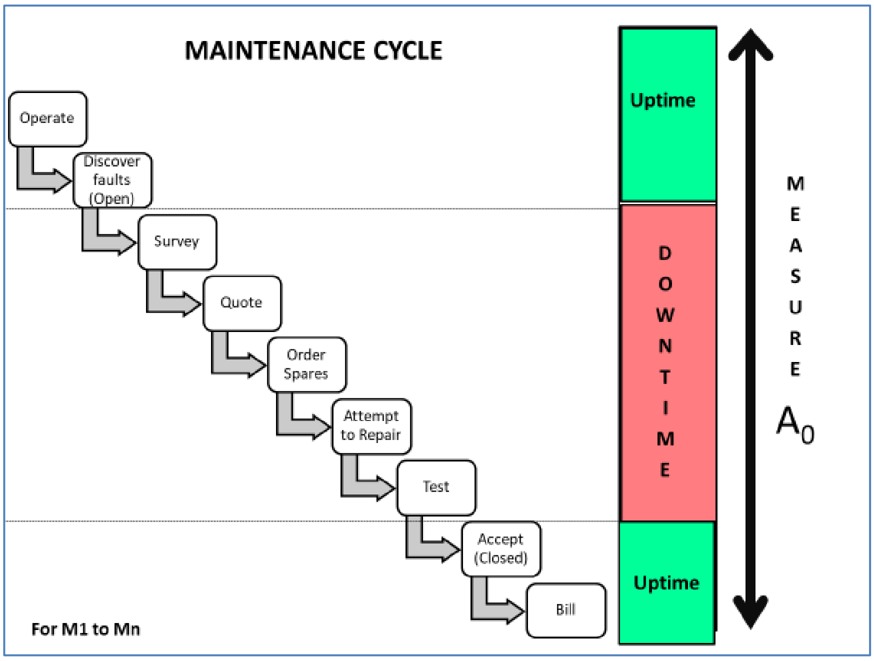


Figure 4.9 Maintenance cycles

The RMN norm is for PV ISS contracts to be awarded for an initial period of three years. Thereafter contracts would normally be extended for a further three years and so on until the end of the ship's life which is approximately 25 to 30 years later. There would be numerous maintenance cycles happening concurrently onboard the ship on a daily basis, and some even concurrently. The initial maintenance contract preparation process "per se" was viewed by PV ISS stakeholders as not having any direct impact on ship operational availability. Only when combined with the information collected from previous ship maintenance cycles it becomes an intrinsic element in the quest of improvement of ship availability. The maintenance cycles depicted in above summarize the maintenance activities on-board of naval vessels in accordance with the PV ISS contract. Determining the relationship of these activities to uptime and downtime was a key driver in being able to feedback information for future contract designs.

4.2.5 Relationship between Availability, Maintenance Activities and Cycles - simplified

The relationship between operational availability, maintenance activities and maintenance cycles for the ISS contract which is generically typical to most other navies has been simplified as described in Figure 4.10. During the contract period, there would be uptimes and downtimes for the naval vessels. M denotes the various maintenance cycles which takes place both sequentially and in parallel, involving uptime and downtime, over the contract period. This downtime includes the maintenance periods (M_1 to Mn) as described earlier in Figure 4.9. The contract manager monitors the operational availability during the contract period, which is affected by both human and equipment related factors.

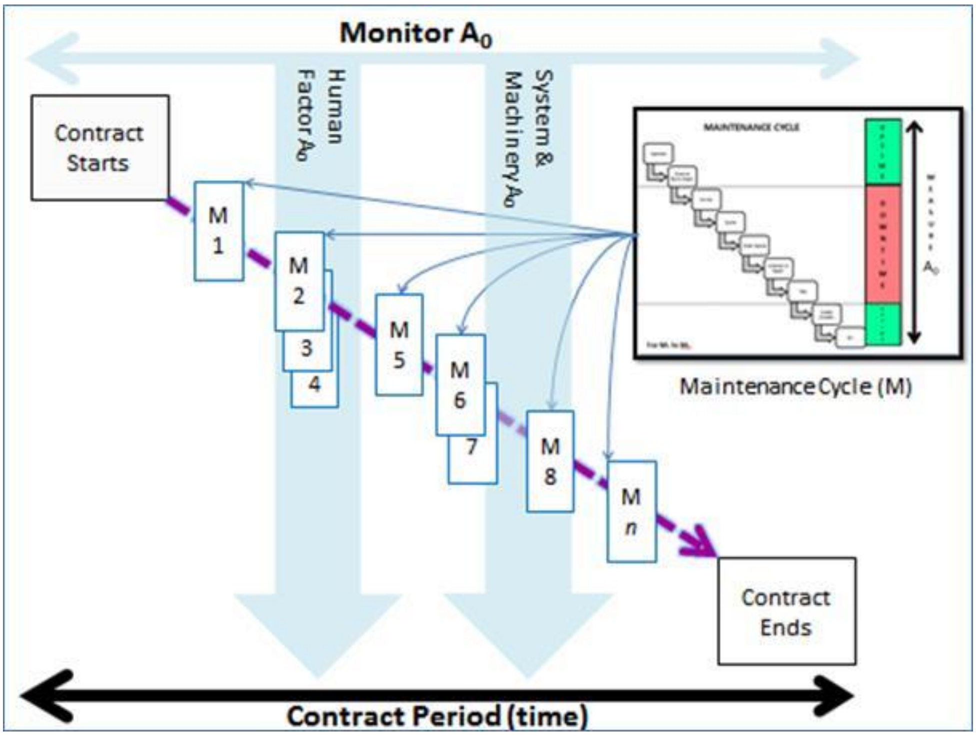


Figure 4.10 Relationship between operational availability, maintenance activities and cycles

The DIFs would be the factors that influence the downtime, whereby those that have a significant negative impact especially 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. Improvements from lesson learned could be expected to be implemented in the next contract.

4.2.6 **Availability-oriented System Development Spiral**

As a result of step 7 in Chapter 3, the researcher realised the necessity to develop a simple diagram to reflect the steps taken in the study, so that all stakeholders to the PV ISS could comprehend the research process easily. The step by step approach would also benefit other ISS organizations globally to trace the steps taken in the development of the research until the production of the model and system. A contract management control and monitoring system spiral developed for the benefit of improving ship availability has been produced and is reflected in Figure 4.11.

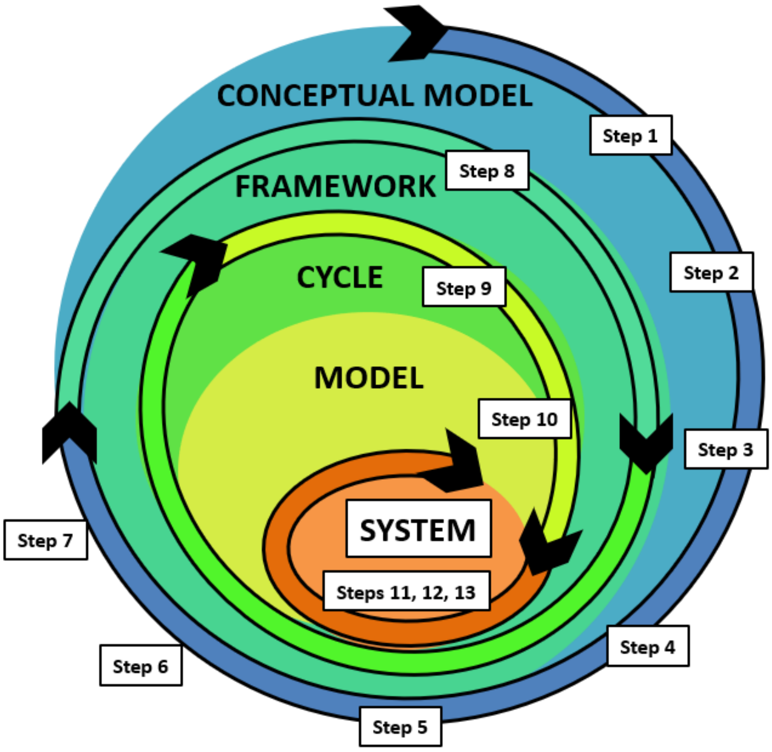


Figure 4.11 Contract Management Control and Monitoring System (ConCaMS) development spiral

4.2.7 **Recommended 4-Steps Availability Improvement**

Upon introducing a new simple perspective of the relationship between DIFs and availability described in earlier sections, the researcher summarized the activities via a "4-Steps towards availability improvement". Step one involves the identification of human and machinery related causes of downtime via FGD. In step two, a risk assessment methodology is applied to identify DIFs with high impact and high likelihood to be categorized as severe DIFs. Step three focuses on the quantification of severe DIFs as obtained via a 7-stage modified Delphi approach with 30 industrial experts and five top management experts. In step 4, the reduction of the DIF size is targeted by applying the developed severity index (SI) formula. It is important to highlight that step four involves the buy-in and participation of all ISS contract stakeholders. The details of the 4-step approach are illustrated in Figure 4.12.

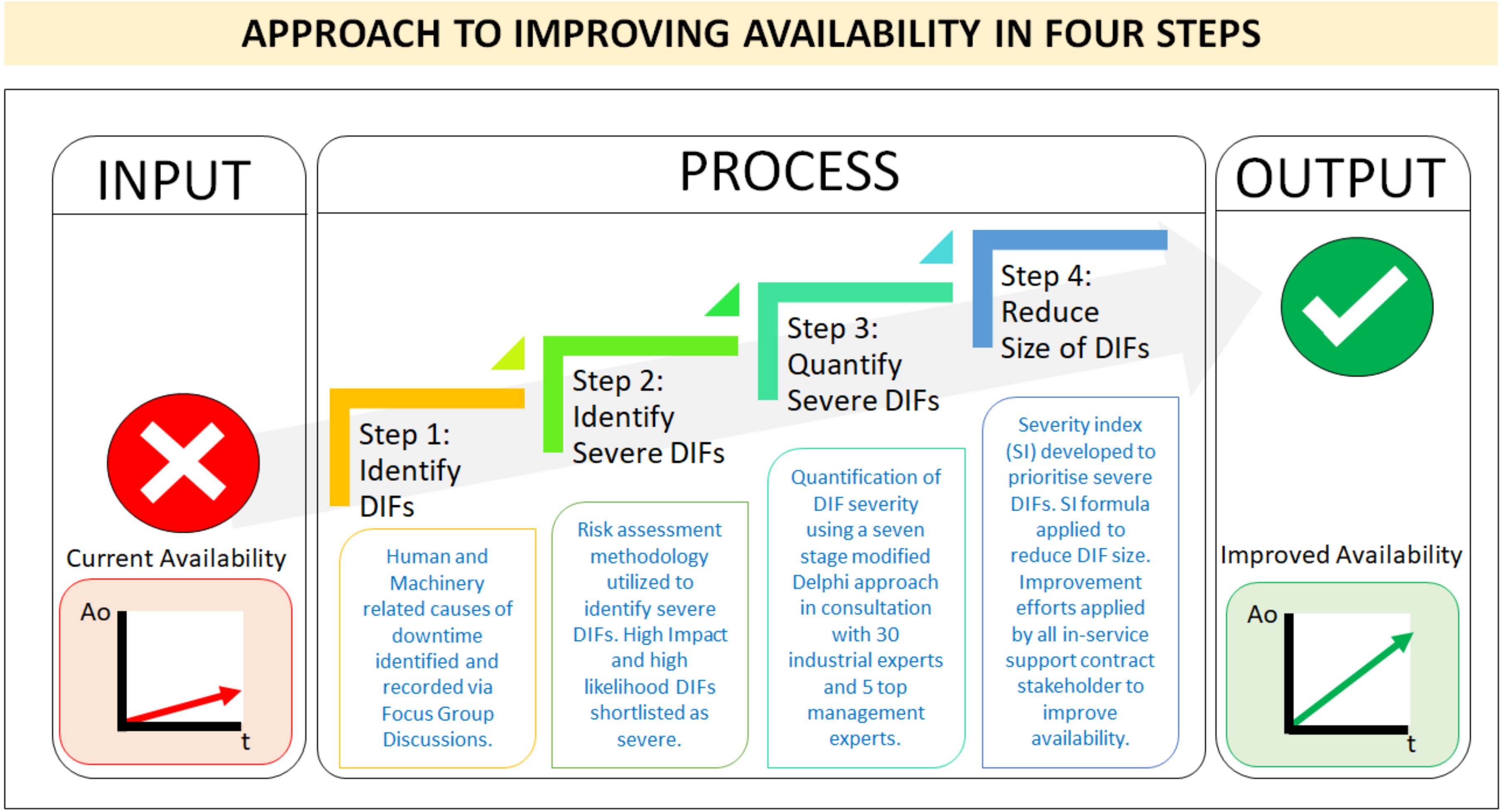


Figure 4.12 4- steps towards availability improvement

4.3 The Results of the Seven Stages of Mixed Method Sequential Delphi

The modified sequential Delphi approach to determine the DIFs for the RMN ISS PV consisted of seven rounds conducted with two panels of experts as summarized in Table 4.2.

Table 4.2 The results of the seven stages of the Delphi study

Research Stage	Phase, Expert Group and Delphi Round	Activity and Results
Stage 1: Focus group discussions (FGD)	Phase 1 expert group 1	• Focus group discussion conducted. • 50 DIFs pooled from various literatures across various engineering fields.
Stage 2: Delphi round 1	Phase 1 expert group 1	• 30 experts identified for survey. • 50 DIFs confirmed by experts. • Weightage of severity (probability versus likelihood of occurrence) through risk analysis obtained.
Stage 3: Delphi round 2	Phase 1 Expert group 1	• Same 30 experts surveyed. • Consensus from previous rounds achieved. • Severe DIFs identified with probability of likely (4 and above) and impact (4 and above). • Snowballing to identify top management experts conducted. • Selection criteria of top management experts.
Stage 4: Delphi Round 3	Phase 2 Expert Group 2 (Top Management)	• 5 top management experts selected and surveyed. • Confirmation of 50 DIFs. • Weightage of severity to identify 15 most severe DIFs.
Stage 5: Delphi Round 4	Phase 2 Expert Group 2 (Top Management)	• Same 5 top management experts surveyed. • Consensus from top management experts achieved. • Reconfirmation of severe DIFs. • 15 most severe DIFs ranked.
Stage 6: Delphi Round 5	Phase 3 Expert Group 2 (Top Management)	• Same 5 top management experts surveyed. • Confirmation of DIFs that impact ship availability from KPI impact assessment.
Stage 7: Delphi Round 6	Phase 3 Expert Group 2 (Top Management)	• Same 5 top management experts surveyed. • Consensus from top management experts achieved.

For stages 1 to 3, the objective was to discover and better understand the unavailability causes and to highlight as well as to prioritize the areas of improvement. To fulfil this objective, a group of 30 experts were selected consisting of individuals who were working directly on the RMN ISS contract with adequate working experience and knowledge in ship maintenance. The panel member demographic is summarized in Table 4.3.

Table 4.3 Panel member demographics by gender, qualifications, type of organization, design and experience

Gender	No
Male	27
Female	3
TOTAL	**30**

Qualifications	No
O'Level, Diploma, Certificate	17
Bachelor Degree	10
Masters	3
TOTAL	**30**

Type of Organization	No
ISS Contractor	17
Shipyard 1	5
Shipyard 2	1
Shipyard 3	1
Shipyard 4	2
Customer – Senior Navy Officers	4
TOTAL	**30**

Designation	No
Technical Executive	6
Senior Technical Executive	9
Supervisor	1
Senior Supervisor	2
Assistant Manager	1
Manager	3
Project Manager	1
Head of Division	3
Commanding Officer Navy Ships	3
TOTAL	**30**

Contract Management Experience	No
1 Years	3
2-3Years	2
4-5Years	7
6-7 Years	6
8-9 Years	3
10-11 Years	2
13-15 Years	2
16-17 Years	2
21-23 Years	3
TOTAL	**30**

In subsequent stages 4 to 7, the opinion of five top management experts as proposed via snowballing technique in earlier rounds were elicited. Table 4.3 contains the list of top management panel members and their positions.

Table 4.4 List of the panel members

Type of Organization	Number
ISS Contractor Top Management	1
Shipyard Top Management	1
Navy Admiral (Engineering)	3
Total	5

The selected experts represented a balanced view of top management perspectives from both the contractor and customer. These experts possessed extraordinary knowledge and experience in ship maintenance, project management, financial management, maintenance philosophies as well as policies and procedures, and were positioned in their respective organizations to ensure that their organizations benefit from the results of the study. All experts possessed over 20 years of experience in the naval ship maintenance industry. The average was 35 years of working experience. Their selection provided a fair and balanced top-level view for the Delphi study. All the panel members fulfilled the criteria requirements of Delphi technique.

4.4 Identification of DIFs and Severe DIFs that impact Operational Availability

This section explains the identification of DIFs and severe DIFs that impact operational availability. The results of the focus group discussion and the various rounds of Delphi are described in the following subsections.

4.4.1 Results from Stage 1: Focus Group Discussion

The focus group discussion (FGD) was designed to confirm and screen the wide range of factors that were harvested from the literature review on factors affecting the down time or availability of naval ships as well as from other engineering fields as seen in Figure 4.14.

Figure 4.13 Experts participating in Brainstorming, FGD and survey during Delphi Rounds: (a) The PV ISS Maintenance organisation (b) The RMN officers

The 30 expert members identified and consolidated the variables from various interpretations and carefully pooled into 50 agreed categories called DIFs that impact ship availability as displayed in Table 4.4.

Table 4.5 Downtime Influence Factors (DIFs) confirmed by panel members

DIF No	DIF for ship operational availability	DIF No	DIF for ship operational availability
1	Equipment and Systems – Hull and Design	26	Capability of Customer performing Maintenance
2	Equipment and Systems – Main Propulsion	27	Morale and Attitude of Customer involved in Maintenance
3	Equipment and Systems – Electrical	28	Morale and Attitude of Contractor involved in Maintenance
4	Equipment and Systems – Weapon Systems	29	Efficiency of Processes, Procedures and reporting structure include Finance
5	Equipment and Systems – Auxiliaries	30	Ship Operational/sailing schedule
6	Equipment and Systems – Outfittings	31	Commonality of Equipment issues
7	Maintenance Policy - Priority on Type of Maintenance	32	Non-Redundancy of Equipment
8	Awareness of Importance of Maintenance / Attitude – including hiding problems from becoming official.	33	High Turnover of maintenance supervisors.
9	Maintenance Budget Allocation	34	High Turnover of maintainers
10	Information Management	35	Different location of ships

Table 4.5 (cont'd) Downtime Influence Factors (DIFs) confirmed by panel members

DIF No	DIF for Ship Operational Availability	DIF No	DIF for Ship Operational Availability
11	Preventive Maintenance	36	Statutory requirements
12	Corrective Maintenance	37	Cash flow shortages
13	Predictive Maintenance	38	Government of Malaysia Requirements (i.e. Economic Enhancement Programme, Offset etc.)
14	Emergency Repair and Docking	39	Variation Order and Contract Change
15	Equipment Technology / System Complexity	40	Ageing of Equipment
16	Scheduling Issues	41	Force Majeure
17	Maintenance of Special Tools, Test Equipment	42	Accidents and Hazards
18	Availability of Facilities	43	Extraordinary Price Escalations (Spares, Consumables, Equipment)
19	Spares Availability	44	Pilferage, Theft and Fraud and Cheat
20	Obsolescence Issues	45	OLM, ILM, DLM - Overlap of maintenance duties (contractual) and impact if not performed
21	Design Change Issues	46	Contract Management across a wide range of stakeholders with conflicting interests
22	Knowledge Management including. Training, Knowledge and Skills	47	Impact of Parallel Contracts to Schedule, Genuinity of Spares, Professionalism of Repair Team etc.
23	Availability of Original Equipment Manufacturer (OEM) Expert Support	48	Supporting of the Vessel outside of home ports (e.g. issue on mob, avail of materials etc.)
24	Availability of Local vendor support	49	Exogenous factors (i.e. company profit margin, administrative costs, peripheral costs, support cost)
25	Complexity and efficiency of existing contract	50	Exogenous factors - Contract Concept (Total Maintenance Package against segregated orders without interrelationships) and based on recommendations
Note: Panel Agreement: 100%			

In accordance to Chan *et al.* (2001) only the measures that have been selected, proposed or agreed by 50% of experts or above will be selected for further consideration. Therefore all 50 DIFs above have met the requirements to be brought forward to Stage 2 of the study due to the 100% panel agreement. Refer to Appendix A for the list of DIFs identified from literatures and confirmed by the 30 experts.

4.4.2 Results from Stage 2: Delphi Round 1

In Stage 2, Delphi round 1 consensus among the expert group members regarding the importance of each of the 50 DIF was achieved. Based on the risk analysis methodology detailed in Chapter 3, a DIF with a total value or median of 16 was defined as "severe" and considered as important. Table 4.5 displayed the severe DIFs ranking from most severe (rank 1) to least severe (rank 15) obtained from Delphi round 1.

Table 4.6 Severe DIFs to ship availability from Delphi round 1

Severe DIFs	Count	Mean	Median	Mode	Rank
Corrective maintenance	30	24.2	25.0	25.0	1
Spares availability	30	22.9	25.0	25.0	2
Impact of parallel contracts to schedule, genuinity of spares, professionalism of repair team etc.	30	21.7	25.0	25.0	3
Cash flow shortages	30	21.6	25.0	25.0	4
Knowledge management including training, knowledge, skills and system	30	19.6	20.0	20.0	5
Equipment and systems - Main propulsion	30	18.8	20.0	20.0	6
Maintenance policy - priority on type of maintenance	30	18.0	20.0	20.0	7
Availability of OEM expert support	30	17.4	16.0	16.0	8
Maintenance budget allocation	30	17.2	16.0	16.0	9
Awareness of importance of maintenance / attitude – including hiding problems from becoming official.	30	17.0	16.0	16.0	10
Availability of facilities	30	16.7	16.0	16.0	11
Availability of local vendor support	30	16.7	16.0	16.0	12
Complexity and efficiency of existing contract	30	16.2	16.0	16.0	13
Scheduling issues	30	16.0	16.0	16.0	14
Equipment and systems - Auxiliaries	30	15.3	16.0	16.0	15

4.4.3 **Results from Stage 3: Delphi Round 2**

In Delphi round 2, the 30 respondents were asked to confirm their agreement to the DIFs listed as the most severe factors that impact the RMN’s ship operational availability. All the experts confirmed the list of 15 DIFs as being severe and provided their views of the severity of each DIF. The summarized results are as per Table 4.6. The coefficient of variation (CoV) values in Delphi round 1 (CoVR1) and Delphi round 2 (CoVR2) were calculated for each severe DIFs as presented in Table 4.7.

Table 4.7 Severe DIFs to ship availability from Delphi round 2

List of Severe DIFs	Count	Mean	Rank
Corrective maintenance.	30	24.5	1
Spares availability.	30	23.4	2
Impact of parallel contracts to schedule, genuinity of spares, professionalism of repair team etc.	30	22.8	3
Cash flow shortages.	30	22.63	4
Knowledge management including training, knowledge, skills and system.	30	20.2	5
Equipment and systems - Main propulsion.	30	20.0	6
Maintenance policy - priority on type of maintenance.	30	19.1	7
Availability of OEM expert support.	30	17.4	8
Maintenance budget allocation.	30	17.4	9
Awareness of importance of maintenance / attitude – including hiding problems from becoming official.	30	17.22	10
Availability of facilities.	30	17.1	11
Availability of local vendor support.	30	17.0	12
Complexity and efficiency of existing contract.	30	17.0	13
Scheduling issues.	30	16.8	14
Equipment and systems - Auxiliaries.	30	16.3	15

Table 4.8 The agreement level among the panel members in Delphi round 1 and 2

List of Severe DIFs	Count	Mean	Median	Mode	Rank	CV R1	CV R2	CV R1-R2
Corrective maintenance.	30	24.50	25.00	25.00	1	0.09	0.06	0.03
Spares availability.	30	23.40	25.00	25.00	2	0.19	0.16	0.03
Impact of parallel contracts to schedule, genuinity of spares, professionalism of repair team etc.	30	22.80	25.00	25.00	3	0.23	0.17	0.06
Cash flow shortages.	30	22.63	25.00	25.00	4	0.24	0.15	0.09
Knowledge management including training, knowledge, skills and system.	30	20.20	20.00	20.00	5	0.09	0.08	0.01
Equipment and systems - Main propulsion.	30	20.03	20.00	20.00	6	0.20	0.06	0.14
Maintenance policy - priority on type of maintenance.	30	19.13	20.00	20.00	7	0.22	0.15	0.07
Availability of OEM expert support.	30	17.43	16.00	16.00	8	0.17	0.17	-
Maintenance budget allocation.	30	17.37	16.00	16.00	9	0.13	0.13	-
Awareness of importance of maintenance / attitude – including hiding problems from becoming official.	30	17.23	16.00	16.00	10	0.14	0.13	0.01
Availability of facilities.	30	17.10	16.00	16.00	11	0.15	0.14	0.01
Availability of local vendor support.	30	17.00	16.00	16.00	12	0.21	0.20	0.01
Complexity and efficiency of existing contract.	30	16.97	16.00	16.00	13	0.19	0.13	0.06
Scheduling issues.	30	16.83	16.00	16.00	14	0.18	0.12	0.06
Equipment and systems - Auxiliaries.	30	16.33	16.00	16.00	15	0.27	0.19	0.08

In summary, the values of mean, median, maximum and minimum of the difference between CV are:

i) Mean of (CV R1 – CV R2): 0.04

ii) Median of (CV R1 – CV R2): 0.03

iii) Max of (CV R1 – CV R2): 0.14

iv) Min of (CV R1 – CV R2): 0.00

Whilst Dajani *et al.* (1979) marked that values of (CV R1 – CV R2) below 0.2 are considered as minor, Shah and Kalaian (2009) added that henceforth the stopping rule is applied for the Delphi study. Noting such highlights, it is deduced that stability of each severe DIF was reached at round 2 and no further Delphi rounds were required. However, whilst the consensus amongst experts had increased the ranking of the Severe DIFs remains unchanged as displayed in Table 4.8. The results mean that the agreement level among the panel members have improved.

Table 4.9 Validation result of severe DIFs via Delphi round 2

Severe DIFs	**Count**	**Mean**	**Median**	**Mode**	**Rank**
Corrective maintenance.	30	24.50	25.00	25.00	1
Spares availability.	30	23.40	25.00	25.00	2
Impact of parallel contracts to schedule, genuinity of spares, professionalism of repair team etc.	30	22.80	25.00	25.00	3
Cash flow shortages.	30	22.63	25.00	25.00	4
Knowledge management including training, knowledge, skills and system.	30	20.20	20.00	20.00	5
Equipment and systems - Main propulsion.	30	20.03	20.00	20.00	6
Maintenance policy - priority on type of maintenance.	30	19.13	20.00	20.00	7
Availability of OEM expert support.	30	17.43	16.00	16.00	8
Maintenance budget allocation.	30	17.37	16.00	16.00	9
Awareness of importance of maintenance / attitude – including hiding problems from becoming official.	30	17.23	16.00	16.00	10
Availability of facilities.	30	17.10	16.00	16.00	11
Availability of local vendor support.	30	17.00	16.00	16.00	12
Complexity and efficiency of existing contract.	30	16.97	16.00	16.00	13
Scheduling issues.	30	16.83	16.00	16.00	14
Equipment and systems - Auxiliaries.	30	16.33	16.00	16.00	15

Figure 4.15 illustrates the view of the 30 Experts for Stage 3. The key observation is that whilst the vast majority of experts had assessed the severe DIFs with a rating of 16 and above, there were a few outliners. The researcher requested the experts to provide justification for the rating. The key factor in assigning a significant different rating was due to having been exposed to a lesser extent to the DIF due to limited ISS contract experience and limited working experience.

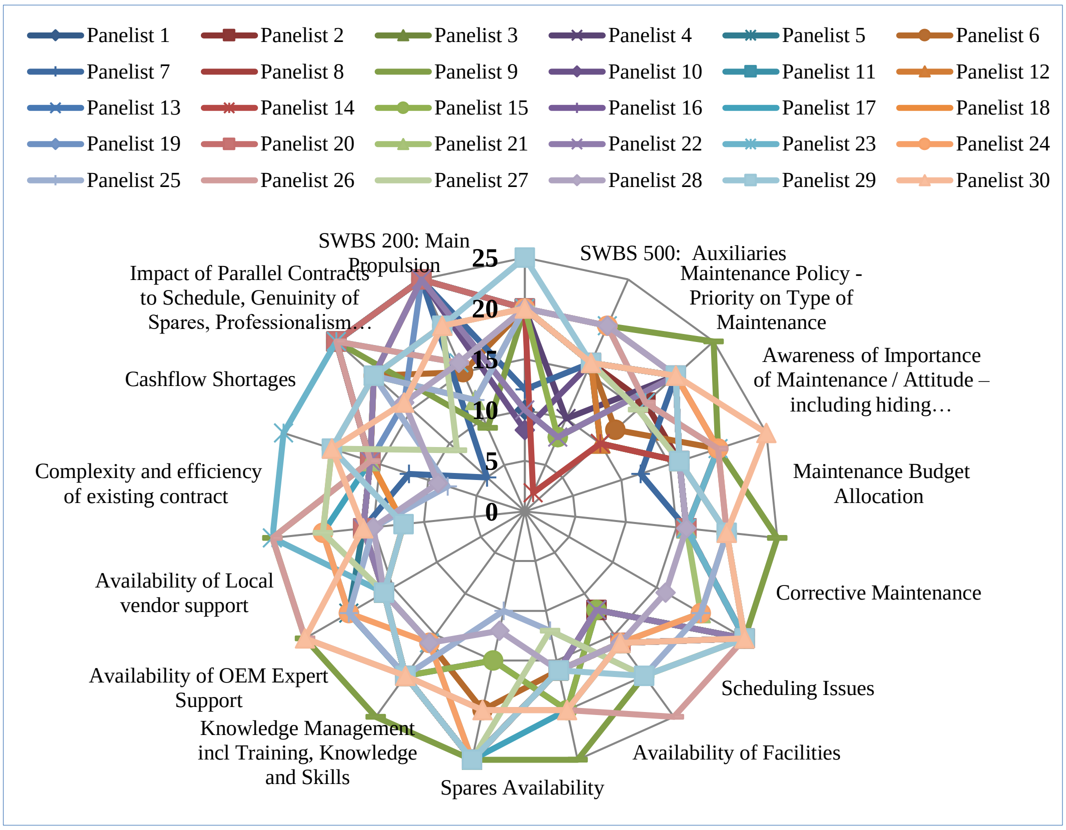


Figure 4.14 Severe DIFs risk assessment results based on expert panel of 30

To add an additional step of rigour to the Delphi study, the researcher proceeded to analyse via descriptive statistics with the help of the statistical package SPSS whether the demographics of the expert sample consisting of gender, designation, years of experience, organization type had an impact on the results of the Delphi Stage 3.

Table 4.9 summarizes the SPSS output for gender with the observation that with 90% the vast majority of respondents is male. Only 10% of the respondents were female as highlighted in pink. Whilst the female participation may appear to be a low percentage, there are very few female staffs or officers from either organisations that are involved in the RMN ISS activities

Table 4.10 SPSS univariate analysis output for respondents' gender

Gender

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	27	90.0	90.0	90.0
	Female	3	10.0	10.0	100.0
	Total	30	100.0	100.0	

Table 4.10 summarizes the SPSS output for designation with the observation that 50% of the respondents are technical executives and senior technical executives as highlighted in grey. Over 30% of respondents hold a managerial position of either supervisors, senior supervisor, managers or head of divisions as highlighted in yellow, 10% are RMN commanding officers as highlighted in orange and 3% are RMN contract managers.

Table 4.11 SPSS univariate analysis output for respondent's designation

Designation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Technical Executive	6	20.0	20.0	20.0
	Senior Technical Executive	9	30.0	30.0	50.0
	Supervisor	1	3.3	3.3	53.3
	Senior Supervisor	2	6.7	6.7	60.0
	Assistant Manager	1	3.3	3.3	63.3
	Manager	3	10.0	10.0	73.3
	Project Manager	1	3.3	3.3	76.7
	Head of Division	3	10.0	10.0	86.7
	Commanding Officer RMN	3	10.0	10.0	96.7
	Contract Manager RMN	1	3.3	3.3	100.0
	Total	30	100.0	100.0	

Table 4.11 showcases the SPSS frequency graph for years of experience. On average the overall working experience is 23 years and 22 years in the marine industry working experience. Nevertheless, it is interesting to note that the standard deviation in both cases is above 9 years as highlighted in pink. Only 13% of respondents had less than 10 years of working experience, 47% of respondents had between 10 years and 24 years of experience and 40% of respondents had over 25 years of experience. The panel member's working experience related to the required job function and the wide spectrum of job positions in both the contractor and the customer's organizations ensured the validity of this phase of Delphi research.

Table 4.12 SPSS descriptive statistic output for respondent's working experience

Statistics

		Working Experience in Years	Marine Industry in Years	ISS Contract Experience in Years	Contract Management Experience in Years	Naval Experience in Years
N	Valid	30	30	30	30	30
	Missing	0	0	0	0	0
Mean		23.1333	22.1000	3.0167	7.4667	13.5667
Median		24.0000	24.0000	2.5000	5.5000	22.0000
Std. Deviation		9.37250	9.00326	2.39426	6.44731	10.97861

The frequency graph for years of experience in Figure 4.16 graphically exhibits the stark contrast of working experience in years

Figure 4.15 Respondents working experience in years SPSS frequency graph

Table 4.12 summarizes the SPSS output for organisation type with the observation that over 60% of the respondents are from the main contractor organisation BNT and BNS as highlighted in grey. Approximately 23% are from other Malaysian commercial shipyards as highlighted in yellow and just above 13% are from the RMN. The majority of respondents were from the ISS contractor organization type, a minority of the panel is made up of naval officers.

Table 4.13 SPSS descriptive statistic output for respondent's organisation type

Organisation

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	BNT HQ Lumut	12	40.0	40.0	40.0
	BNT Kota Kinabalu	4	13.3	13.3	53.3
	BNT Kuantan	1	3.3	3.3	56.7
	GOMS	5	16.7	16.7	73.3
	LSE	1	3.3	3.3	76.7
	NGVTech	1	3.3	3.3	80.0
	BNS	2	6.7	6.7	86.7
	RMN	4	13.3	13.3	100.0
	Total	30	100.0	100.0	

Whilst the sampling methodology is based on non-quantitative methods and as such typically generalizations of findings should not take place, i.e. typically researchers will not make conclusion beyond the data set and shall not make inference onto the population. Nevertheless, descriptive statistics enabled the researcher to pinpoint relationships or trends in the data so that any significant relationship in demographic impact onto study results could be highlighted. However, as in the case of the Delphi expert selection a vast majority of the ISS experts in Malaysia have been involved in the study it is highly plausible that their opinions are representative of the population of interest and if required findings could be generalized, although it is not the intention of the researcher.

All respondents were requested to assess the "impact" and "likelihood of occurrence" of a DIF. The outcome of impact multiplied by the likelihood was labelled as “weightage of severity” (WOS) of a DIF. The researcher formulated initial hypothesis that panellist’s gender would impact WOS. The researcher assumes that panellists with less working experience may assess “the impact and likelihood” of a DIF differently to the more experienced experts. The grouping of information by the researcher into categories of less than 10 years of experience, between 10 to 24 years of experience and above 25 years of experience is made to better understand the panellists likely working exposure and expertise.

Respondents with below 10 years of experience at any of the organizations are less likely to have been involved and interacted with the various stakeholders and may have only had a limited exposure to contract management per se. Panellists with over 10 years of experience but below 25 years of experience are expected to have a “fair to good exposure” to contract management. Experts with over 25 years of experience are considered to have a “very good exposure” to contract management. In addition, the researcher tested the null hypothesis that designation, organization type and qualifications impacted the WOS for each DIF.

Means of plot analysis with the help of the statistical package SPSS was initially conducted and only a few DIFs WOS that appeared to be impacted by the sample demographics. It is important to clarify that the observed relationship did not impact the selection of the shortlisted DIF. The first finding is that the WOS for DIF1 “Equipment and Systems - Hull and Design” was rated differently by senior supervisors, head of divisions, commanding officers and RMN contract manager who assigned a lower rating than their counterparts as per Figure 4.17.

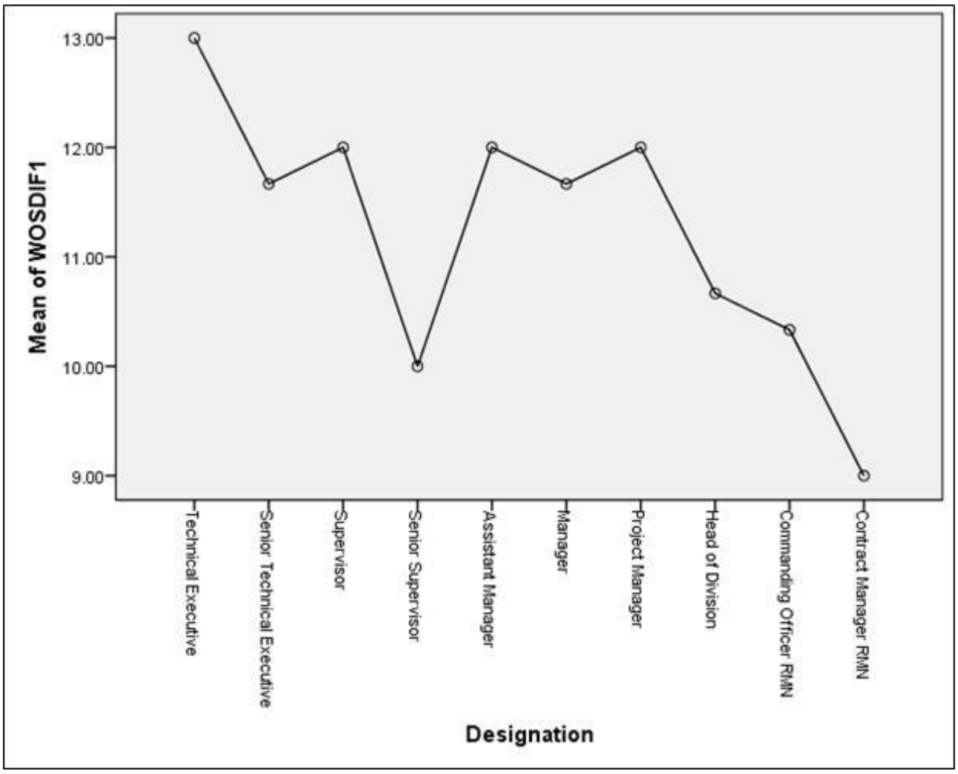


Figure 4.16 SPSS output means of plot WOS DIF1 vs. designation

Nevertheless, based on subsequently performed Pearson's chi square test there was no significant evidence to show a relationship between WOS and designation, simply put there was no evidence that the rating is impacted by designation for WOS DIF1 Equipment and system - Hull and Design. With a p value above 0.05, there is no evidence that WOS for DIF1 varies according to designation (Chi-Square 49.130, Degrees of Freedom 36, p=0.710) as per Table 4.13.

Table 4.14 SPSS Output Chi-Square Test

	Value	Df	Asymp. Sig. (2-sided)
Pearson Chi-Square Likelihood Ratio	49.130[a] 30.882	36 36	0.071 0.710
Linear-by-Linear Association	3.162	1	0.075
N of Valid Cases	30		

Whilst cross tabulations by means of Chi-Square tests were able to assist the researcher to confirm relationship between two variables, it was not possible to understand relationships between groups. The researcher proceeded with one-way Anova analysis to identify if any relationships could be found in the collected data for those variables with more than 2 groups and more than 3 observations per group. The results of analysis pointed out that there was a relationship between groups of qualifications and WOS for DIF47 “Impact of parallel contracts to schedule, genuinity of spares, professionalism of repair Team etc.”. The means plot for WOS DIF47 by qualification type graphically represents the varying assessment by qualification group as per Figure 4.18.

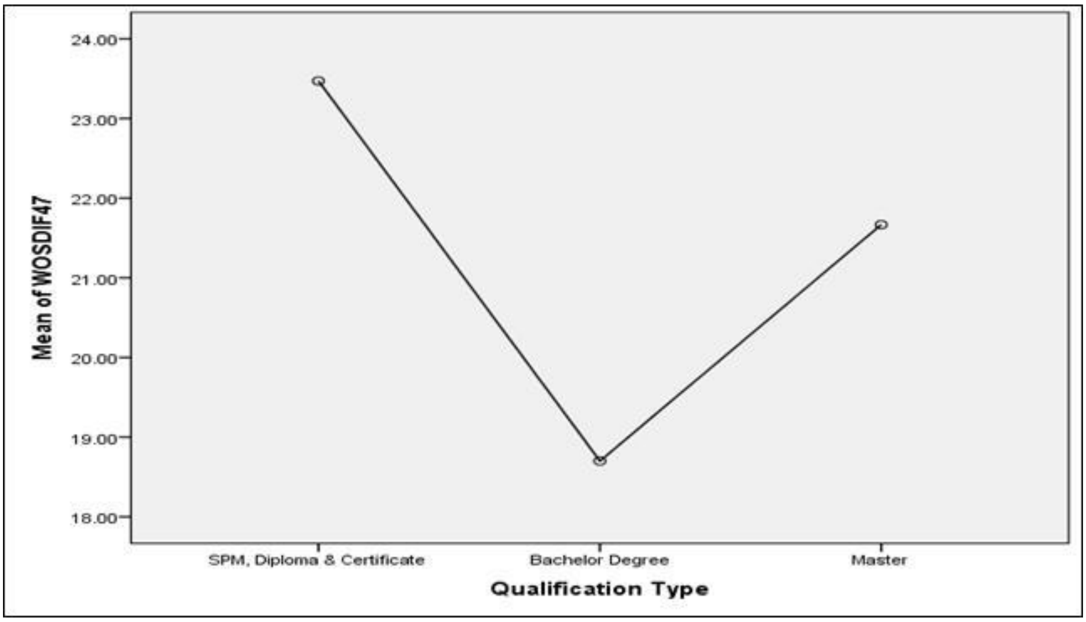


Figure 4.17 SPSS output means of plot WOS DIF47 vs. qualification type

One-way analysis of variance was conducted to evaluate the null hypothesis that there was “no difference” in how panellists rated WOS for DIF47 (impact of parallel contracts by qualification) (N=30). The independent variable, qualification type included 3 groups:

(i) Secondary education (SPM, Diploma and Certificate)
(M = 22.94, SD= 5.02, n=17)
(ii) Tertiary education (Bachelor degree)
(M=21.20, SD=3.61, n=10)
(iii) Postgraduate degree (Master’s degree)
(M=15, SD=5.57, n=3)

The assumption of homogeneity of variances was tested and found tenable using Levene's test, F (3.412), p= 0.048. Thus, there was significant evidence to reject the Null Hypothesis and conclude there is a significant difference in WOS 47 based on qualification type. The convention for interpreting affect size of the actual difference in the mean scores between groups was large for Bachelors and medium for O'Levels/SPM, Diploma and Certificate and Masters. Post hoc comparison was conducted to evaluate pairwise differences amongst group means with use of Tukey HSD Test with the help of SPSS. The test revealed significant pairwise differences between mean scores of WOS 47 for Masters degrees $p < 0.05$ (sig = 0.037). Results from panellist with Masters qualifications do not significantly differ on WOS 47 compared to the other two groups, $p > 0.05$. Nevertheless, all qualifications type rated WOS for DIF 47 as a Severe DIF as per Table 4.14.

Table 4.15 SPSS output post-hoc test pairwise comparison qualifications for WOS DIF47

Multiple Comparison, Dependent Variable: WOSDIF47
Tukey HSD

(I) Qualification Type	(J) Qualification Type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
SPM, Diploma & Certificate	Bachelor Degree	4.77059*	1.82628	.037	.2425	9.2987
	Master	1.80392	2.86973	.806	-5.3113	8.9192
Bachelor Degree	SPM, Diploma & Certificate	-4.77059*	1.82628	.037	-9.2987	-.2425
	Master	-2.96667	3.01663	.593	-10.4461	4.5128
Master	SPM, Diploma & Certificate	-1.80392	2.86973	.806	-8.9192	5.3113
	Bachelor Degree	2.96667	3.01663	.593	-4.5128	10.4461

* The mean difference is significant at the 0.05 level

Based on the statistical analysis conducted for the 30 Delphi expert panellists selected to participate in the survey to identifying the severity of DIFs impacting naval ship operational availability it can be concluded that there is no evidence with the exception of "qualification type" having had an impact on the weightage of severity of the DIFs. Nevertheless, even for qualification type this did not impact the selection of severe DIFs.

4.4.4 **Results from Stage 4: Delphi Round 3**

Delphi Round 3 commenced with the reconfirmation of the DIFs by the five top management experts. The list of DIFs identified from literature, FGD, confirmed by the 30 experts and reconfirmed by the top five management experts can be seen in Appendix A. Subsequently, the ratings of the 15 most severe DIFs were considered by the five top management respondents as shown in Table 4.15. The level of concordance or agreement between experts was calculated with the help of Kendall's coefficient of concordance in Minitab and SPSS. The experts agreed on 12 out of 15 measures (80% Agreement, 95% Confidence Interval, 51.91, 95.67), Kendall's coefficient of concordance is considered high at 0.908291 with Chi Square of 63.5804, 14 Degrees of Freedom and $p < 0.001$.

Table 4.16 Severe DIFs to ship availability from Delphi round 3

List of Severe DIFs	Count	Mean	Median	Rank
Corrective maintenance.	5	25.0	25.0	1
Spares availability.	5	25.0	25.0	2
Impact of parallel contracts to schedule, genuinity of spares, professionalism of repair team etc.	5	23.0	25.0	3
Cash flow shortages.	5	21.2	20.0	4
Knowledge management including training, knowledge, skills and system.	5	20.0	20.0	5
Equipment and systems - Main propulsion.	5	20.0	20.0	66
Maintenance policy - priority on type of maintenance.	5	20.0	20.0	7
Availability of OEM expert support.	5	18.4	20.0	8
Maintenance budget allocation.	5	16.0	16.0	9
Awareness of importance of maintenance / attitude – including hiding problems from becoming official.	5	16.0	16.0	10
Availability of facilities.	5	16.0	16.0	11
Availability of local vendor support.	5	16.0	16.0	12
Complexity and efficiency of existing contract.	5	16.0	16.0	13
Scheduling issues.	5	16.0	16.0	14
Equipment and systems - Auxiliaries.	5	16.0	16.0	15

4.4.5 **Results from Stage 5: Delphi Round 4**

In Delphi round 4, the top management experts were asked to re-assess their ratings in the light of the consolidated results obtained from Delphi round 3. All experts did not make any adjustments to their assessments and the level of concordance remains as per before. Coefficient of variation (CV) between round 3 (CVR3) and round 4 (CVR4) from the experts' interview was determined and the values of mean, median, maximum and minimum of the difference between CV are:

(i) Mean of (CV R4 – CV R3):	0.0
(ii) Median of (CV R4 – CV R3):	0.00
(iii) Max of (CV R4 – CV R3):	0.10
(iv) Min of (CV R4 – CV R3):	0.00

Values of CVR3-CVR4 are below 0.2, which can be considered a minor difference according to Dajani *et al.* (1979) This is the stopping rule for Delphi. Therefore, it could be assumed that stability for each severe DIFs was reached and no further rounds were required. The Kendall's coefficient of concordance confirmed that a high concurrence between experts had been reached.

Figure 4.19 illustrates the view of the five top management experts. In contrast with the polar chart of the severe DIFs risk assessment results for the 30 panellists as per Figure 4.15, the results from Delphi round 4 are more homogenous than in round 2. This is mainly explained due to the homogeneity of background and experience of the top management experts.

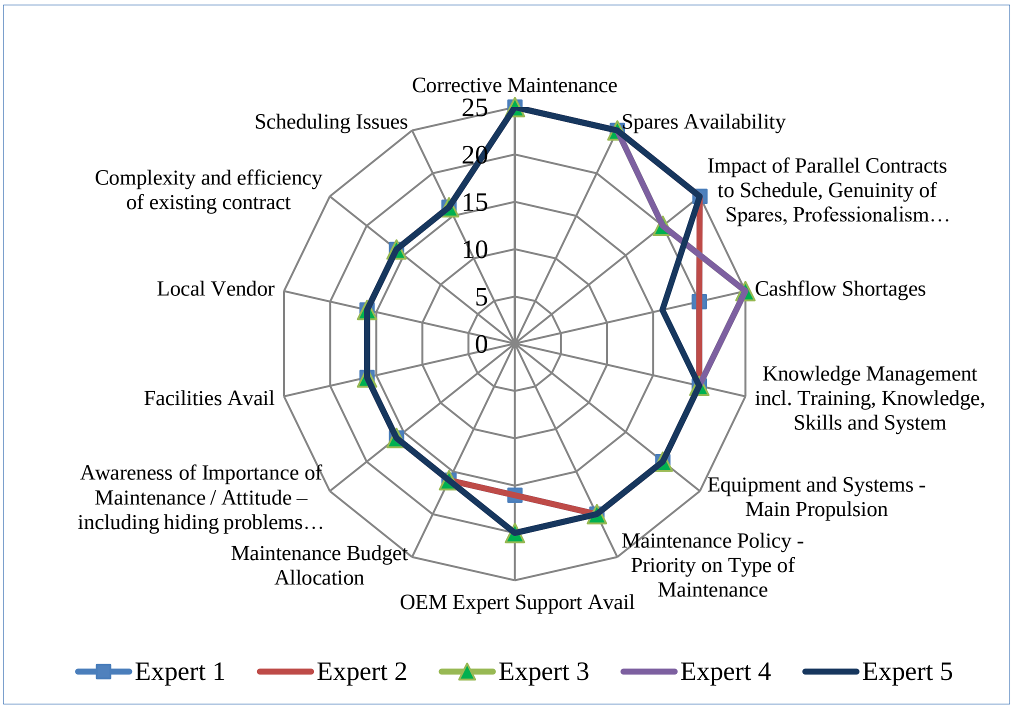


Figure 4.18 Severe DIFs risk assessment results based on top management experts

4.5 Establishment of the DIFs Impact Matrix on Contract and Project Management Elements of "iron triangle of cost, time, quality and scope"

This section establishes the impact of the severe DIFs on contract management and project management elements of the "iron triangle of cost, time, quality and scope". The results of Stage 6 and Stage 7 of the Delphi research are detailed in the following subsections.

4.5.1 Results from Stage 6: Delphi Round 5

There is a clear relationship between project management and contract management, 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 and Preston (2010) explained that project management 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, project management 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 (time, cost, scope and quality) which are basically in accordance with the contract.

Contract management is focused at ensuring that terms and commitments agreed in the contract are adhered to. Contract manager's 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 project and contract management activities for naval ISS contracts are intrinsically linked via the limiting factors or constraints to the ship availability through the DIFs. This aspect presented a further effort by the researcher in answering interdependences and was diagrammatically represented by in Figure 4.20.

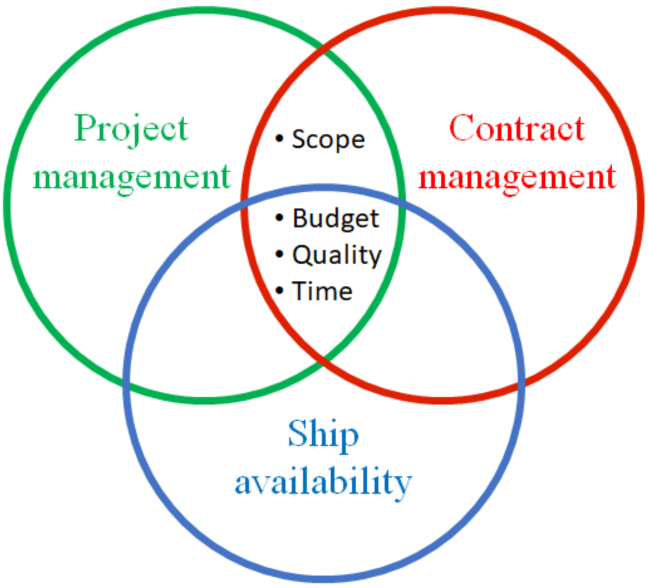


Figure 4.19 Project management, contract management and ship availability constraints

In stage 6: Delphi round 5 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 project management constraints and the contract management objectives. The constraints of "cost", "time", "quality" and scope" were identified as key performance indicators (KPIs). The participants were asked to answer the following question: "if the objective is to improve the ship availability by reducing a DIF, how does the improvement of the identified severe DIFs impact the project management constraints (iron triangle) of cost, time, quality and scope?" A 3-point rating scales for the effect on each KPI was presented as per Table 4.16.

Table 4.17 3-point rating scale to quantify effect on each KPI

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

The abbreviations used where SDIF for severe DIFs and E for expert. The DIFs description was provided as in Table 4.17.

Table 4.18 Severe DIF description

Severe DIF	Description
SDIF 1	Corrective maintenance
SDIF 2	Spares availability
SDIF 3	Impact of parallel contracts to schedule, genuinity of spares, professionalism of repair team etc.
SDIF 4	Cashflow shortages
SDIF 5	Knowledge management including training, knowledge, skills and systems
SDIF 6	Equipment and systems - Main Propulsion
SDIF 7	Maintenance policy - priority on type of maintenance
SDIF 8	Availability of OEM expert support
SDIF 9	Maintenance budget allocation
SDIF10	Awareness of importance of maintenance and attitude – including hiding problems from becoming official.
SDIF11	Availability of facilities
SDIF12	Availability of local vendor support
SDIF13	Complexity and efficiency of existing contract
SDIF14	Scheduling issues
SDIF15	Equipment and Systems – Auxiliaries

Table 4.18 contains the consolidated results on project management and contract management KPIs of cost, time, quality and scope based on the list of 15 severe DIFs.

Table 4.19 Severe DIFs 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	H	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
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

4.5.2 **Results from Stage 7: Delphi Round 6**

In stage 7: Delphi round 6 the five top management experts were shown the consolidated table of results as shown in Table 4.18 before. Experts were asked if they wanted to change their results, however all experts decided to adhere to the answers provided in the previous stage 6: Delphi round 5.

Kendal's coefficient of concordance was calculated in SPSS to determine the level of agreement between the panellists. The coefficient achieved is 0.948436 with a $p < 0.05$. Out of 60 criteria assessed the panellists agreed on 58 criteria. The two instances panellists did not agree on are circled in blue in Table 4.18. It is therefore implied that the panellists have shown a high level of concordance.

Note that negative impacts were highlighted in red bold on Table 4.18 for ease of reference. Subsequently the expert's answers were classified to better understand if the impact of reducing the severe DIFs has an overall "negative", "positive" or "neutral" effect on the contract management and project management constraints as per Table 4.19.

Table 4.20 Effect on contract management and project management KPI

Constraints/ KPIs	Rating Scale	Impact Quantification
Cost	No Impact	Neutral
	Lower	Positive
	Higher	Negative
Time	No Impact	Neutral
	Shorter Duration	Positive
	Extended Duration	Negative
Quality	No impact	Neutral
	Better	Positive
	Reduced	Negative
Scope	Fixed	Neutral

From the severe DIFs impact on contract management and project management KPIs at Table 4.18, and based on the effect interpretation as highlighted in Table 4.19, it can be deduced that:

(i) The improvement of severe DIFs 3, 4, 7, 10, 13 and 14 would not have a negative "cost" or budget impact. The severe DIFs are as follows:

  a. SDIF 3: Impact of parallel contracts to schedule, genuinity of spares, professionalism of repair team etc.
  b. SDIF 4: Cash flow shortages
  c. SDIF7: Maintenance policy - priority on type of maintenance
  d. SDIF10: Awareness of importance of maintenance / attitude – including hiding problems from becoming official.
  e. SDIF13: Complexity and efficiency of existing contract
  f. SDIF14: Scheduling issues

  This is an important contribution since budget and cost constraints are a major limiting factor in introducing changes to existing contracts in the RMN.

(ii) 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.

(iii) The possibility that the negative impact on "costs" to be outweighed by the positive effects on "time" and "quality.

(iv) 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.

(v) An important finding is that contract managers are now able to pinpoint which DIFs to improve when facing budget or cost limitations.

All five top management experts who were already recommended through snowballing technique by another larger group of 30 experts seemed to have a high level of consensus on the results. These findings would definitely help contract and project managers alike to manage their contracts better and to focus on pinpointed areas of concern to increase the operational availabilities of the naval ships in the fleet.

4.6 Development of the Severity Index as the Model Algorithm

After identifying the quantity of key measures of DIFs in the previous Delphi stage 5, the experts scoring was referred to determine the DIF severity index. The starting point was to identify the importance of each weighting.

As explained in Chapter 3, 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. The weighting for each of the top DIFs was computed using the following equation (4.2).

$$W_{SMi} = \frac{M_{SMi}}{\sum_{1}^{15} S_{SMi}} \tag{4.2}$$

where:

W_{SMi} represents the importance weighting of particular severe DIFs

M_{SMi} represents the mean rating of particular severe DIFs

$\sum S_{SMi}$ 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 equation (4.3)

$$SI = W_{SM\ (DIF1)} + W_{SM\ (DIF2)} + W_{SM\ (DIF3)} + W_{SM\ (DIF4)} + W_{SM\ (DIF5)} + W_{SM\ (DIF6)} + W_{SM\ (DIF7)} + W_{SM\ (DIF8)} + W_{SM\ (DIF9)} + W_{SM\ (DIF10)} + W_{SM\ (DIF11)} + W_{SM\ (DIF12)} + W_{SM\ (DIF13)} + W_{SM\ (DIF14)} + W_{SM\ (DIF15)} \quad (4.3)$$

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. Though it seems more sophisticated to use a non-linear model to fit the data obtained, over-fitting is a common problem with non-linear models especially when the sample size is not sufficiently large (Neter *et al.*, 2005; Weisberg, 2005). A guide as provided by Cohen and Manion (1994) was referred to interpret the linear correlations. The suggested size of coefficient is given as in Table 4.20.

Table 4.21 Interpretation of the size of coefficient for linear correlations (Cohen and Manion, 1994)

Size of coefficient	**Interpretation**
0.20-0.35	Slight relationship
0.35-0.65	Useful for limited prediction, usually bivariate relationship
0.66-0.85	Good prediction result from one variable to other
0.86 and above	Two or more variables are related

Pearson correlation matrix was calculated and analysed for the algorithm development in this study using the statistical software package 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 severity index (SI) algorithm to consider the multiplier effect between these factors. A linear correlation or multiplier effect is subsequently singled out and adjusted in the severity index.

The expert scoring was used to develop a DIF severity index according to the 15 key measures DIFs. The importance of each weighting based on the mean scoring from Delphi round two (n=30) and round four (n=5) of the Delphi study is summarized in table 4.21.

Table 4.22 Mean, ranking and importance weighting

Downtime Influence Factors to Ship Availability	**Mean**	**Rank**	**Importance weightings / Severity measure (SM)**
Corrective maintenance.	24.571	1	0.085
Spares availability.	23.629	2	0.082
Impact of parallel contracts.	22.829	3	0.079
Cashflow shortages.	22.429	4	0.078
Knowledge management.	20.171	5	0.070
Equipment and systems – Propulsion.	20.029	6	0.069
Maintenance policy and priority.	19.257	7	0.067
Availability of OEM expert support.	17.571	8	0.061
Maintenance budget allocation.	17.171	9	0.060
Awareness of importance of maintenance and attitude.	17.057	10	0.059
Availability of facilities.	16.943	11	0.059
Availability of local vendor support.	16.857	12	0.058
Complexity and efficiency of existing maintenance contract.	16.829	13	0.058
Scheduling issues.	16.714	14	0.058
Equipment and systems – Auxiliaries	16.286	15	0.056

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 formula (4.2).

Only two instances of linear correlation or multiplier effect were found. These were singled out and adjusted in the severity index as described next. Table 4.22 contains the correlation of weightage of severity (WOS) for the severe DIFs based on Spearman's correlation coefficient for p=0.05.

Table 4.22 Correlation of weightage of severity (WOS) of severe DIFs (Pearson’s correlation coefficient p=0.05)

	Main Propulsion	Auxiliaries	Maintenance Policy	Attitude to importance of maintenance	Maintenance Budget Allocation	Corrective Maintenance	Scheduling Issues	Availability of Facilities	Spares Availability	Knowledge Manag	Availability of OEM Expert Support	Availability of Local vendor support	Complexity and efficiency of existing contract	Cashflow Shortages	Impact of Parallel Contracts
Main Propulsion	1	-0.003	0.008	-0.013	0.035	0.008	0.267	-0.198	0.011	-0.391	-0.015	-0.179	0.256	-0.019	-0.164
Auxiliaries		1	0.591	0.253	0.335	-0.254	0.317	0.117	-0.196	0.133	0.317	0.412	0.22	-0.042	-0.244
Maintenance Policy			1	-0.003	0.207	-0.089	-0.103	0.167	0.081	0.506	0.202	0.158	0.009	0.06	0.209
Attitude to importance of maintenance				1	0.385	-0.04	0.183	0.418	-0.285	-0.023	0.545	0.338	0.505	-0.25	-0.24
Maintenance Budget Allocation					1	-0.213	**0.634**	0.534	-0.173	0.567	0.58	0.338	0.202	-0.263	-0.228
Corrective Maintenance						1	-0.099	0.309	0.33	0.039	-0.121	-0.014	-0.078	0.22	**0.680**
Scheduling Issues							1	0.322	-0.315	0.173	0.507	0.447	0.086	-0.052	-0.337
Availability of Facilities								1	-0.025	0.552	0.463	0.515	0.132	-0.087	0.219
Spares Availability									1	0.176	-0.229	0.086	-0.07	0.258	0.441
Knowledge Manag										1	0.269	0.381	-0.053	0.065	0.303
Availability of OEM Expert Support											1	0.48	0.034	-0.048	-0.232
Availability of Local vendor support												1	0.339	0.237	0.021
Complexity and efficiency of existing contract													1	-0.314	-0.244
Cashflow Shortages														1	0.287
Impact of Parallel Contracts															1

Notes: Statistically significant values for selected p value at 0.05, following Cohen and Manion (1994) guidelines are the following:

a. highest correlation of WOS between “impact of parallel contracts” and WOS “corrective maintenance” at 0.680 with a good prediction;

b. second highest correlation of WOS between “maintenance budget allocation” and WOS “scheduling issues” at 0.634 with a useful for limited prediction.

From Table 4.22 two correlations should be closer scrutinized. The first observation value is 0.680 for WOS "impact of parallel contracts" cross-tabulated to WOS "corrective maintenance" falls in the "good prediction" category as displayed in Table 4.16 based on Cohen and Manion's linear coefficient interpretation. The second highest observation value falling value observed is 0.634 for WOS "maintenance budget allocation" cross-tabulated to WOS "scheduling issues". This observation falls in the useful for limited prediction and was depicted by the researcher for being closest to "good prediction" interval.

Following the selection of these relationship the WOS for the relevant DIFs were analysed with the help of scatterplot graphs and a linear regression line to indicate the relationship. Figure 4.21 showcases the relationship between WOS for "corrective maintenance" and the WOS for "impact of parallel contracts". If the corrective maintenance WOS increases by 1, the impact of parallel contracts, WOS is increased by 0.2588. The p value at 0.000 is below 0.01 which shows the linear correlation is statistically significant. Whilst the r squared is only 46.2% this is not necessarily an indication of a bad fit.

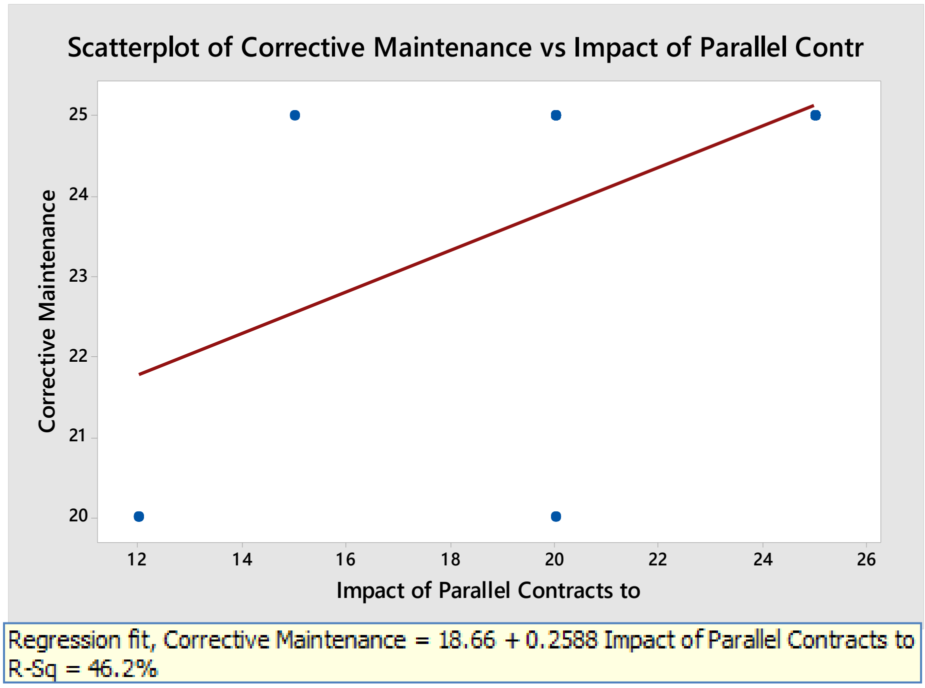


Figure 4.20 Scatterplot "corrective maintenance" vs "impact of parallel contracts"

Figure 4.22 demonstrates the relationship of WOS for “maintenance budget allocation” vs. “scheduling issues”. If the maintenance budget allocation WOS increases by 1, scheduling issues WOS is increased by 0.7135.

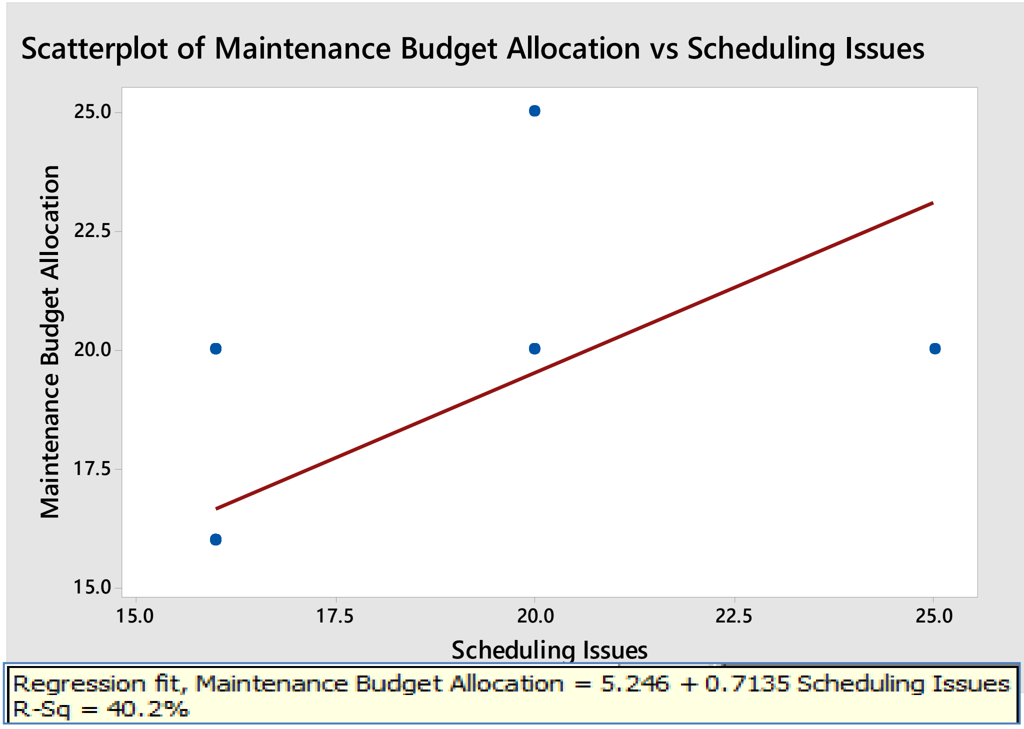


Figure 4.21 Scatterplot “maintenance budget allocation” vs “scheduling issues”

Step 1: Adjustment of linear interdependency between “corrective maintenance” and “impact of parallel contracts”.

i) Corrective maintenance initial M_{SM1} is 0.085, impact of parallel contracts is M_{SM3} is 0.079. The summation of these M_{SM1}+ MS_{M3} is 0.164.

ii) The relationship of 0.2588 as per Figure 4.21 is applied to M_{SM3} resulting in M_{SM3} =0.2588 x M_{SM1}= 0.2588 x 0.085

iii) The adjusted value for M_{SM3} is 0.022

iv) The adjusted value for M_{SM1} is 0.164 – 0.022 = 0.142

Step 2: Adjustment of linear interdependency between “maintenance budget allocation” and “scheduling issues”.

i) Maintenance Budget Allocation initial M_{SM9} is 0.060, Scheduling Issues is M_{SM14} is 0.058. The summation of these M_{SM9}+ MS_{M14} is 0.118.

ii) The relationship of 0.7135 as per Figure 4.22 is applied to M_{SM14} resulting in M_{SM14} 0.7135 x M_{SM9}= 0.7135 x 0.060

iii) The adjusted value for M_{SM9} is 0.075

iv) The adjusted value for M_{SM14} is 0.118 – 0.075 = 0.042.

Based on these findings, the initial severity index (SI) was adjusted as in Equation (4.4) and the rankings changed as a result of the multiplier effect between the singled out severe DIF as shown in Table 5. Whilst the total additive percentage of correlated DIFs does not change, the ranking of DIFs changed due to the interdependencies on each other. The severity index (SI) can now be formulated following in Equation 4.3 as a composite indicator to evaluate severity of the DIF for a particular contract or project.

***SI*=** 0.142 *X* C*orrective maintenance* (4.4)

+ 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*

The adjusted SI has not had a major impact on the ranking, as shown in Table 4.23.

Table 4.23 SI adjusted ranking

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
Cash flow shortages.	4	3	0.078	0.078
Knowledge management.	5	5	0.070	0.070
Equipment and systems – Main propulsion.	6	6	0.069	0.069
Maintenance policy and priority.	7	7	0.067	0.067
Availability of OEM expert support.	8	8	0.061	0.061
Maintenance budget allocation.	9	4	0.060	0.075
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	14	0.058	0.042
Equipment and systems – Auxiliaries	15	13	0.056	0.056
			1.000	1.000

The result showing corrective maintenance (CM) is ranked highest even after adjusted ranking is consistent with the findings by Marais *et al.* (2013) that 80% of maintenance performed on Arleigh Burke Class destroyers have been CM. The author also claimed that large portion of CM is normally found on various class of naval ships.

The SI formula application is best demonstrated via a short illustration using example figures as presented later in Section 4.9.3. It must be noted that since the downtime was calculated in full days, the individual importance weighting is only differentiated when there are above 30 days onwards of downtime as all coefficients must be rounded to a minimum of 1 day.

4.6.1 A suggested Mechanism for Improving Availability through Change in Contract Clauses

Based on the researchers' experience, during the naval ship ISS maintenance contract preparation and negotiation stage, neither the RMN nor the subcontractor are 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 had been no betterment 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 1) "not relevant" as (NR), 2) "relevant with editions required to clauses" as (1) and 3) "relevant but no editions required" as (0).

An example is Clause 1: Definitions of Terms of the PV ISS contract. 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 GOM. 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 researcher has 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 4.23 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 4.22 Illustration of impacted clauses based on availability-oriented approach

The proposed mechanism would require 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 researcher 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 4.24.

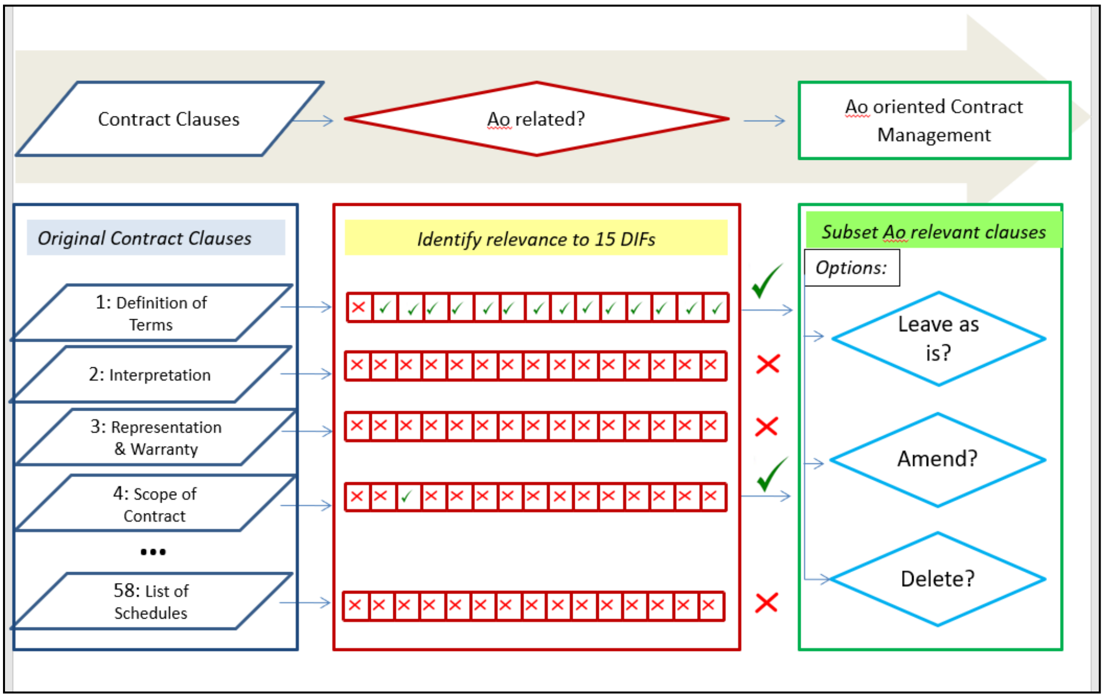


Figure 4.23 Contract clause flow mechanism

4.7 Development of an Availability-oriented Model

This section contains the development of an availability-oriented model. The contract management cycle and the contract management control and monitoring system (ConCaMS) is described in detail in the following subsections. The model development and the research in general has been made contemporary with the necessary diversity with the involvement and valuable feedback from academicians and industrial experts as per Table 4.24.

Table 4.24 Discussions, presentations, brainstorming, paper development involving various organizations leading to model development

S/No	Conference / Journal	Organization	Activity & Research Objectives (RO)	Status	Paper Title
Presentations and discussions at International Conferences organized by:					
1	AIMC 2017, May 2017	Universiti Teknologi Malaysia	Presentation and discussion on RO1	Proceedings published. Published in IJET journal	Measuring severity of downtime influence factors to naval ship operational availability – A Delphi study.
2	ICSESS 2017, May 2017	Universiti Teknologi Malaysia	Presentation and discussion on RO1	Proceedings published. Published in ARPN journal.	Severity of downtime influence factors impacting naval ship operational availability – a five stage Delphi consensus procedure with snowballing technique.
3	ICSESS 2017, May 2017	Universiti Teknologi Malaysia	Presentation and discussion on RO1	Proceedings published.	Identification of downtime influence factors to naval ship operational availability – for sustainment of naval force.
4	ICE-SEAM, Aug 2017	Universiti Teknologi Malaysia Melaka	Presentation and discussion on RO2	Proceedings published. Paper accepted for JAMT journal.	Impact of severe downtime influence factors on operational availability of naval ships – from the contract and project management perspectives.
5	ICCSCE 2017 (IEEE), Nov 2017	Universiti Teknologi Mara	Presentation and discussion on RO3	Proceedings published. Published in IEEExplore	Development of a downtime influence factor severity index for improvement of naval ship availability – a simple approach for the Malaysian patrol vessel in-service support contract.
6	ICCSCE 2017 (IEEE), Nov 2017	Universiti Teknologi Mara	Presentation and discussion on RO1	Proceedings published. Published in IEEExplore	A Delphi approach to identifying the severity of downtime influence factors impacting naval ship operational availability – does the panel demographic impact expert opinion?
7	ISOSH 2018, Jul 2018	Universiti Tun Hussein Onn Malaysia	Discussion on model validation process	Paper published. IJIE journal.	Contract Management Control and Monitoring System for the Royal Malaysian Navy – post survey validation via top management experts.
Journals, co-authoring of papers, discussions, editing of papers and research collaboration:					
8	Defence S&T Technical Bulletin	Science Technology Research Institute for Defence (STRIDE)	Discussions and co-author of papers – RO1 to O4	Paper published.	Availability-oriented contract management approach: a simplified view to a complex naval issue.
9			Discussions RO1 to RO4	Paper published.	Demystifying ship operational availability – an innovative approach for management of in-service support contracts
10	J. of EngScience and Technology	Taylor's University (JESTEC)	Discussions RO1 to RO4	Paper published.	Demystifying Ship Operational Availability – an alternative approach for the maintenance of naval vessels.

4.7.1 **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 4.7 previously. The DIFs would be the factors that influence the downtime, whereby those that have a negatively high impact especially over a prolonged period are considered severe DIFs. At the end of the 3-year PV ISS contract period, the targeted availability is compared with the actual availability of the vessels. If there is any shortfall, an immediate study shall be conducted on the range of human and equipment-related DIFs discovered from this research, 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 researcher for this purpose following discussions with the experts as described in Figure 4.25.

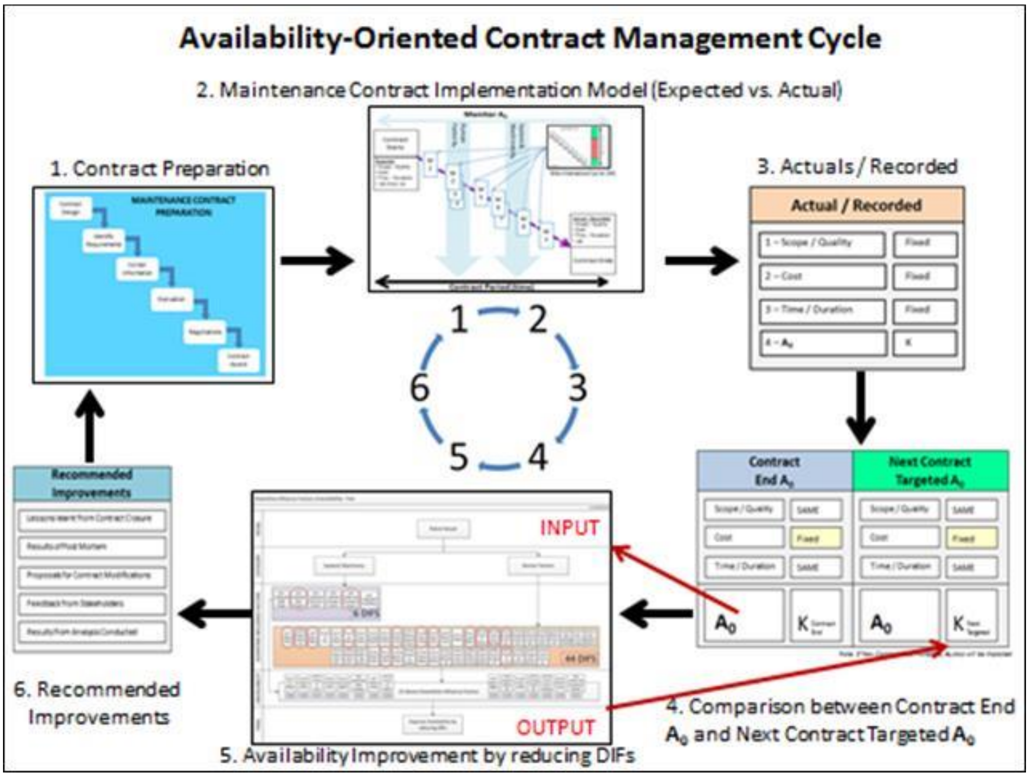
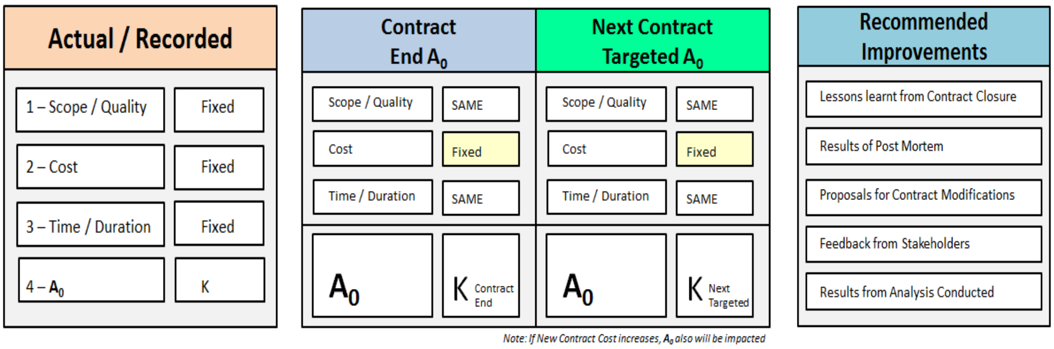


Figure 4.24 Availability-oriented contract management cycle

In fact, the comparison between the targeted availability and actual availability could ideally be conducted more frequently so that actions could be taken by the contract manager much earlier than completion of the contract period. The key monitoring criteria for the availability-oriented contract management cycle is reflected in Figure 4.26 and the steps to be followed are described in Steps 1 to 6 in Figure 4.25.



(a) (b) (c)

Figure 4.25 Key monitoring criteria: (a) Actual vs recorded (b) Comparison of contract-end Ao vs targeted Ao (c) Recommended improvements

On this phenomena Van Offenbeck and Vos (2015) explained that project leaders face issues on how to prioritize within the complexity of issues faced during the project lifecycle, and further explained that project managers will often form an impression and act upon the 'noise' that emerges during a project. Naturally, priority would be based on the "the squeaky wheel gets the grease". On the other hand, many of the stakeholders agreed that an in-depth research as triggered by the researcher is necessary before a concerted effort could be placed in improving the implementation of the PV ISS contract in the future, as they are currently blind to the root causes as well as the recommended solutions based on priority. This has been the motivation and driving factor for the researcher to develop a systematic approach towards managing these real-life and legacy issues.

4.7.2 The Contract Management Control and Monitoring System

The step by step approach in the contract management control and monitoring system (ConCaMS) development spiral with associated objectives as reflected earlier in Figure 4.8 would provide all stakeholders with a clearer view of the 13 Steps availability-oriented contract management approach taken for the purpose of achieving the target of improving ship operational availability. This included the development of conceptual models, determination of DIFs, ranking of DIFs using risk analysis methodology, analysis 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. An availability-oriented contract management framework 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 ConCaMS. 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. The ConCaMS model shown in Figure 4.27 displays the contract timeline in days, the actual operational availability versus the target availability. An illustration has been provided of an actual operational availability of 70% compared to a target availability of 93%. The tachometer displays the current status for fast visualisation of the actual availability. Downtime and available days are displayed for reference.

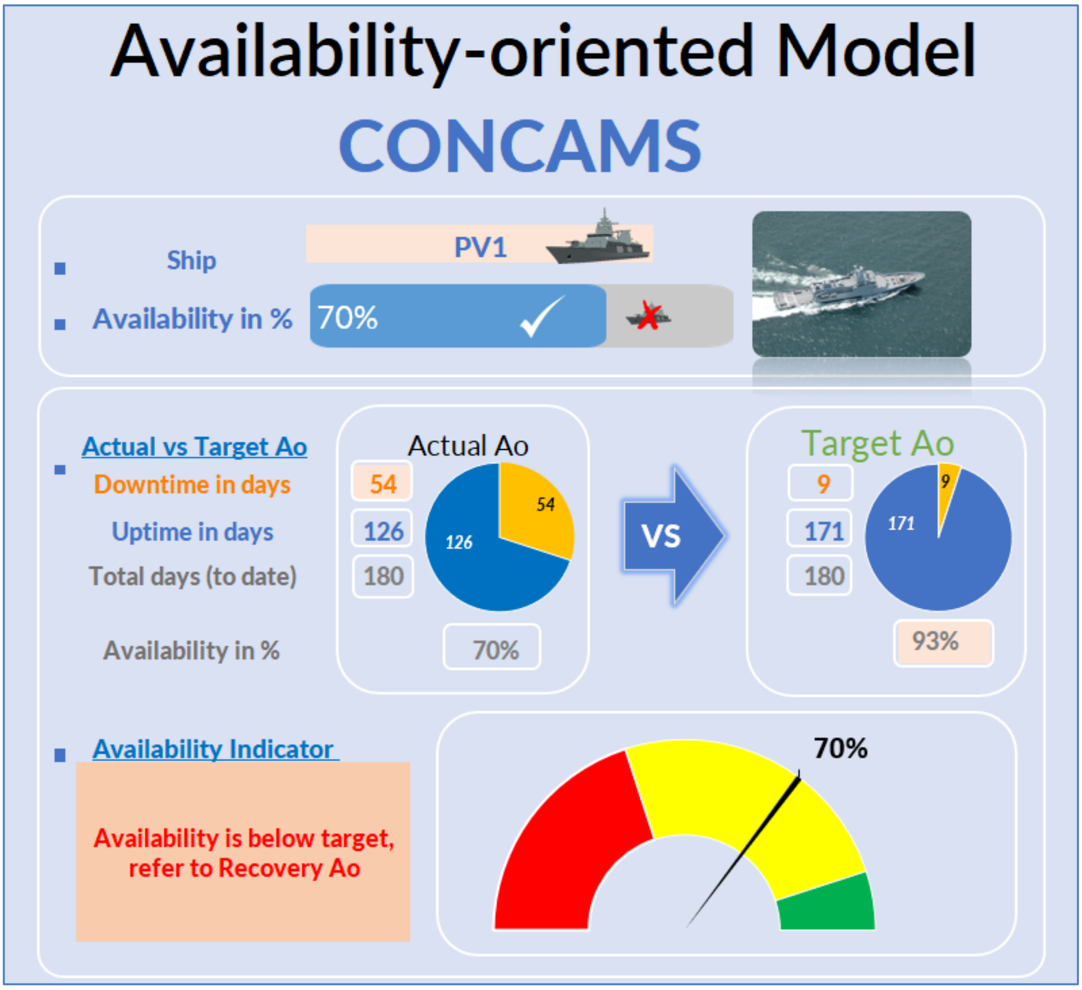


Figure 4.26 Availability-oriented contract management control and monitoring system (ConCaMS) model output

Figure 4.28 provides the second output of the ConCaMS model. The user is provided details on the downtime due to severe DIFs and the causes of these downtime. This is displayed in a tabular and graphical manner to guide users on areas to focus their improvement efforts. The downtime days are broken down according to the categories of severe DIFs. The recovery operational availability is displayed to guide users on the maximum downtime days that can be afforded to be lost if the targeted availability is to be adhered to for the balance of the contract period. Please refer to Appendix E for a brief user guide of ConCaMS and Appendix F for testimonials of asset management software companies regarding ConCaMS commercial development.

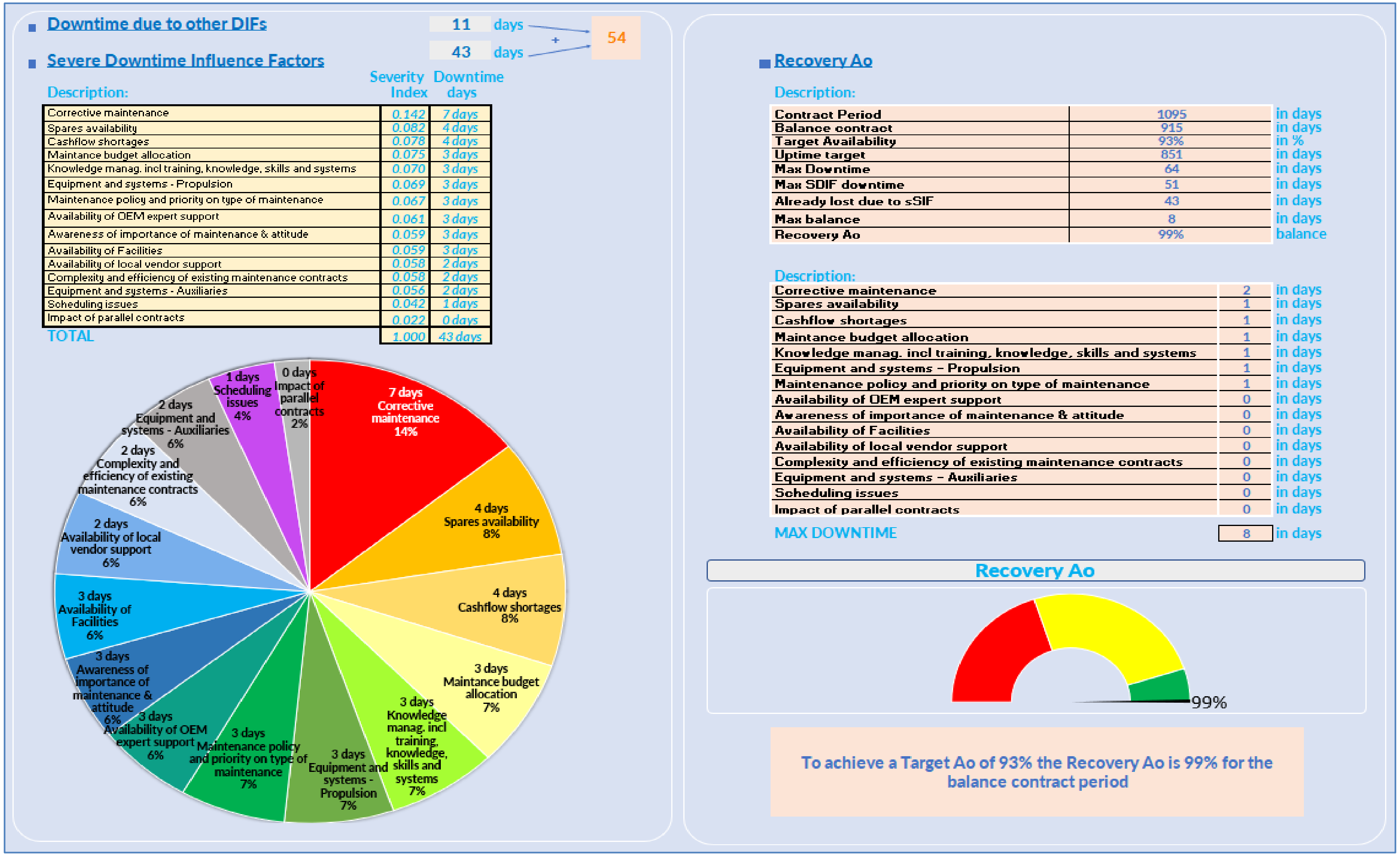


Figure 4.27 Dashboard input and output screen illustrations

For the benefits of future research, a template of an availability-oriented contract management model has been developed by the researcher. The dashboard was developed with feedback from the experts and confirmed by top management of the RMN planning department 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 researcher 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. For the recovery, an example of possible list of actions to be focussed on are as follows:

i. Spares issue: Critical spares shall be procured ahead of time and kept in stock at a prescribed stock level, and not only wait for new orders only to proceed with procurement.
ii. Awareness: A continuous rapidly scheduled awareness discussions and briefings to be conducted at all levels.
iii. Local vendor: Continues training by the OEMs to be made mandatory to be attended by local vendors with extended validity certificates issued every year.
iv. Facilities: A weekly inspection of the facilities to be conducted to ensure available and in good working order.

The example list could be improved into an official list of action plan in future research. An illustration of the dashboard input and output screens are as per Figure 4.29.

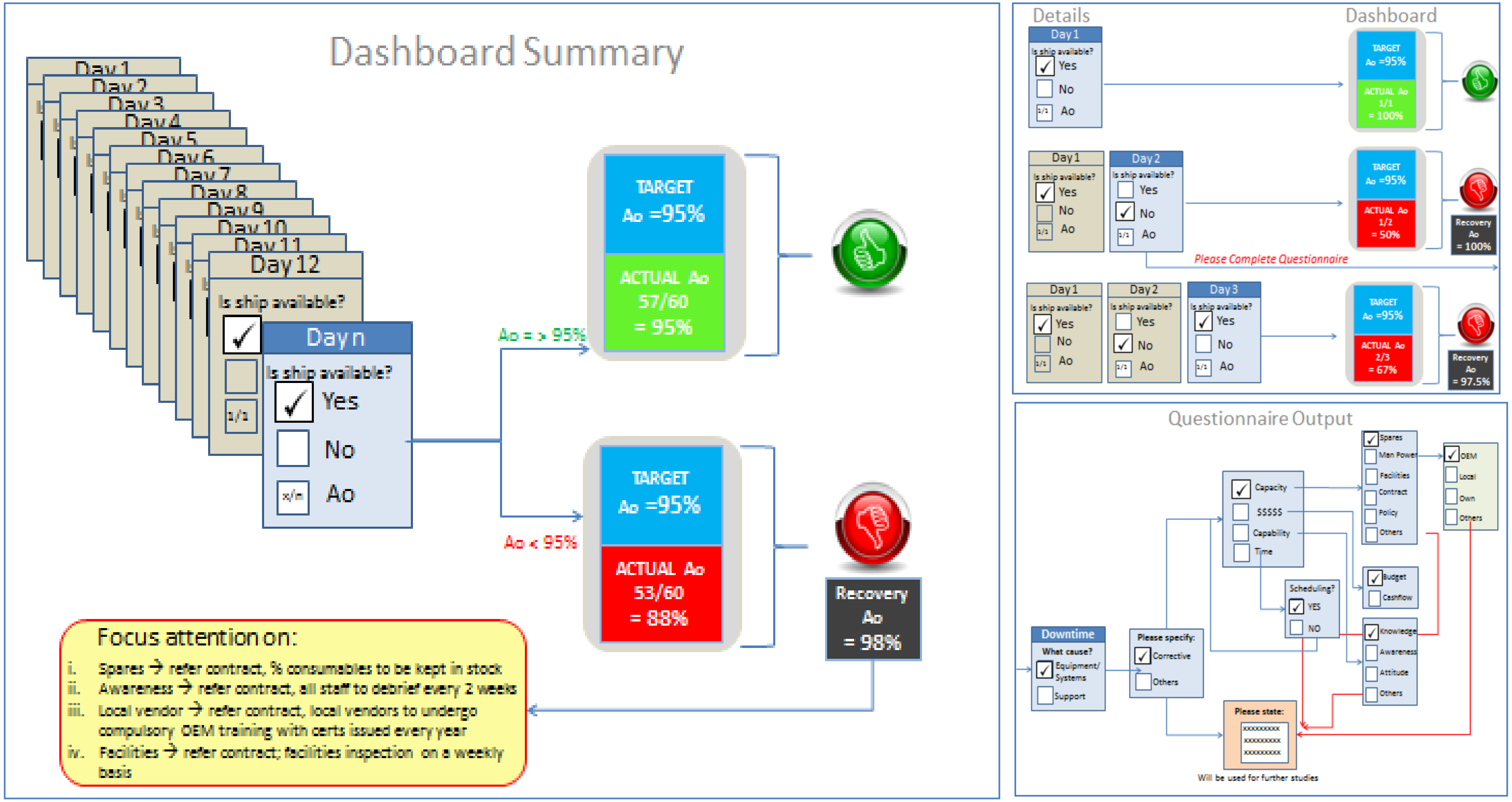


Figure 4.28 Dashboard input and output screen illustrations

It is important to point out that even good models would have some shortcomings. For the ConCaMS model, since the calculations are conducted in days, the number of days for improvement and calculation on days of recovery would only be easily understood when the model calculates after running for a reasonable amount of time, say at least 6 months. This is acceptable since the contract period for ISS contracts would be in years. Similarly, recording of DIFs would need to be converted to days instead of hours, to meet the input requirements of the model. This matches to the calculated "Recovery Availability", which will also be in days.

4.8 Evaluation and Validation of the model

In a final step an evaluation and verification process of the proposed model (ConCaMS) took place by means of an independent set of industrial leaders, and RMN and Malaysian Maritime Enforcement Agency (MMEA) top management. The results obtained via the post-survey validation questionnaire are summarized in Table 4.25.

Table 4.25 Post-survey validation results

S/N	Question	Yes	No
1	The real data extracts taken from the ISS contract implementation used to populate the model are a fair representation of the actual patrol vessel situation up to now.	Answer Count:5	Answer Count:0
2	Prior to the publication of the papers described in prelude above, there were no guideline on how to improve availability throughout the in-service support (ISS) contract period.	Answer Count:5	Answer Count:0
3	Up to now, the system used to monitor ship maintenance activities for ISS contract only reports defects and unable to pinpoint to problems areas or severe factors that impact most on ship availability.	Answer Count:5	Answer Count:0
4	Up to now, the system used to monitor ship maintenance activities for ISS contract is unable to assist the stakeholders to project or predict future potential problems impacting negatively on ship availability.	Answer Count:5	Answer Count:0
5	Up to now, the present attempts by stakeholders to improve availability are by random effort or equivalent effort only as there has not been any guidelines.	Answer Count:5	Answer Count:0
6	Due to existing inability to focus on defined factors that impact availability negatively, there is an unclear area on accountability within the navy between executive branch, technical branch and logistics branch, and between the navy and external parties including ISS contractor, vendors and OEMs.	Answer Count:3 Note [1]	Answer Count:0

S/N	Question	Yes	No
7	Based on the demonstration of the model and the achieved results, are you convinced that concentrating efforts on the identified severe factors is highly likely to improve the availability?	Answer Count:5	Answer Count:0
8	Based on the demonstration of the model and the achieved results, are you convinced that adhering to the 'availability-oriented contract management model' will improve availability of the naval ships?	Answer Count:5	Answer Count:0
9	Based on the demonstration of the model, would the model assist Contract managers in managing their contracts better and assist Policymakers, maintainers, logisticians, and other stakeholders to contribute better in improving ship availability?	Answer Count:5	Answer Count:0
10	If the availability of the fleet of naval vessels is successfully improved, would this impact positively towards the navy's overall preparedness and readiness in multiple dimensions such as improved capability, greater flexibility in assigning ship tasks, improved efficiency, saved cost in unnecessarily having to purchase new vessels, less work stress onboard current high-availability vessels, etc.	Answer Count:3 Note [2]	Answer Count:0 .

Note[1]: 2 Respondents replied that they had insufficient insight to answer this question.

Note[2]: 2 Respondents replied that they had insufficient insight to answer this question.

The answers of the experts are graphically displayed in Figure 4.30. The level of concordance was measured in instances of agreement of replies. There was 100% agreement on 8 out of 10 questions, for 2 out of 10 questions 2 respondents specified that whilst they were positively inclined to reply "YES" they had insufficient insight into the day to day operations of the RMN to be able to answer the questions. These answers were recorded as "Not Applicable" (N/A). As the level of concordance was 92% (46 over 50 questions) the questionnaire stage of evaluation and validation could be successfully concluded.

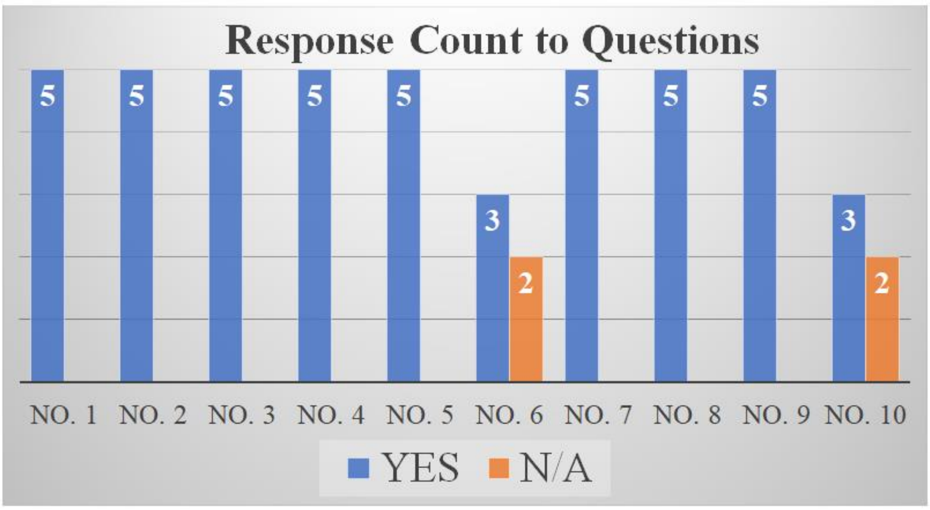


Figure 4.29 Response count to questions 1 to 10.

The selected shipyard, MMEA and RMN as ISS industry leaders were able to independently validate the 7-Stage Mixed Method Delphi Results. It is worth pointing out that all five of the validation experts provided positive and complimentary remarks of the model and its associated advantages, in addition implementation concerns were also raised. The key highlights of their remarks are analysed as follows:

i) This study is a new approach in determining operational availability (Ao), which is currently based on conventional methods.
ii) The proposed methodology is able to determine the factors that contribute to either high or low Ao in a simple manner.
iii) The proposed model with 15 factors would assist the RMN in identifying the key performance indicators and hence assist in the measurement of the overall preparedness reporting.
iv) The RMN could use the ConCaMS model to identify the root causes affecting the readiness of the fleet with an objective methodology that is not easily manipulated.
v) The model can be used to ensure the Navy moves away from procuring spares "just in case" to "just in time" saving money.
vi) The model can be used to tackle ineffective contract management as it provides clear visibility of the critical factors contributing to realising the Navy's efficiency savings initiative to save much needed funds and scarce resources.
vii) The method can be implemented to MMEA for the new projects, in particular identify fleet readiness and assist to improve new ISS clauses. It will assist contract managers in ensuring fleet availability is high as expected.
viii) The approach requires a lot of commitment and effort on data entry, nevertheless there would not be any excuse to monitor closely on a daily basis.
ix) The approach requires full commitment from the top management, however, how to resolve the identified problem has not been explored. This is an opportunity for further research.
x) The model presented consist of equipment and human factor, where human factor is a bit tricky and intangible, in some aspect. Thus, methodology to

quantify human factor that contributed to low or high Ao need to be identified.

The detailed comments by the validation panel is enclosed in Appendix C. It is also significant to point out that all 3 RMN and MMEA top management experts with naval experience were in 100% agreement for the below questions of the follow-up questionnaire as per Appendix C:

i) Serial No.6: Due to existing inability to focus on defined factors that impact availability negatively, there is an unclear area on accountability within the Navy between Executive branch, Technical branch and Logistics branch, and between the RMN and external parties including ISS contractor, vendors and OEMs.
ii) Serial No.10: If the availability of the fleet of naval vessels is successfully improved, would this impact positively towards the Navy's overall preparedness and readiness in multiple dimensions such as improved capability, greater flexibility in assigning ship tasks, improved efficiency, saved cost in unnecessarily having to purchase new vessels, less work stress onboard current high-availability vessels, etc.

This further indicates that the RMN as the end-customer of the RMN ISS contract believe in the advantages of the proposed model. It is also worth pointing out that all five of the validation experts provided positive and complimentary remarks of the model and its associated advantages, in addition implementation concerns were also raised. Refer Appendix C.

4.9 Discussion on meeting Research Objectives

In this chapter, a summary of main findings according to the research objectives is discussed. Section 4.8.1 discusses the findings related to the first research objective (RO1) that is to determine the DIFs to naval ship availability. Subsequently, Section 4.8.2 discusses the development of the DIF's impact matrix on contract and project management elements of the “iron triangle of cost, time, quality and scope”, related to the second research objective (RO2). The subsequent Section 4.8.3 explains (RO3) which is the development of the severity index (SI) as the mathematical algorithm to the model. Consequently, (RO4) is described in Section 4.8.4 on developing a “ship availability-oriented model” for ISS contract. Finally, Section 4.8.5 discusses the results of the evaluation and validation of the developed model.

4.9.1 Determination of the Downtime Influence Factors (DIFs) to Naval Ship Availability (RO1)

This section discusses the findings pertaining to the first research objective (RO1), which is to determine the downtime influence factors (DIFs) to naval ship availability. Specifically, it seeks to provide justifications to the corresponding research questions:

RQ1a: What are the human and equipment related downtime influence factors (DIFs) affecting ship availability?

The researcher began with an extensive literature review as described in Chapter 2 in identifying key variables or factors impacting availability involving naval ships and also from other engineering disciplines. The methodology in determining the research variables have been described in Section 3.5. This was followed by a FGD as described in Section 4.4.1 that managed to confirm, screen and pool from the wide range of factors that were harvested from the literature review. The resulting 50 variables called DIFs involving human and equipment has been successfully pooled and confirmed by the 30 expert members, as described in Table 4.4 of Section 4.4.1. Therefore, the RQ1a has been successfully answered and RO1 has been partially achieved.

RQ1b: How can the DIFs affecting ship availability be ranked and prioritized?

From Section 4.4.2, consensus among the expert group members were achieved and a list of 50 DIFs impacting naval ship availability has been determined. Subsequently, based on risk analysis methodology detailed in Chapter 3, a DIF with a total value of 16 and above were defined as "severe" and considered as important. Table 4.5 of Chapter 4 displayed the severe DIFs ranked from most severe (rank 1) to least severe (rank 15) obtained from Delphi round 1. From Section 4.4.3, all the 30 experts confirmed the list of 15 DIFs as being severe and provided their views of the severity of each DIF. The summarized results are displayed in Table 4.6 of Chapter 4. The coefficient of variation (CV) values in Delphi round 1 (CVR1) and Delphi round 2 (CVR2) were calculated for each severe DIFs as presented in Table 4.7 of Chapter 4.

The agreement level of the experts had improved and the results presented in Table 4.8 of Chapter 4. From Section 4.4.4 of the subsequent Delphi stage, the ratings of the 15 most severe DIFs were considered by 5 top management experts as shown in Table 4.15 of Chapter 4. The experts agreed on 12 out of 15 measures (80% agreement, 95% confidence interval, 51.91, 95.67), Kendall's coefficient of concordance is considered high at 0.908291 with Chi Square of 63.5804, 14 degrees of freedom and $p < 0.001$. From Section 4.4.5, further rigor was executed with another round of survey for the top management experts. In this Delphi Round 4, the top management experts were asked to re-assess their ratings in the light of the consolidated results obtained from Delphi Round 3. All experts did not make any adjustments to their assessments and the level of concordance remains as per before. This is the stopping rule for Delphi as it could be assumed that stability for each severe DIFs was reached and no further rounds were required. The Kendall's coefficient of concordance confirmed that a high concurrence between experts had been reached. The view of the final ranking of the 15 severe DIFs have been achieved, following several Delphi rounds with the 35 panellists. The result is reflected in Figure 4.21 of Chapter 4. The 5-stage sequential modified Delphi approach including snowballing technique has provided the necessary verification, validity, accuracy and rigorousness in studying the factors affecting availability, holistically. Therefore, the RQ1b has been successfully answered and RO1 has been fully met.

The researcher did not proceed with further studies on the insurmountable tasks of proposing solutions for severe DIFs determined through this RO1, instead it is sufficient for the researcher to conduct an exhaustive literature review over 700 literatures of the topics and summarized in Chapter 2. The review of individual DIFs is beneficial to other researchers in academia as well as maintainers from various industries as it pinpoints all related publications on each subject matter along with some summary of important statements, interesting findings, and some issues as well as proven or recommended solutions. As an example of a common and favourite topic would be on spares, ranked second in the list. One possible solution that is recommended by the researcher based on his experience is to standardize or commonalize equipment, therefore the spares would be common too. Sufficient amount of stocks could be kept by the RMN or by suppliers as the probability of purchase would be much higher than randomized stocks.

This is consistent with Reiff (2016) that standardising within and between ship types to achieve a purchase advantage, increase in house knowledge and improve service and quality. Two other options have been suggested by the researcher, first is by specifying that a minimum stock as per the suggested preventive maintenance plan must be purchased ahead of time in order to avoid spare parts unavailability, albeit many researchers and maintainers would argue that this will result in additional costs besides the possible risk of the spares not being utilized at all. The other option to improve downtime days on spares is to include a mechanism or additional contract clause in the PV ISS contract to link items classified as beyond economical repair (BER) to automatically be notified to the government. This will ensure no wastage of time as by definition, the BER items would automatically require replacement anyway. There exist more aggressive options such as described by (Koehn et al, 2004) whereby operational availability is increased by replacing all mission-critical spares simultaneously at scheduled intervals or just before a mission, but this has proven to be very costly as the result would be replacement of parts prematurely and disposal before the end of their service life.

4.9.2 Development of the DIF's Impact Matrix on Contract and Project Management Elements of the "iron triangle of cost, time, quality and scope" (RO2)

This section discusses the findings pertaining to the second research objective (RO2), which is the development of a DIFs Impact Matrix on contract and project management elements of the "iron triangle". Specifically, it seeks to provide justifications to the corresponding research questions:

RQ2a: How do the DIFs impact the contract and project management elements of the "iron triangle of cost, time, quality and scope"?

From Section 4.5, the relationship between DIFs to the contract and project management elements of the "iron triangle" has been illustrated in Figure 4.20 of Section 4.5.1. The impact to the elements of the "iron triangle in terms of cost, time, scope and quality" has been reflected in Table 4.18 of Section 4.5.1. Hence RQ2a has been successfully answered and RO2 has been partially me.

RQ2b: Is it possible to improve ship operational availability by improving DIFs?

From the results reflected in Table 4.18 of Section 4.5, several conclusions could be derived based on effect interpretation as highlighted in Table 23, one of which is that the improvement of severe DIFs 3, 4, 7, 10, 13 and 14 would not have a negative "cost" or budget impact. These DIFs could be reduced therefore improving ship operational availability even without additional allocation of additional budget. Hence RQ2b has been successfully answered and RO2 has been fully achieved.

RQ2c: What areas can be improved when faced with budget constraints, if RQ2b is positive?

Similar to the answer to RQ2b above, from the results reflected in Table 4.18 of Section 4.5, the improvement of the following severe DIFs would not have a negative "cost" or budget impact:

i) SDIF 3 - Impact of parallel contracts
ii) SDIF 4 - Cashflow shortages
iii) SDIF 7 - Maintenance policy and priority
iv) SDIF 10 - Awareness of importance of maintenance and attitude
v) SDIF 13 - Complexity and efficiency of existing maintenance contract
vi) SDIF 14 - Scheduling issues

This finding is also an important contribution since budget constraints are a major limiting factor in introducing changes to existing contracts within the RMN. Hence RQ2c has been successfully answered and RO2 has been completely achieved.

4.9.3 Development of the Severity Index as the Mathematical Algorithm to the Model (RO3)

This section discusses the findings pertaining to the fourth research objective (RO3), which is the development of a severity index as the mathematical algorithm to the model.

RQ3: Is it possible to develop an index based on ranking of the DIFs to indicate the severity of the DIFs?

From the results explained in Section 4.6, the SI formula has been produced and reflected in. Therefore, RQ3 has been successfully answered and RO3 has been achieved.

For better understanding, the SI formula application is best demonstrated via a short illustration using example figures. It must be noted that since the downtime was calculated in full days, the individual importance weighting is only differentiated when there are above 30 days onwards of downtime as all coefficients must be rounded to a minimum of 1 day. First the targeted ship operational availability is required. Assuming that our ship operational availability target stands at 90% this would be translated to 329 full days. The next step is to establish the actual ship operational availability. We assume in our example that the measured actual availability stands at 71% translating to 259 days full days. Therefore, the downtime in days is 70 days. For the purposes of simplification, the idea behind this is to locate the most troublesome failures and concentrate resources on them (Wang *et al.*, 2010), the researcher follows the Pareto principle and assume that 80% of downtime is due to the 15 severe DIFs, therefore of 70 days of downtime, 56 days are assumed to be due to the severe DIFs. The maximum improvement achievable is 56 days following the proposed formula, efforts would be made to reduce the DIFs as in Figure 4.31.

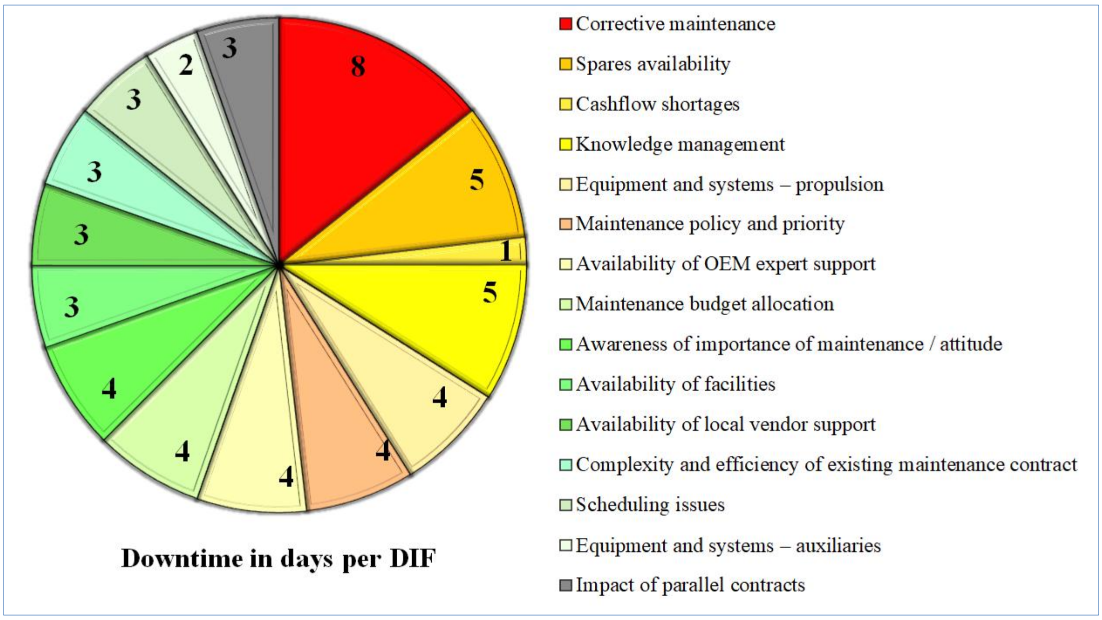


Figure 4.30 Distribution of DIFs and corresponding days for sample

Even though all of the DIFs are categorized as severe DIFs, it can be seen that priority should be given to corrective maintenance with a total of 8 days downtime to improve, followed by spares with 5 days downtime to improve and the corresponding DIFs with the descending priority as described in Figure 4.31.

4.9.4 Development of the Ship Availability-Oriented Model (RO4)

This section discusses the findings pertaining to the fourth research objective (RO4), which is the development of a “ship availability-oriented model” for ISS contract. Specifically, it seeks to provide justifications to the corresponding research questions:

RQ4: Is it possible to develop a new model to assist stakeholders to better understand the availability concept and assist contract managers to monitor and control the contract better?

As Signoret (2010) correctly pointed out, how many methods working well on paper prove to be not tractable for systems comprising more than three or four components? Academic works and tool developers often forgot this problem but when performing a production availability study, the results are needed at once (i.e. in some minutes not in days). Taking a cue from this, the developed “ship availability-oriented model” has been successfully achieved. The main reason and added value of the model is due to its simplicity and dual-purpose as a decision-making as well as a “close to real time” control and monitoring tool for all levels of stakeholders. Even though the tool is different as the concept of which it was designed for is different than the model by VanMulligen (2015), the researcher believes that the foundation remains the same. Similar to the lifecycle cost (LCC) model by Van Mulligen (2015), the ConCaMS is able to measure the performance (availability) of the system, relative to the targeted performance (availability). Furthermore, the ConCaMS has added advantages such as calculating the recovery availability as a feedback mechanism for contract managers, and policymakers.

With regard to the newly developed availability-oriented model, the ability for all stakeholders to understand their individual contribution towards improving ship availability, the capability of the model to pinpoint the exact areas as well as quantify the severity of the various factors affecting downtime, would already be cherished and appreciated by many. This capability will undoubtedly reduce interdepartmental accusations and arguments on accountability. This model would be useful to manage the inter-organisational communication challenges faced by the stakeholders involved with the PV ISS contract in Malaysia, and quite possibly benefit other organizations globally. This has also been agreed and verified in Section 4.8 by the experts, therefore RQ4 has been successfully answered and RO4 has been achieved.

On the issue whether the developed model is the best model for the job, the researcher quotes the statement by Dekker (1996) that there is no general model covering all possible cases, and despite the multitude of models, there is little knowledge on which models are suited for which practical problems nor which type of data involving maintenance are really driving the problem. Assets requiring maintenance involves a variety of actions on all kind of technical systems deteriorating in various ways. (Dekker, 1996). On usage of commercially available tools, the researcher quotes Erkoyuncu et al, (2013) that practitioners in both supplier and customer have preference for commercial tools as it simplifies verification and validation especially on costing. Erkoyuncu continued to explain that unfortunately commercial tools are not always able to cope with specific circumstances. In this case, special-to-purpose models in Microsoft excel (or similar) are best suited, and so is the argument by the researcher on the suitability of the newly developed excel-based availability-oriented model called ConCaMS from this research.

4.9.5 **Evaluation and Validation of the Developed Model**

This section discusses the findings pertaining to evaluation and validation of the developed model. The methodology adapted for this stage has been consistent with Ramasamy (2017) who also used post-survey expert validation to validate her final framework in her thesis. Justifications to the corresponding research questions are as follows:

(i) How can the developed model assist the various organizations in their ultimate effort for improving the ship availability?

The panel of experts in the post-survey expert validation have all agreed that the developed model would assist the various organisations in their ultimate effort in improving ship availability. They have concurred with the benefits elaborated in RQ4 in Section 4.9.4 and believe that it would reduce the “blaming game” between organizations involved in ISS as the pinpointed areas of responsibility and stakeholder contribution has been made more transparent towards improving the ship availability. The knowledge gained from the model and associated formula based on the DIF Severity Index would also be an added advantage to other organizations facing similar issues worldwide.

Furthermore, if a certain ship or fleet targeted availability figure cannot be met, despite all efforts to improve availability and the availability target is consistently missed, the model will assist the government to consider purchasing new vessels in order to meet operational patrolling requirements in the wide security region of Malaysian waters.

(ii) How can the model assist contract managers in managing their contracts better?

Compared to traditional ship availability approaches that require an in depth understanding of systems and equipment to calculate the relevant downtime, this research provides contract managers with a fairly simplified decision-making support tool that can guide them in the execution of the ISS contract with the view to improving ship availability in the specific ISS contract period. The researcher also believes that project managers and contract managers globally shall be able to manage their contracts better with these identifications of constraints and interdependencies, which they will endeavour to implement according to contract management better practices (Australian National Audit Office, 2012). The model allows contract managers who in practice may not have an engineering background, to proactively structure ISS contracts that will result in improved ship availability.

The pioneering concept of recovery availability is another breakthrough found by the panel of experts to provide immediate feedback for contract managers to try overcome the situation. Unlike most methods and tool that suggest implementation at the start of new developments, such as new design or acquisition phase (Goosens, 2015), this tool is able to be implemented at any time during the contract and shall inevitably assist in the development of the new contract. After careful study, all panel of experts in the post-survey expert validation agreed that the contract managers would benefit and able to manage their contract better.

(iii) How can the model assist policymakers, maintainers and logisticians, as well as other stakeholders to contribute better in improving ship availability?

Based on the evaluated and verified findings in Section 4.8, yes the model is confirmed to be beneficial and would assist policymakers, maintainers and logisticians, as well as other stakeholders to contribute better in improving ship availability. This is consistent with remarks by Wang *et al.* (2010) that a complex and long methodology is not likely to find favours with the shipboard personnel, as they are already overburdened by being both operators and maintainers.

The researcher further agrees with Wang *et al* (2010) describing that the ship crew are rarely trained in maintenance management and risk management techniques, especially those that require statistical approach. They are more of a “jack of all traits, but master of none” as opposed to be specialized, particularly mathematical. Therefore, the researcher has simplified the situation and provided a simple tool which has taken consideration of the statistical and risk management approach prior to the development of the model. The situation has been agreed by the panel of experts in the post-survey expert validation.

(iv) How can this model and associated research finding specifically benefit other navies implementing ISS contract, and generally benefit other engineering industries as well?

This research may be the most comprehensive study of on the subject of DIFs consolidation in the naval ship territory, but generally applicable to the other engineering fields as well. The findings of this paper would assist organizations including other navies in prioritizing their efforts in controlling specific downtime factors which greatly impact their organizations. In this newly explored area of study, the acquired DIFs and severe DIFs captured both human and equipment related issues which are commonly faced by all maintenance organizations globally facing continuous inter-related issues in improving their operational availability. Equally important, the researcher through has set a fundamental basis of an availability-oriented contract management framework and model as new knowledge towards improving naval ship operational availability.

In their qualitative research on the ISS Stage for the lifecycle of Royal Navy (RN) vessels, Ford *et al.* (2015) admitted that there are similarities with the railway, power company and airlines. Furthermore, as the original pooling of downtime factors were gathered from various engineering industries including, oil and gas, construction, nuclear, aviation and aerospace, business intelligence, energy and mining, it would be logical that the benefit should be reciprocated as well. Accordingly, the situation has been concurred by the panel of experts in the Post-Survey expert validation.

4.10 **Summary**

The motivation behind this research is to simplify the issue of naval ship operational availability that has been plaguing the RMN as well as many other navies globally. Maximizing the ship's service life is essential (Nguyen, 2017), and the need to balance fiscal reality and a continued need for ready ships is likely to be an ongoing challenge (Button *et. al*, 2015). This is consistent with Deris *et al.* (1999) explaining some important factors that impede achievement of a high rate of availability for the RMN vessels. Furthermore, the researcher supports the idea of Wang *et al.* (2010) and Weibull (2017) proposing the 80/20 Pareto rule in problem solving. The idea behind this is to locate the most troublesome failures and concentrate resources on them. That is the main strategy applied by the researcher in this study, beginning with the pooling stage of the factors at FGD level, subsequently when ranking the factors with a selected cut-off point based on risk analysis and finally applying the Pareto principle, during the calculation of downtime and recovery availability by the developed model.

The challenging journey began when the researcher 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 through the various research objectives above, the researcher 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 steps researched in this thesis. Besides the production of the ConCaMS system, the ConCaMS spiral with the labelled location of the various steps would further assist policymakers and stakeholders of various organisations to develop their respective action-plans in their respectful organizations. This is an added advantage as other organizations could emulate following the steps through the ConCaMS spiral and backtrack when needed.

The mixed-method modified sequential Delphi with snowballing technique applied by the researcher throughout this research has been very rigorous, with multiple stages and snowballing to ensure accuracy and validity of the results. The model has been finally examined and validated through post-survey expert validation, a valid technique in this type of research (Ramasamy, 2017). The independent post-survey validation carried out achieved a level of concordance amongst experts of 92%, with all experts confirming that the proposed availability-oriented contract management model is valid and beneficial to both industry and relevant government agencies. The researcher has successfully achieved the 4 research objectives with the detailed results in Section 4.4.2 to 4.8 and discussion in Section 4.9.1 to 4.9.5, which has proven the successful achievement of the research aim of demystifying the complex naval ship availability issue through the development of a decision-making model in improving naval ship operational availability especially for the ISS contract.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusion and knowledge gained from this research, limitations related to the research and identifies areas for further research. It begins with conclusion of the research by addressing all the formulated research objectives in Section 5.2. While Section 5.3 presents contributions of the research to knowledge and industry, areas of application of the developed availability-oriented contract management model is outlined in Section 5.4. Finally, the limitations of the research and recommendations for future research are presented in Sections 5.5 and 5.6 respectively.

5.2 Conclusions

The conclusions of the research are as follows:

(i) Improving operational availability of naval vessels requires the reduction or eradication of a multitude of equipment and human-related downtime influence factors (DIFs).

(ii) A total of 50 DIFs impacting naval ship operational availability has been determined, of which 15 were ranked to be most severe. The list of 15 severe DIFs that provide greatest negative impact to naval ship operational availability is listed in Table 4.17.

(iii) The list of top five severe DIFs that have the greatest negative impact to naval ship operational availability according to rank are:

Rank 1) Corrective maintenance (SI 0.142),
Rank 2) Spares availability (SI 0.082),
Rank 3) Cash flow shortages (SI 0.078),
Rank 4) Maintenance budget allocation (SI 0.075),
Rank 5) Knowledge management including training and skills (SI 0.070).

(iv) The DIFs relationship to the project and contract management "iron triangle" of cost, time and quality has been determined; and interestingly, ship operational availability could be still be improved even with budget constraints. When facing budget constraints, operational availability could still be improved by focusing on six severe DIFs which consist of Impact to parallel contract, cash flow shortages, scheduling issues, awareness of importance of maintenance and attitude, complexity of existing contracts and maintenance policy and priority.

(v) An availability-oriented severity index (SI) has been developed for implementation on ISS contracts.

(vi) The ship availability-oriented contract management model developed is capable to assist policy makers to make correct judgements, assist contract managers with a handy decision-making support tool to continuously track, manage and control the contract better at almost "real time" with the necessary feedback and recovery information enabling faster decision-making. It will also assist maintainers, storekeepers, trainers and all stakeholders to have a better appreciation of their individual contribution towards improving ship availability figures.

(vii) The comprehensive approach which integrates mixed method and including Focus Group Discussion (FGD) with 7 stages of sequential Delphi, added with snowballing technique and validated with the established post survey validation has ensured the required rigor, accuracy and validity of this complex exploratory research on availability improvement. The research has also been made contemporary with the necessary diversity with the involvement and feedback from UTM, UiTM, UTeM, UTHM, STRIDE and UPNM.

The researcher has successfully achieved the four research objectives which has proven the successful achievement of the research aim of demystifying the complex naval ship availability issue through the development of a decision-making model in improving naval ship operational availability especially for the ISS contract. This research has provided valuable contribution to the body of knowledge towards improving naval ship availability. This exploratory but highly specialized research in naval ship maintenance spanned over six years. Due to the time, resources and financial constraints involved and in order for the results to remain current for the partial fulfilment of the Doctorate in Mechanical Engineering, the researcher has concluded the study. A way for more focused future research has been paved in all of the areas covered in the thesis especially in the following sections 5.3 to 5.6.

5.3 Research Contribution

This research contributes to the field of naval ship maintenance and availability improvement in these two areas: contribution to knowledge and contribution to the industry.

5.3.1 Contribution to Knowledge

Prior to this study, there has been limited literatures pinpointing to the root cause of the various downtime in naval ship maintenance, called downtime influence factors (DIFs). The limited literatures on DIFs are further restricted in the study of a single factor such as obsolescence or spares availability, or two or three factors at most, whilst in reality the DIFs encompasses a wide range of human and equipment related factors that most researchers have not attempted to study.

The researcher has extensively studied and screened though more than 700 literatures of possible factors affecting maintenance from various engineering disciplines during this study and produced a comprehensive literature review concerning human and equipment related factors in Chapter 2 and summarized in Appendix A. The study may be the most comprehensive study of its nature in consolidating the DIFs in the naval ship domain, but also in the maintenance engineering field in general. The DIFs were analysed and consequently top 15 most severe factors towards naval ship availability has been determined using risk assessment matrix. It has been proven that contrary to popular belief, ship operational availability can be improved even with budget constraints. A severity index (SI) was developed to produce the availability-oriented contract management model and presented as ConCaMS. Therefore, the newly developed model is able to guide and assist all relevant stakeholders in managing any ISS contracts globally.

The results from the research provides statistical and empirical evidence on a multitude of equipment and human-related factors that impact ship operational availability. A simple and novel approach has been introduced to improve the availability figures which could be easily understood by the international community at all levels. The step by step approach and simple concepts introduced graphically would enable ease of replication and initiate further studies on the new approach to availability improvement. Researchers on naval ships worldwide would have a holistic understanding of the entire cloud surrounding the complex naval availability issue, dissected to ‘bite-size’ for easy comprehension in order to participate in further research on individual or multiple combination of factors affecting naval ship availability. The methodology applied could be used for other complex exploratory research in military studies and other engineering fields. As a result, more research opportunities with international collaboration would be expected.

5.3.2 **Contribution to the Industry**

The novel contribution to the industry has been the simplification of the complex naval issue concerning naval ship availability. This developed model provides the linkage between human and equipment related factors holistically impacting naval ship availability that has to date been mostly tackled separately by policymakers, maintainers and logisticians as well as researchers who own conflicting goals and objectives. The outcomes of the model, approach, cycle and process benefit every stakeholder.

The overriding advantage is that stakeholders, especially policymakers, are able to achieve tangible improvement with a transparent measurement by focusing improvement efforts with prioritization placed on identified severe DIFs based on the developed decision-making tool. Furthermore, policymakers are able to pinpoint which DIFs to improve when there are budget or cost constraints. Contract managers would have an efficient and handy decision-making support tool to continuously track, manage and control the contract better with the necessary feedback and recovery information enabling faster decision-making. Maintainers, storekeepers, trainers and all other stakeholders would have better appreciation of the tasks at hand with a clearer view of their individual contribution towards improving the navy's availability figures. Resources would therefore be ensured to be put to the best use. Greater accountability could be accorded to the various stakeholders involved in the ISS contract.

The developed model has been proven to be a reliable mechanism or tool to compare contract performance of similar type contracts. Project analysts would have a better systematic system for evaluation of contract or project. The outcome of the research would benefit other engineering fields in general that have continuously attempted to improve the productivity and availability of their assets, but has been traditionally focussing on equipment-related factors only. The approach provides a way out to many organizations that are aiming for high availability of their assets and keen on implementing 'availability-based contract', but have not the budget for it. On the other hand they are not willing to remain with the inefficient traditional 'per-order' type contract and suffer with low availability figures.

The novelty for the availability-oriented approach introduced in this research is that it provides these organizations with the opportunity to still improve their operational availability when they are forced to remain with the traditional type 'per-order' contract, by focussing efforts on pinpointed areas.

5.4 **Areas of Application**

Although this model was primarily developed for Malaysian naval vessels, it could be applied and replicated for naval vessels globally under the designated name ConCaMS (contract management control and monitoring system). The model is very useful and flexible in terms of implementation, and customers internationally may use the model as-is if they do not have any opportunity to conduct an independent study. On the other hand, the customers could follow the step-by-step approach and replicate the study by adjusting the model appropriately depending on organization, personnel, policy, structure, culture, system, contract clauses and provisions, environment and other elements. Stakeholders could integrate this model with as part of their standard procedure and methodologies in practice.

Therefore, the model could be used as-is or customized by the customers enhancing it to be suitable with their own circumstances. Overall organization performance in business would improve as achieved availability could be compared with targeted availability figures, with specific pointers on problem areas quantified for easy assessment and accountability. Stakeholders at every level would be motivated and inspired as accusations and blaming-game would be reduced. The ConCaMS would be a reliable and effective tool to be used internationally for contract performance comparison on various contracts, with desired availability targets.

5.5 **Limitations of Study**

Although this research has achieved the development of an availability-oriented contract management model for better management of ISS contracts, there were a few limitations identified. Firstly, the number of experts on ISS contracts in Malaysia is still very limited as only a handful of the vessels have been awarded ISS contracts to date. Secondly, the distant geographical location of the vessels under study in Kota Kinabalu, Kuantan and Lumut added with their ever-changing availability due to operational sailing schedules had created difficulty in continuous data collection due to constraints in term of time, financial, and resources. Similar issue applies to availability of the experts due to their geographical locations, movement and time.

Thirdly, the process and resulting model was developed based on experts from of ISS contract from the government and commercial sector in Malaysia. Similar implementation in other countries may discover other elements or factors peculiar to the country, which may impart more knowledge to the study. Fourthly, due to the time, financial and resources constraints of this study which has spanned over 6 years, further daily data collection as a result of the recommended dashboard could not be exercised. Similar to the third limitation above, other elements or factors could be discovered. The fifth obstacle of the research was 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. However, whilst some organizations collected minimal data, some collected too much unusable data. The same issue on verification and validation applies for the findings by the researcher on recommended amendments to contract clauses, as the time-consuming Delphi technique would not work as the availability of the experts could not be guaranteed for an extended amount of time. Lastly, the study involved military vessels which has very strict access and approval process to protect confidential information due to national security requirements.

5.6 Recommendations for Future Research

Recommendations for improvement and further research are as follows:

(i) Further focussed research on individual DIFs and especially on various combination of DIFs may shed more light on this newly explored area of study.

(ii) A suitable procedure on verification and validation to be developed for amendments to contract clauses, as the time-consuming Delphi technique would not work as the availability of the experts could not be guaranteed for an extended amount of time.

(iii) It is recommended that the process, method and model used in this study to be applied in other ISS contracts worldwide to compare the findings.

(iv) The same work could be replicated by other industries that seek to maintain a high asset availability target.

(v) If the recommended dashboard is implemented and detailed daily data could be collected from each vessel at various locations, then the result could be compared to the Delphi technique findings from this study. In fact, this could lead to the discovery of new factors not identified to date.

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APPENDICES

APPENDIX A

List of 50 Downtime Influence Factors identified from Literature

50 Downtime Influence Factors and the relevant Literature (AlShafiq *et al*, 2018c)

S/No	DIFs for Ship Operational Availability	Authors of Literatures from various Fields	Experts (n=30) Stages 1 to 3	Experts (n=5) Stages 4 to 7
1	Equipment and Systems – Hull and Design	(GAO, 1981), (GAO, 1982), (GAO, 2014a), (GAO, 2014b), (GAO, 2014c), (Rosenberger and Pointner, 2015), (Dell'Isola and Vendittelli, 2015), (Forsthoffer, 2005), (Block and Geitner, 2012), (Jardine *et al*., 1996), (Allred, 1995), (IAEA, 2005), (Prasertrungruang and Hadikusumo, 2009), (Glorian and Spiegelberg, 1998), (Dhillon, 2002), (Papavinasam, 2013), (Najjar, 1998), (Nepal and Park, 2004), (WEC, 1991), (Balafas *et al*. 2010), (Odeyinde, 2008), (Lazakis *et al.*, 2010),(Sinnasamy *et. al*, 2017).	Yes	Yes
2	Equipment and Systems – Main Propulsion		Yes	Yes
3	Equipment and Systems – Electrical		Yes	Yes
4	Equipment and Systems – Weapon Systems including guns and missiles		Yes	Yes
5	Equipment and Systems – Auxilliaries		Yes	Yes
6	Equipment and Systems – Outfittings		Yes	Yes
7	Maintenance Policy - Priority on Type of Maintenance	(Dell'Isola and Vendittelli, 2015), (GAO, 2014b), (GAO, 2014c), (Sullivan, 2011), (Driessen *et al.* 2010), (Stackley, 2009), (Dhillon, 2002), (Edwards *et al*., 1998), (Jonsson, 1997), (Gits, 1994), (Ford *et al*., 2013), (GAO, 1982), (Jardine et al., 1996), (Najjar, 1998), (Marquez and Gupta, 2005), (Colosi *et al.*, 2010), (Pascual *et al*., 2008), (Park *et al.*, 2010), (Nepal and Park, 2004), (Goossens, 2015), (Jazouli and Sandborn, 2011), (Stambaugh and Barry, 2014), (Pan *et al.*, 2012), (Reliability Analysis Centre, 2004), (Boyle *et al.*, 2011), (Farajiparvar, 2012), (NAVSEA, 2014).	Yes	Yes
8	Awareness of Importance of Maintenance / Attitude – including hiding problems from becoming official.	(Leva *et al.*, 2013), (GAO, 1982), (Block and Geitner, 2012), (Morris and Sember, 2008), (Jonsson, 1997), (Marquez and Gupta, 2005), (U.S. Congress, 1986), (Banaitiene and Banaitis, 2012), (Attwater *et al*., 2014), (Mafini and Dubihlela, 2013), (Odoom and Amedzro, 2011), (Seresht *et al*., 2014), (Chang, 1999), (Blaikie, 1993)	Yes	Yes
9	Maintenance Budget Allocation	(Dell'Isola and Vendittelli, 2015), (Sullivan, 2011), (Dhillon, 2002), (GAO, 2014b), (Commission on Wartime Contracting, 2011), (Jardine *et al*., 1996), (Stambaugh and Barry, 2014), (Nepal and Park, 2004), (Jonsson, 1997), (Dekker, 1996), (GAO, 1982), (Walker, 2005), (Bateson, 1985), (Kazi, 2005), (Swanson, 2001), (Henry and Bil, 2015), (Garel, 2013), (Romzek and Johnston, 2002), (Apte *et al.*, 2008), (Yuan, 2016), (Atkinson, 1999), (Pascual et al., 2008), (Eckstein, 2016), (Erwin, 2014), (Balafas *et al.*, 2010), (Odeyinde, 2008), (Seresht *et al*,. 2014), (Lock, 2014), (GAO, 2014a).	Yes	Yes
10	Information Management	(GAO, 1982), (Ford *et al.*, 2013), (Geitner and Bloch, 2012), (Jonsson, 1997), (Ljungberg *et*	Yes	Yes

S/No	DIFs for Ship Operational Availability	Authors of Literatures from various Fields	Experts (n=30) Stages 1 to 3	Experts (n=5) Stages 4 to 7
		al., 2009), (Belkhamza and Wafa, 2012), (U.S. Congress, 1986), (RAND, 1996), (IAEA, 2005), (Jardine et al., 1996), (Dekker *et al*, 1998), (GAO, 2002), (Mathew *et al.*, 2006), (Harz, 1981).		
11	Preventive Maintenance	(Rosenberger and Pointner, 2015), (Driessen *et al.*, 2010), (Dhillon, 2002), (Block and Geitner, 2012), (Edwards *et al.*, 1998), (Pecht, 2009), (Jonsson, 1997), (IAEA, 2005), (Gits, 1994), (Dell'Isola and Vendittelli, 2015), (Pogačnik *et al*., 2015), (Marquez and Gupta, 2005), (Katsikas *et al.*, 2014), (Kadry, 2013), (Alabdulkarim *et al*., 2004), (Pan *et al.*, 2012), (Mathew *et al.*, 2006), (Marais *et al*., 2013), (Popovic *et al.*, 2011).	Yes	Yes
12	Corrective Maintenance	(GAO, 1981), (Driessen *et al.*, 2010), (Dhillon, 2002), (Jonsson, 1997), (Cooke and Paulsen, 1997), (Ross, 2009), (Dell'Isola and Vendittelli, 2015), (Pogačnik *et al*., 2015), (Kadry, 2013), (Chang, 1999), (Marais *et al*., 2013), (Schreiber *et al*., 2007), (Deris *et al.*, 1999), (Eti *et al*., 2004), (Weibull, 2017).	Yes	Yes
13	Predictive Maintenance	(Dell'Isola and Vendittelli, 2015), (Dhillon, 2002), (Block and Geitner, 2012), (Edwards *et al.*, 1998), (Cooke and Paulsen, 1997), (Swanson, 2001), (Marquez and Gupta, 2005), (Katsikas *et al.*, 2014), (Popovic *et al.*, 2011), (Offenbeek and Vos, 2016).	Yes	Yes
14	Emergency Repair and Docking	(Houtum and Kranenburg, 2015), (Pizam, 2010), (Telsang, 2007), (GAO, 2005), (Dhillon, 2002), (Jonsson, 1997), (Kowalski, 2002).	Yes	Yes
15	Equipment Technology / System Complexity	(Dell'Isola and Vendittelli, 2015), (McNamara *et al.*, 2015), (Jonsson, 1997), (Psenka, 2008), (Ross, 2009), (Pecht, 2009), (Kobbacy and Murthy, 2008), (Dean, 2003), (Walsh, 2014), (Darnall and Preston, 2010), (Deris *et al.*, 1999), (Glorian and Spiegelberg, 1998), (Xia et al., 2012), (Ford *et al.*, 2013), (Dhillon, 2002), (Blaikie, 1993), (Marquez and Gupta, 2005), (Mavris, 2007).	Yes	Yes
16	Scheduling Issues	(Persson and Stirna, 2015), (Wilson, 2015), (Wilson, 2014), (Peters, 2014), (Bawa, 2009), (Kerzner, 2013), (Burford, 2012), (Banaitiene and Banaitis, 2012), (Badiru, 2009), (Colosi *et al*., 2010), (Park *et al.*, 2010), (Odeh and Battaineh, 2002), (Darabaris, 2006), (Deris *et al.*, 1999), (GAO, 1981, (Xia *et al*., 2012), (Dhillon, 2002), (Miau andHoldaway, 2013), (Pogačnik *et al*., 2015), (Atkinson, 1999), (Marquez and Gupta, 2005), (Nepal and Park, 2004), (Pan *et al.*, 2012), (Jonsson, 1997), (Marais *et al*., 2013), (Dekker *et al*, 1998), (Swanson, 2001).	Yes	Yes
17	Maintenance of Special Tools, Test Equipment	(Dell'Isola and Vendittelli, 2015), (Pecht, 2009), (Dhillon, 2002), (GAO, 1982), (Atkinson, 1999), (Staub-French and Nepal, 2007), (Harz, 1981), (Mathew *et al.*, 2006).	Yes	Yes
18	Availability of Facilities	(Dell'Isola and Vendittelli, 2015), (Rosenberger and Pointner, 2015), (Banaitiene and Banaitis, 2012), (GAO, 1981), (Denman, 1999), (GAO, 2015b), (IAEA, 2005), (Dhillon, 2002), (GAO, 1982), (Deris *et al.*, 1999), (Henry and Bil, 2015), (Pogačnik *et al*., 2015), (Nepal and Park, 2004), (Harz, 1981), (Balafas *et al*., 2010), (Darabaris, 2006).	Yes	Yes
19	Spares Availability	(McNamara *et al.*, 2015), (Dell'Isola and Vendittelli, 2015), (Rosenberger and Pointner, 2015), (Banaitiene and Banaitis, 2012), (Driessen *et al*., 2010), (Gits, 1994), (RAND, 1996), (Denman, 1999), (Dhillon, 2002), (GAO, 1982), (GAO, 1981), (Jardine et al., 1996), (Marquez and Gupta, 2005), (Colosi *et al*., 2010), (Nepal and Park, 2004), (Harz, 1981),	Yes	Yes

S/No	DIFs for Ship Operational Availability	Authors of Literatures from various Fields	Experts (n=30) Stages 1 to 3	Experts (n=5) Stages 4 to 7
		(Balafas *et al.*, 2010), (Sandborn, 2013).		
20	Obsolescence Issues	(Allman, 2015), (Dell'Isola and Vendittelli, 2015), (Mequignon and Haddou, 2014), (Moir and Seabridge, 2012), (Finch, 2012), (Bartels *et al.*, 2012), (Clavareau and Labeau, 2009), (Adriaansen, 2004), (National Research Council, 1993), (Driessen *et al.*, 2010) , (Stambaugh and Barry, 2014), (Colosi *et al.*, 2010), (Nepal and Park, 2004), (Ladetto, 2015), (Sandborn, 2013), (Berkok *et al.*, 2013), (Freeman and Paoli, 2015), (Benedetto, 2014b), (Erkoyuncu *et al.*, 2015), (Rojo *et al.*, 2009).	Yes	Yes
21	Design and Design Change Issues	(Rosenberger and Pointner, 2015), (Dell'Isola and Vendittelli, 2015), (Papavinasam, 2013), (Xia et al., 2012) , (Dhillon, 2002) , (GAO, 1982), (Abowitz and Toole, 2010), (Block and Geitner, 2012), (Jonsson, 1997), (Dekker, 1996), (Pecht, 2009), (Coles *et al.*, 2003), (Smith, 2005), (Temple and Collette, 2013), (Sullivan, 2011), (Australian National Audit Office, 2001), (Psenka, 2008), (Najjar, 1998), (Stambaugh and Barry, 2014), (Ridgway *et al.*, 2009), (Marquez and Gupta, 2005), (Pascual et al., 2008).	Yes	Yes
22	Knowledge Management incl Training, Knowledge and Skills	(Dell'Isola and Vendittelli, 2015), (GAO, 2014c), (Block and Geitner, 2012), (Pecht, 2009), (Ross, 2009), (Dollschnieder, 2010), (Dhillon, 2002), (Swanson, 2001), (Najjar, 1998), (Glorian and Spiegelberg, 1998), (Jonsson, 1997), (U.S. Congress, 1986), (GAO, 1982), (Lock, 2014), (Goh and Yip, 2014), (Commission on Wartime Contracting, 2011), (GAO, 2002), (Glorian and Spiegelberg, 1998), (Al-Shammari, 2009), (Henry and Bil, 2015), (Apte *et al.*, 2008), (Atkinson, 1999), (Colosi *et al.*, 2010), (Nepal and Park, 2004), (Harz, 1981), (Balafas *et al.*, 2010), (Pascual *et al.*, 2008), (Bianchetti, 2012).	Yes	Yes
23	Availability of OEM Expert Support	(Dell'Isola and Vendittelli, 2015), (IAEA, 2005), (Dhillon, 2002), (U.S. Congress, 1986), (Stackley, 2009).	Yes	Yes
24	Availability of Local vendor support	(Dell'Isola and Vendittelli, 2015), (More, 2013), (IAEA, 2005), (Dhillon, 2002), (Denman, 1999), (GAO, 1982), (Palvia *et al.*, 1996), (Karampelas, 2005).	Yes	Yes
25	Complexity and efficiency of existing contract	(Xia *et al.*, 2012), (McNamara *et al.*, 2015), (Pecht, 2009), (Pascual *et al.*, 2008), (Offenbeek and Vos, 2016), (Balafas *et al.*, 2010), (Price, 2013), (Wiggins, 1985), (Stackley, 2009).	Yes	Yes
26	Capability of Customer performing Maintenance	(Dell'Isola and Vendittelli, 2015), (Banaitiene and Banaitis, 2012), (Driessen *et al.*, 2010), (Dearden *et al.* 1999), (Dollschnieder, 2010), (Gibson, 2013), (Al-Shammari, 2009), (Jonsson, 1997), (Ayyub, 2000), (GAO, 1982), (Berkok *et al.*, 2013), (Mokaya and Kittony, 2008), (Harz, 1981), (Morris and Sember, 2008), (Odoom and Amedzro, 2011).	Yes	Yes
27	Morale and Attitude of Customer involved in Maintenance		Yes	Yes
28	Morale and Attitude of Contractor involved in Maintenance	(Jonsson, 1997), (GAO, 1982), (U.S. Congress, 1986), (Leva *et al*, 2013), (Block and Geitner, 2012), (Morris and Sember, 2008), (Banaitiene and Banaitis, 2012), (Odoom and Amedzro, 2011), (Attwater *et al.*, 2014), (Odeh and Battaineh, 2002), (Rendon, 2009), (Rendon and Snider, 2008).	Yes	Yes
29	Efficiency of Processes, Procedures and reporting structure include Finance	(Dell'Isola and Vendittelli, 2015), (Sullivan, 2011), (Lin *et all*, 2015), (Thai, 2004), (Burford, 2012), (Odeh and Battaineh, 2002), (Foerst, 2010), (Goh and Yip, 2014), (McIntosh, EandY, 2003), (Block and Geitner, 2012), (Jardine *et al.*, 1996), (Edwards *et al.*, 1998), (GAO, 1982), (Harz, 1981), (Bianchetti, 2012).	Yes	Yes
30	Ship Operational/sailing schedule	(RAND, 2006), (House of Commons Defence Committee, 2006), (Popovic *et al.*, 2011),	Yes	Yes

S/No	DIFs for Ship Operational Availability	Authors of Literatures from various Fields	Experts (n=30) Stages 1 to 3	Experts (n=5) Stages 4 to 7
		(Marais *et al*., 2013).		
31	Non-Commonality of Equipment issues	(Driessen *et al*., 2010), (Chang, 1999).	Yes	Yes
32	Non-Redundancy of Equipment	(Driessen *et al*., 2010), (Dekker, 1996), (U.S. Congress, 1986), (Rosenberger and Pointner, 2015), (Nannapaneni *et al*., 2014), (Lin *et al*, 2015), (Staub-French and Nepal, 2007), (More, 2013), (Marquez and Gupta, 2005), (Pascual *et al*., 2008).	Yes	Yes
33	High Turnover of maintenance supervisors.	(Chitram, 2008), (Dhillon, 2002), (Tan *et al*., 2002), (Lowry *et al*., 2006), (Mathew *et al*., 2006), (Mokaya and Kittony, 2008), (Thomas, 2013), (Mafini and Dubihlela, 2013), (GAO, 2014c), (Belkhamza and Wafa, 2012), (Price, 2013), (Parliament UK, 2008), (Wang *et al*, 2010).	Yes	Yes
34	High Turnover of maintainers		Yes	Yes
35	Different location of ships	(RMN, 2011), (Dhillon, 2002), (GAO, 2015), (Golding and Griffis, 2003), (Lu *et al*., 2010), (Skoko *et al*, 2013).	Yes	Yes
36	Statutory requirements	(IAEA, 2005), (WEC, 1991), (Goh and Yip, 2014), (Marquez and Gupta, 2005), (Glorian and Spiegelberg, 1998), (Lock, 2014).	Yes	Yes
37	Cashflow Shortages	(Banaitiene and Banaitis, 2012), (IAEA, 2005), (GAO, 1982), (GAO, 1981), (GAO, 2014a), (GAO, 2014c), (Denman, 1999), (Lock, 2014), (GAO, 2014b), (Glorian and Spiegelberg, 1998).	Yes	Yes
38	Government Requirements and Policies (i.e. EEP, Offset etc),	(MOF, 2011), (TDA, 2010-2017), (Berkok *et al*., 2013), (Bil and Mo, 2013), (Rendon, 2009), (FPDS, 2010), (Lee and Dobler, 1971), (Moe, 1984), (Romzek and Johnston, 2002).	Yes	Yes
39	Variation Order and Contract Change	(Banaitiene and Banaitis, 2012), (Lock, 2014), (Apte *et al*., 2008), (Carter, 2015), (Odeh and Battaineh, 2002), (Rendon, 2009), (Thai, 2004), (Rendon and Snider, 2008), (GAO, 2009), (Rendon, 2009b), (Humbert and Mastice, 2014), (Price, 2013), (Romzek and Johnston, 2002).	Yes	Yes
40	Ageing /Aging of Equipment	(Mathew *et al*., 2006), (Ladetto, 2015), (Glorian and Spiegelberg, 1998), (Colosi *et al*., 2010), (Garel, 2013), (Marquez and Gupta, 2005), (Keller *et al*., 2002), (Stambaugh and Barry, 2014), (Pascual et al., 2008), (Park *et al*., 2010), (Mafini and Dubihlela, 2013), (Offenbeek and Vos, 2016), (Davis, 2014), (Boonstra *et al*., 2008), (Bianchetti, 2012), (Rendon, 2009), (FPDS, 2010), (Nepal and Park, 2004), (Chang, 1999), (Rendon and Snider, 2008).	Yes	Yes
41	Force Majeure	(RMN, 2011), (IAEA, 2005), (Nepal and Park, 2004).	Yes	Yes
42	Accidents and Hazards	(IAEA, 2005), (Reuvid, 2012), (Driessen *et al*., 2010), (Twigge-Molecey and Price, 2013), (Banaitiene and Banaitis, 2012), (Bawa, 2009), (U.S. Bureau of Mines, 1998), (British Robot Association, 1984), (Ridgway *et al*., 2009), (Nepal and Park, 2004), (Mathew *et al*., 2006), (Soares, 2014), (Mahaffey, 2014), (Deodatis *et al*., 2013), (Berkok *et al*., 2013), (Rendon, 2009), (Ceric, 2014), (Stambaugh and Barry, 2014), (Sawyer, 1997), (Rendon and Snider, 2008).	Yes	Yes
43	Extraordinary Price Escalations (Spares, Consumables, Equipment)	(Banaitiene and Banaitis, 2012), (Lock, 2014), (Driessen *et al*., 2010).	Yes	Yes
44	Pilferage, Theft and Fraud and Cheat	(McAfee and Champagne, 1994), (Hayes, 2014), (Doig, 2012), (Taska and Barnes, 2012), (Foerst, 2010), (U.S. Congress, 1986), (McIntosh EandY, 2003), (Commissioning on Wartime	Yes	Yes

S/No	DIFs for Ship Operational Availability	Authors of Literatures from various Fields	Experts (n=30) Stages 1 to 3	Experts (n=5) Stages 4 to 7
		Contracting, 2011), (GAO, 2015c).		
45	OLM, ILM, DLM - Overlap of maintenance duties (contractual) and impact if not performed	(Xia *et al*., 2012), (Jonsson, 1997), (GAO, 1982), (Henry and Bil, 2015), (Balafas *et al.*, 2010), (Ford *et al.*, 2013), (Deris *et al.*, 1999), (Crane and Livesey, 2003), (Lim *et al.*, 2016), (Offenbeek and Vos, 2016), (Sword, 2010).	Yes	Yes
46	Contract Management across a wide range of stakeholders with conflicting interests	(Lock, 2014), (Gracht, 2012), (Wilkinson, 2009), (Chermack and Nimon, 2008), (Aven and Korte, 2003), (Rendon, 2009), (Price, 2013), (Kwak and Smith, 2009), (Nasab *et al.*, 2015), (Seresht *et al*., 2014), (Jardine *et al*., 1996), (Ford *et al.*, 2013), (NAVSEA, 2012), (Pogačnik *et al*., 2015), (Atkinson, 1999), (Davis, 2014), (Boonstra et al., 2008), (Xia *et al*., 2012), (Taska and Barnes, 2012), (Rendon and Snider, 2008), (Offenbeek and Vos, 2016).	Yes	Yes
47	Impact of Parallel Contracts to Schedule, Genuinity of Spares, Professionalism of Repair Team etc.	(Sahoo, 2013), (Wearne, 1993), (Lawson *et al.*, 1999), (Carter, 2013).	Yes	Yes
48	Supporting of the Vessel outside of home ports (e.g. issue on mob, availability of materials etc.)	(Dell'Isola and Vendittelli, 2015), (GAO, 2015), (Golding and Griffis, 2003), (Lu *et al.*, 2010), (Skoko *et al*, 2013).	Yes	Yes
49	Exogenous factors (i.e. company profit margin, administrative costs, peripheral costs, support cost)	(Dell'Isola and Vendittelli, 2015), (Banaitiene and Banaitis, 2012), (IAEA, 2005), (Henry and Bil, 2015), (Staub-French and Nepal, 2007), (Darnall and Preston, 2010), (Mathew *et al.*, 2006).	Yes	Yes
50	Exogenous factors - Contract Concept (Total Maintenance Package against segregated orders without interrelationships) and based on recommendations	(Dell'Isola and Vendittelli, 2015), (RAND, 1996), (Keller *et al.*, 2002), (Rusi Defence System, 2012).	Yes	Yes

APPENDIX B

APPENDIX B

Questionnaires Stage 2 to Stage 7

Faculty of Mechanical Engineering
University Technology Malaysia
81030 UTM Johor Bahru
Johor Darul Ta'zim
Malaysia

SHQ/PERS/2015 – (7)
1 March 2015

Dear YBhg Dato'/ Datuk/Panglima/Sir/ Madam,

Assalamualaikum wmt wbkth.

PARTICIPATION IN QUESTIONNAIRE SURVEY FOR UNIVERSITI TEKNOLOGI MALAYSIA.

With regard to the above matter, with great pleasure I would like to bring to YBhg. Dato'/Datuk/Panglima/Sir/Madam's attention that Universiti Teknologi Malaysia (UTM) is undertaking a research on the Availability of Naval Vessels. The research is supervised by Assoc. Professor Ir. Dr Mohd Zamani Ahmad and Dr Koh Khor King.

The research using Delphi Method would require several rounds of conducting survey questionnaires for the purpose of validating the variables, provide appropriate rating, reassessing the rating in the light of consolidated results, and confirmation of contract clauses to develop the model.

All responses will be treated as confidential and shall be used for academic purposes only.

Therefore, I respectfully request YBhg. Dato'/Datuk/Panglima/Sir/Madam's participation and request your professional response to questionnaires in the attachment, and your kind cooperation in participating in the subsequent stages of research.

YBhg. Dato'/Datuk/Panglima/Sir/Madam's cooperation and support is greatly appreciated. Thank you.

Very Respectfully,

Al-Shafiq bin Abdul Wahid
Phd Student
Faculty of Mechanical Engineering
Universiti Technologi Malaysia
Email: al_shafiq@hotmail.com

Faculty of Mechanical Engineering
University Technology Malaysia
81030 UTM Johor Bahru
Johor Darul Ta'zim
Malaysia

EXPERT GROUP SESSIONS:

NAME: ____

SESSION NO 1:

DATE: ____

SESSION NO 2:

DATE: ____

SIGNATURE: ____

REMARKS: ____

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SESSION NO 3:

DATE: ____

SIGNATURE: ____

REMARKS: ____

____

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DELPHI QUESTIONNAIRE: STAGE 2 TO STAGE 3 (30 EXPERTS)

QUESTIONNAIRES FOR EXPERT GROUP

PART 1: BACKGROUND INFORMATION

1. Name: ____
2. Address: ____
3. Telephone Number: ______________________________
4. Current Designation: ______________________________
5. Total years of working experience: _____years
6. Years of experience in the marine industry: _____ years
7. Length of experience on the ISS Contract: _____ years
8. Contract Management: _____ years
9. Years of experience in the Navy: _____ years
10. Academic background: ____________________________
11. Professional qualifications: _________________________
12. Company Name: ________________________________

Declaration:

I hereby declare that the information provided in the next pages is a reflection of my professional opinion on the matters questioned.

Signature: ______________________________

Date: ________________________________

Page **1** of **4**

Ship Availability Downtime Influence Factors (DIF)

i. In your expert opinion, which of the following criteria have an impact on Ship Availability? Please tick all boxes that apply.

ii. For those relevant boxes, kindly indicate the following;

a. Impact of the DIF onto Availability of the Naval Vessels for the ISS contract, using the following scale

Extreme	5
High	4
Medium	3
Low	2
Negligible	1

b. Probability of the DIF occurring throughout the contract duration

Almost Certain	5
Likely	4
Possible	3
Unlikely	2
Rare	1

Potential Downtime Influence Factors	Applicable?	Impact	Probability
SWBS 100: Hull and Design			
SWBS 200: Main Propulsion			
SWBS 300: Electrical			
SWBS 400: Weapon Systems			
SWBS 500: Auxiliaries			
SWBS 600: Outfittings			
Maintenance Policy - Priority on Type of Maintenance			
Awareness of Importance of Maintenance / Attitude – including hiding problems from becoming official.			
Maintenance Budget Allocation			
Information Management			
Preventive Maintenance			
Corrective Maintenance			
Predictive Maintenance			
Emergency Repair & Docking			
Equipment Technology / System Complexity			

Potential Downtime Influence Factors	Applicable?	Impact	Probability
Scheduling Issues			
Maintenance of Special Tools, Test Equipment			
Availability of Facilities			
Spares Availability			
Obsolescence Issues			
Design Change Issues			
Knowledge Management incl Training, Knowledge and Skills			
Availability of OEM Expert Support			
Availability of Local vendor support			
Complexity and efficiency of existing contract			
Capability of Customer performing Maintenance			
Morale & Attitude of Customer involved in Maintenance			
Morale & Attitude of Contractor involved in Maintenance			
Efficiency of Processes, Procedures and reporting structure include Finance			
Ship Operational/sailing schedule			
Commonality of Equipment issues			
Non Redundancy of Equipment			
High Turnover of maintenance supervisors.			
High Turnover of maintainers			
Different location of ships			
Statutory requirements			
Cashflow Shortages			
Government of Malaysia Requirements (i.e. PPE, Offset etc))			
Variation Order and Contract Change			
Ageing of Equipment			
Force Majeure			
Accidents & Hazards			
Extraordinary Price Escalations (Spares, Consumables, Equipments)			
Pilferage, Theft & Fraud & Cheat			
OLM, ILM, DLM - Overlap of maintenance duties (contractual) and impact if not performed			

Potential Downtime Influence Factors	Applicable?	Impact	Probability
Contract Management across a wide range of stakeholders with conflicting interests			
Impact of Parallel Contracts to Schedule, Genuinity of Spares, Professionalism of Repair Team etc.			
Supporting of the Vessel outside of home ports (e.g. issue on mob, avail of materials etc.)			
Exogenous factors (i.e. company profit margin, administrative costs, peripheral costs, support cost)			
Exogenous factors - Contract Concept (Total Maintenance Package against segregated orders without interrelationships) and based on recommendations			

Snowballing Questionnaire (n=30)

Snowball Sampling for Expert Selection

Question:
In your opinion following the consolidation of results of the questionnaire you have participated in, who would you recommend to be the panel members of experts to provide the best feedback on the subject matter?

Note:

1. **Title of the study**:
   Ship-availability based Contract Management model for In Service Support Contracts on Maintenance of Naval Vessel.

2. **Experts should possess the following qualities**

Qualities	Delphi Qualities	References
a) Experts are truly knowledgeable in their field. b) Experts have vast experience in their field. c) Experts truly understand the In Service Support Background, T&C, Implementation and Contract Clauses.	Have pertinent info to share	Delbecq *et al.* (1975)
d) Experts are expected to be busy but will most likely participate positively to ensure the research is successfully completed, due to his or her passion on the subject matter.	Motivated to participate Feels personally involved	
e) Availability of the Experts administratively and logistically.	Availability of the Experts administratively and logistically	
f) Senior position with clear bird's eye view to discuss on policy level issue but knowledgeable and detailed enough to understand the issues at ground level.	Qualified if top management decision makers who would utilize the study for	
g) Truly interested not just on the subject matter, but also truly believes that his or her contribution along with other experts shall assist in a successful research being done, of which the result would be of good use to himself or herself and the industry.	Feel that the aggregation of judgments of a respectable panel, which they too value to which they would not otherwise have access	

Snowball Sampling for Expert Selection

3. Suggested candidates

CANDIDADATE TYPE: CUSTOMER	CANDIDATE TYPE: ISS CONTRACTOR OR SHIPYARD	CANDIDATE TYPE: ISS TOP MANAGEMEENT
- - - -		

FINAL DELPHI ROUND QUESTIONNAIRE

All 30 experts that participated in the various stages of the Delphi Questionnaire had been selected due to their operational background. A subset of these experts is directly involved or exposed with the In Service Support contracts of the Royal Malaysian Navy, namely RMN and Boustead personnel.

Only these personnel will be requested to answer the section below:

To confirm results, we would like to invite members of the top management that have experience with In-Service Support (ISS) contracts and are still part of the Senior Management or have been part of the Senior Management Team of the Royal Malaysian Navy or Boustead Naval Shipyard, with an extensive experience in ISS contracts.

In your professional opinion, which members of the Senior Management team should be interviewed to confirm or otherwise the results. Kindly provide all names that are applicable:

1.____

2.____

3.____

4.____

5.____

6.____

7.____

8.____

9.____

10.____

DELPHI QUESTIONNAIRE: STAGE 4 TO STAGE 5
FIVE (5) TOP MANAGEMENT EXPERTS

TOP MANAGEMENT DELPHI QUESTIONNAIRE

Attached is a List of 50 Downtime Influence Factors (DIFs) to Naval Ship's Operational Availability.

The list of the 50 Downtime Influence Factors (DIFs) have been produced through the earlier stages of Delphi Method, from the selected experts representing a wide spectrum of naval ship maintenance professionals with preferably ISS Contract Experience or at minimum having Contract Management experience in Malaysia.

Questionnaire 1: In your expert opinion, which of the following criteria have an impact on ship availability?

DIF No	DIF for Ship Operational Availability	Please Tick all boxes that apply
1	Equipment and Systems – Hull and Design	
2	Equipment and Systems – Main Propulsion	
3	Equipment and Systems – Electrical	
4	Equipment and Systems – Weapon Systems and Gun	
5	Equipment and Systems – Auxiliaries	
6	Equipment and Systems – Outfittings	
7	Maintenance Policy - Priority on Type of Maintenance	
8	Awareness of Importance of Maintenance / Attitude – including hiding problems from becoming official.	
9	Maintenance Budget Allocation	
10	Information Management	
11	Preventive Maintenance	
12	Corrective Maintenance	
13	Predictive Maintenance	
14	Emergency Repair & Docking	
15	Equipment Technology / System Complexity	
16	Scheduling Issues	

TOP MANAGEMENT DELPHI QUESTIONNAIRE

17	Maintenance of Special Tools, Test Equipment	
18	Availability of Facilities	
19	Spares Availability	
20	Obsolescence Issues	
21	Design Change Issues	
22	Knowledge Management incl. Training, Knowledge, Skills and System	
23	Availability of OEM Expert Support	
24	Availability of Local vendor support	
25	Complexity and efficiency of existing contract	
26	Capability of Customer performing Maintenance	
27	Morale & Attitude of Customer involved in Maintenance	
28	Morale & Attitude of Contractor involved in Maintenance	
29	Efficiency of Processes, Procedures and reporting structure include Finance	
30	Ship Operational/sailing schedule	
31	Commonality of Equipment issues	
32	Non Redundancy of Equipment	
33	High Turnover of maintenance supervisors.	
34	High Turnover of maintainers	
35	Different location of ships	
36	Statutory requirements	
37	Cashflow Shortages	
38	Government of Malaysia Requirements (i.e. PPE, Offset etc.)	
39	Variation Order and Contract Change	
40	Ageing of Equipment	
41	Force Majeure	
42	Accidents & Hazards	
43	Extraordinary Price Escalations (Spares, Consumables, Equipment)	

44	Pilferage, Theft & Fraud & Cheat	
45	OLM, ILM, DLM - Overlap of maintenance duties (contractual) and impact if not performed	
46	Contract Management across a wide range of stakeholders with conflicting interests	
47	Impact of Parallel Contracts to Schedule, Genuinity of Spares, Professionalism of Repair Team etc.	
48	Supporting of the Vessel outside of home ports (e.g. issue on mob, avail of materials etc.)	
49	Exogenous factors (i.e. company profit margin, administrative costs, peripheral costs, support cost)	
50	Exogenous factors - Contract Concept (Total Maintenance Package against segregated orders without interrelationships) and based on recommendations	

TOP MANAGEMENT DELPHI QUESTIONNAIRE

From the 50 DIFs, the experts from the previous group of Delphi were asked to conduct a Risk Analysis by rating the Impact x Probability of the individual DIFs, based on a 1-5 Likert Scale as follows:

IMPACT	
Extreme	5
High	4
Medium	3
Low	2
Negligible	1

PROBABILITY	
Almost Certain	5
Likely	4
Possible	3
Unlikely	2
Rare	1

In this research, the severe DIFs were shortlisted based on a cut-off point of 16 which reflects DIFs which has a minimum of High Impact (4 points) x minimum of Likely for Probability (4 points) is considered as severe. Anything of category Medium Impact (3) and lower, and Possible Probability (3) and lower is considered not severe. Only the severe DIFs are regarded as IMPORTANT and remain for the re-evaluation in this stage of Delphi Study.

Below is the list of 15 Severe DIFs shortlisted by the earlier respondents from the earlier stage of Delphi Research. These are the results following two rounds of reassessment by the previous group of respondents:

TOP MANAGEMENT DELPHI QUESTIONNAIRE

List of Severe DIFs	**Mean**	**Median**	**Mode**	**RANK**
Corrective Maintenance	24.20	25.00	25.00	1
Spares Availability	22.90	25.00	25.00	2
Impact of Parallel Contracts to Schedule, Genuinity of Spares, Professionalism of Repair Team etc.	21.70	25.00	25.00	3
Cashflow Shortages	21.57	25.00	25.00	4
Knowledge Management incl. Training, Knowledge, Skills and System	19.63	20.00	20.00	5
Equipment and Systems - Main Propulsion	18.83	20.00	20.00	6
Maintenance Policy - Priority on Type of Maintenance	18.00	20.00	20.00	7
Availability of OEM Expert Support	17.43	16.00	16.00	8
Maintenance Budget Allocation	17.23	16.00	16.00	9
Awareness of Importance of Maintenance / Attitude – including hiding problems from becoming official.	16.97	16.00	16.00	10
Availability of Facilities	16.70	16.00	16.00	11
Availability of Local vendor support	16.70	16.00	16.00	11
Complexity and efficiency of existing contract	16.20	16.00	16.00	13
Scheduling Issues	16.03	16.00	16.00	14
Equipment and Systems - Auxiliaries	15.33	16.00	16.00	15

TOP MANAGEMENT DELPHI QUESTIONNAIRE

Questionnaire 2: In your expert opinion, please kindly re-assess the Severe DIF ratings as per above In the light of the consolidated results obtained from the experts in the earlier stage of Delphi study.

List of Severe DIFs	Tick if you Agree?	If you disagree kindly rate each DIF as per Likert Scale indicated above: IMPACT	X	PROBABILITY
Corrective Maintenance				
Spares Availability				
Impact of Parallel Contracts to Schedule, Genuinity of Spares, Professionalism of Repair Team etc.				
Cashflow Shortages				
Knowledge Management incl. Training, Knowledge, Skills and System				
Equipment and Systems - Main Propulsion				
Maintenance Policy - Priority on Type of Maintenance				
Availability of OEM Expert Support				
Maintenance Budget Allocation				
Awareness of Importance of Maintenance / Attitude – including hiding problems from becoming official.				
Availability of Facilities				
Availability of Local vendor support				
Complexity and efficiency of existing contract				
Scheduling Issues				
Equipment and Systems - Auxiliaries				

DELPHI QUESTIONNAIRE: STAGE 6 TO STAGE 7
FIVE TOP MANAGEMENT EXPERTS

Questionnaire Delphi Top Management

In previous sessions the severe Downtime Influence Factors (DIF) were identified. In this session we cover the link to the Project Management Constraints and Contract Management Objectives.

Namely, if the objective is to improve the ship availability by reducing a DIF, how does the improvement of the identified severe DIFs impact the Project Management constraints (PMI Iron Triangle) of Cost, Time, Quality and Scope and the Contract Management objectives of Time, Cost and Quality?

1. Kindly indicate below the impact that reducing a DIF significantly would have on the following project management and contract management KPI?

   Please kindly refer to the following three-point rating scales for the effect on each KPI:

Cost:
- No Impact
- Lower
- Higher

Time:
- No Impact
- Shorter Duration
- Extended Duration

Quality
- No Impact
- Better
- Reduced

Scope:
Fixed

In your opinion reducing the Severe DIFs as per table below would have the following impact on the Project Management Constraints and Contract Management Objectives?

Kindly refer to the Three-Point rating scale provided above:

Severe DIFs	Cost	Time	Quality	Scope
Corrective Maintenance				
Spares Availability				
Impact of Parallel Contracts to Schedule, Genuinity of Spares, Professionalism of Repair Team etc.				
Cashflow Shortages				
Knowledge Management incl Training, Knowledge, Skills and Systems				
Equipment and Systems - Main Propulsion				
Maintenance Policy - Priority on Type of Maintenance				

Severe DIFs	Cost	Time	Quality	Scope
Availability of OEM Expert Support				
Maintenance Budget Allocation				
Awareness of Importance of Maintenance / Attitude – including hiding problems from becoming official.				
Availability of Facilities				
Availability of Local vendor support				
Complexity and efficiency of existing contract				
Scheduling Issues				
Equipment and Systems - Auxiliaries				

Remarks/ Comments:

APPENDIX C

APPENDIX C

Post Survey Validation

INDEPENDENT FOLLOW UP QUESTIONNAIRE

PRELUDE

This is an independent follow up questionnaire to a previously concluded Sequential Exploratory Mixed Method Delphi study. This questionnaire is to be completed by key Industry, Government and Academic Top Management experts that have not previously taken part in any of the Delphi rounds. The aim of this questionnaire is to cross-validate the findings of the Delphi study and to gain further insights into other top management expert's feedback independent of the previous Delphi rounds.

In the previous conducted Delphi studies, the Down Time Influence Factors (DIFS) to Naval Ship Availability for the Royal Malaysian Navy (RMN) Patrol Vessel (PV) In-Service Support (ISS) had been identified, severe DIFS were prioritized based on a risk assessment approach, and the impact of improvement of DIFs on Contract Management, Project Management and Availability had been evaluated. The results and finding of the various Delphi rounds resulted in a proposed Ship Availability-Oriented Contract Management Model for In Service Support (ISS) Contracts of Naval Vessel highlighting its applicability in the industry and implementation considerations.

Based on the various stages of the Delphi study completed up to now, various papers have been published consolidating the findings as follows:

v) AlShafiq et. al. 2018, *"Availability Oriented Contract Management Approach - a simplified view to a complex naval issue"*, Defence S&T Technical Bulletin, Vol.11,No.1, pp.132-153.

vi) AlShafiq et. al. 2018b, *"Severity of Downtime Influence Factors Impacting Naval Ship Operational Availability - A Five-Stage Delphi Consensus Procedure with Snowballing Technique"*, ARPN Journal of Engineering and Applied Sciences Vol.13, No.3, Feb. 2018, pp. 939-946.

vii) AlShafiq et. al. 2017a, "A Delphi Approach to Identifying the Severity of Downtime Influence Factors Impacting Naval Ship Operational Availability – Does the Panel Demographic Impact the Expert Opinion?", *2017 7th IEEE International Conference on Control System, Computing and Engineering (ICCSCE)*, Penang, 2017, pp. 289-292.

viii) AlShafiq et. al. 2017b, "Development of a Downtime Influence Factor Severity Index for Improvement of Naval Ship Availability - A Simple approach for the Malaysian Patrol Vessel In-Service Support Contract", *2017 7th IEEE International Conference on Control System, Computing and Engineering (ICCSCE)*, Penang, 2017, pp. 305-309.

The content of the papers listed above have been discussed and presented to the relevant independent Top management experts prior to undertaking this Independent Follow Up questionnaire.

Signature: ______________________

DELPHI QUESTIONNAIRE - CONCLUSION

SECTIONS:

The questionnaire covers the following sections:

1. SECTION A: Demonstration and explanation of the model (25 Minutes).

2. SECTION B: Feedback on the demonstrated model and implementation considerations (10 Minutes)

3. SECTION C: Any further feedback (5 Minutes).

DETAILS:

NAME: ____

DATE: ____

Signature: ______________________

INDEPENDENT FOLLOW UP QUESTIONNAIRE

SECTION B: After demonstration of the model mechanism, kindly answer the following questions by ticking the appropriate answer box:

S/N	Question	YES	NO	Kindly elaborate/ explain ONLY if you answer NO
1	The real data extracts taken from the ISS Contract Implementation used to populate the model are a fair representation of the actual Patrol Vessel situation up to now.			
2	Prior to the publication of the papers described in Prelude above, there were no guideline on how to improve availability throughout the In-Service Support (ISS) contract period.			
3	Up to now, the system used to monitor ship maintenance activities for ISS contract only reports defects and unable to pinpoint to problems areas or severe factors that impact most on ship availability.			

Signature: ________________________

INDEPENDENT FOLLOW UP QUESTIONNAIRE

S/N	Question	YES	NO	Kindly elaborate/ explain ONLY if you answer NO
4	Up to now, the system used to monitor ship maintenance activities for ISS contract is unable to assist the stakeholders to project or predict future potential problems impacting negatively on ship availability.			
5	Up to now, the present attempts by stakeholders to improve availability are by random effort or equivalent effort only as there has not been any guidelines.			
6	Due to existing inability to focus on defined factors that impact availability negatively, there is an unclear area on accountability within the Navy between Executive branch, Technical Branch and Logistics Branch, and between the Navy and external parties including ISS Contractor, vendors and OEMs.			
7	Based on the demonstration of the model and the achieved results, are you convinced that concentrating efforts on the identified severe factors is highly likely to improve the availability?			

Signature: ______________________

INDEPENDENT FOLLOW UP QUESTIONNAIRE

S/N	Question	YES	NO	Kindly elaborate/ explain ONLY if you answer NO
8	Based on the demonstration of the model and the achieved results, are you convinced that adhering to the 'availability-oriented contract management model' will improve availability of the naval ships?			
9	Based on the demonstration of the model and the achieved results, are you convinced that the 'availability-oriented contract management model' will contribute towards solving the accountability issue faced presently within the Navy branches, and between the Navy and external parties?			
10	If the availability of the fleet of naval vessels is successfully improved, would this impact positively towards the Navy's overall Preparedness and Readiness in multiple dimensions such as improved capability, greater flexibility in assigning ship tasks, improved efficiency, saved cost in unnecessarily having to purchase new vessels, less work stress onboard current high-availability vessels, etc.			

Signature: ________________________

INDEPENDENT FOLLOW UP QUESTIONNAIRE

SECTION C: After completing the questionnaire above are there any further comments and/ or feedback points you would like to make?

Please kindly use space provided below.

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THANK YOU!

Signature: ______________________

Post-Survey Validation Questionnaire: Consolidated Answers

SECTION A: DEMONSTRATION AND EXPLANATION OF THE MODEL					
Details:	PSE-1	PSE-2	PSE-3	PSE-4	PSE-5
Designation	First Admiral	Executive Director	Chief Executive Officer/ Managing Director	Chief of Staff Strategic Management	Director Maritime Safety & Surveillance Division
Organisation	RMN	Shipyard	Shipyard	RMN	MMEA
Total Years working experience	28	24	42	34	40
Total Years Marine industry	28	24	38	34	35
Date	5-April-2018	15-April-2018	18-April-2018	20-April-2018	18-April-2018
SECTION B: FEEDBACK ON THE DEMONSTRATED MODEL AND IMPLEMENTATION CONSIDERATION					
Q1:	YES	YES	YES	YES	YES
Q2:	YES	YES	YES	YES	YES
Q3:	YES	YES	YES	YES	YES
Q4:	YES	YES	YES	YES	YES
Q5:	YES	YES	YES	YES	YES
Q6:	YES	Not able to comment	Not able to comment	YES	YES
Q7:	YES	YES	YES	YES	YES
Q8:	YES	YES	YES	YES	YES
Q9:	YES	YES	YES	YES	YES
Q10:	YES	Not able to comment	Not able to comment	YES	YES

SECTION C: ANY FURTHER FEEDBACK				
PSE-1	PSE-2	PSE-3	PSE-4	PSE-5
1. This study is a new approach in determining Ao, which currently based on conventional method. However, the approach a lot of commitment (data entry) for the dashboard and efforts. 2. This methodology able to determine factor that contributed to Ao, either high or low. However, how to resolve the identified problem has not been explored. This is an opportunity for further research. 3. The model presented consist of equipment and human factor, where human factor is a bit tricky and intangible, in some aspect. Thus, methodology to quantify human factor that contributed to low or high Ao need to be identified. This paper had identified the human elements, but not on how to improve further on human capital - quantifying improvements.	1. Overall is good method. Can implement to MMEA for the New NGPC and OPV also under ISS maybe also MMEA New Projects Multi-Purpose Vessel. 2. Maybe the rectify result can be used to improve on NEW ISS clauses for MMEA New Ships.	1. The model is good and the approach is exciting. However, implementation require full commitment from the top management. 2. In the aviation industry, whenever an aircraft is classified as non-operational (AOG - Aircraft on the Ground) the Maintenance Manager is given unquestionable authority to make the aircraft operational. Such a policy/ authority should be implemented for ships.	1. As the manager of the Navy strategic performance measurement, I find the model proposed with the 15 factors would easily facilitate the Navy in identifying Key Performance Indicators, which will assist in the measurement of the overall preparedness reporting. 2. Secondly the model will now allow the Navy to identify the root causes which have been affecting the readiness state of the fleet. We were not able to ascertain this using the current Urgent Defect model which is very subjective and easily manipulated by certain quarters in the Navy. It will also ensure the Navy moves away from procuring spares "just in case" to "just in time" saving money. 3. Lastly, the issue of ineffective contract management can be addressed quickly as the model provides clearly visibility of the critical factors. This will also ensure the Navy's efficiency savings initiative is realised and save much needed funds and scarce resources.	1. An exciting effort to identify critical factors in meeting MMEA's fleet readiness. I believe the model presented would be of a great help for MMEA to enhance the ship operational availability. In my years of working experience, I have never seen anyone study or being introduced with such model which is very related to our job. 2. Since in MMEA, all vessels maintenance are done through contracts, I hope this model will make the contract manager's job easy. There will be no excuse for them not to be able to monitor closely and will ensure the fleet availability is high as expected. 3. I hope this study are done for the betterment of the MMEA in monitoring our ships availability. This can be achieved if we can find and solve the right inputs as suggested by the model.

APPENDIX D

APPENDIX D

Publications

IEEE EXPLORE

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A delphi approach to identifying the severity of downtime influence factors impacting naval ship operational availability — does the Panel Demographic Impact the Expert Opinion?

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3 Author(s)
Al-Shafiq Abdul Wahid ; Mohd Zamani Ahmad ; Aisha Abdullah
View All Authors

Abstract | Authors | Figures | References | Citations | Keywords | Metrics | Media

Abstract:
High Operational Availability of Naval vessels remains a challenge to many navies worldwide despite increasing and novel approaches to availability. Numerous literatures are published on concepts of availability optimization, nevertheless so far there has been limited holistic research into the combined human and equipment root causes of naval vessel unavailability caused by the various downtime or simply put the naval Downtime Influence Factors (DIFs). To overcome the literature shortage a Delphi approach into the DIFs for the Royal Malaysian Navy In-Service Support for Patrol Vessels was carried out to shed light into unavailability causes and to pinpoint the areas of improvement. In the first stages of the Delphi study a panel of 30 professionals directly involved in naval ship maintenance was selected. A common criticism of the Delphi technique highlights that the selection of experts significantly influences the outcome of the studies. This research analyses via descriptive statistics whether the demographics of the expert sample had an impact on the outcome of the expert opinion, concluding that in most cases neither gender, designation, years of experience, organization type or qualifications impacted the weightage of importance allocated to each DIFs explaining outliners where applicable.

Published in: Control System, Computing and Engineering (ICCSCE), 2017 7th IEEE International Conference on

Date of Conference: 24-26 Nov. 2017

Date Added to IEEE *Xplore*: 08 February 2018

▸ **ISBN Information:**

INSPEC Accession Number: 17577209

DOI: 10.1109/ICCSCE.2017.8284421

Publisher: IEEE

Conference Location: Penang, Malaysia

Browse Conferences > Control System, Computing and...

Development of a downtime influence factor severity index for improvement of naval ship availability: A simple approach for the Malaysian patrol vessel in-service support contract

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8 Author(s)
Al-Shafiq Abdul Wahid ; Mohd Zamani Ahmad ; Sunarsih ; Nur Hanani Ahmad Azlan ; Arifah Ali ; Mohd Najib Abdul Ghani Yolh... View All Authors

Abstract | Authors | Figures | References | Citations | Keywords | Metrics | Media

Abstract:
Navies worldwide have applied with a varied degree of success various maintenance concepts to achieve certain targeted operational ship availability. Nevertheless, few concepts focus on both the human and equipment factors that drive the unavailability or downtime. These factors can be designated as Downtime Influence Factors (DIFs). In previous research the severe DIFs had been identified via a 5-Stage Delphi conducted with experts in the field of Patrol Vessel (PV) In-Service Support (ISS) Contracts in Malaysia. By prioritizing and rating these DIFs based on Risk Assessment it was possible to determine a Severity Index formula. In a first step, the Severity Index (SI) prioritized the DIFs that are severe. In a subsequent step, the interrelationship of the DIFs was analyzed with the help of SPSS and the SI index was adjusted to take into account interrelationships. The resulting adjusted SI assists PV ISS contract stakeholders to pinpoint and focus on human and equipment factors that are the main causes of downtime.

Published in: Control System, Computing and Engineering (ICCSCE), 2017 7th IEEE International Conference on

Date of Conference: 24-26 Nov. 2017

Date Added to IEEE *Xplore*: 08 February 2018

▸ **ISBN Information:**

INSPEC Accession Number: 17577239

DOI: 10.1109/ICCSCE.2017.8284424

Publisher: IEEE

Conference Location: Penang, Malaysia

VOL. 13, NO. 3, FEBRUARY 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

SEVERITY OF DOWNTIME INFLUENCE FACTORS IMPACTING NAVAL SHIP OPERATIONAL AVAILABILITY - A FIVE-STAGE DELPHI CONSENSUS PROCEDURE WITH SNOWBALLING TECHNIQUE

Al-Shafiq Bin Abdul Wahid[1], Mohd Zamani[1], Sunarsih[2], Mohd Najib Bin Abdul Ghani Yolhamid[3], Mohamad Abu Ubaidah Amir Abu Zarim[3], Aisha Binti Abdullah[4] and Nur Hananibt Ahmad Azlan[1]
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ABSTRACT

Operational availability of naval ships, which reflects the number of days they are available for operational tasking in a year, is a complex problem. The number of days the ships are able to spend in an area of operations reveals the sustainability of the naval force in showing of presence and deterrent capability. There have been numerous literatures on calculating downtime through Mean Time between Failure (MTBF) and Mean Time to Repair (MTTR) to obtain availability value; however there have been limited literatures pinpointing to the root cause of the various downtime, called Downtime Influence Factors (DIF) for naval vessels. The limited literatures on DIFs of naval vessels are further restricted in the study of a single factor such as obsolescence or spares availability, or two or three factors at most, whilst in reality the DIFs encompasses a wide range of human and equipment related factors that most researchers have not attempted to study. The situation is further complicated by issues of equipment and component redundancies as well as possible interdependencies between each DIFs. The current research uses a five-stage sequential modified Delphi approach including risk analysis and snowballing technique to identify, validate and rank the severity of all DIFs from two sets of experts in naval ship maintenance contracts. The study revealed 15 severe DIFs involving human and equipment related factors impacting naval ship availability. The result complemented and validated the findings of previous study by the authors involving 30 experts. The results enable the navies and supporting industries to focus on pinpointed areas of concern to enable them to increase the operational availabilities of their ships in the fleet.

Keywords: naval vessels, navy ship maintenance, operational availability, downtime influence factors (DIFs), delphi method.

DEFENCE S&T TECHNICAL BULLETIN

VOL. 11 NUM. 1 YEAR 2018 ISSN 1985-6571

Availability Oriented Contract Management Approach: A Simplified View to a Complex Naval Issue 132 - 153
Al-Shafiq Abdul Wahid, Mohd ZamaniAhmad, Khairol Amali Ahmad & Aisha Abdullah

Ministry of Defence Malaysia

SCIENCE & TECHNOLOGY RESEARCH INSTITUTE FOR DEFENCE (STRIDE)

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

Al-Shafiq Abdul Wahid[*1], Mohd Zamani Ahmad[2], Khairol Amali Ahmad[3] & Aisha Abdullah[4]

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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.*

DEFENCE S&T TECHNICAL BULLETIN

VOL. 11 NUM. 2 YEAR 2018 ISSN 1985-6571

Demystifying Ship Operational Availability: An Innovative Approach for Management of In-Service Support Contracts 338 - 360
Al-Shafiq Abdul Wahid, Mohd Zamani Ahmad, Khairol Amali Ahmad, Joshua P. Taylor, Aisha Abdullah, Al-Athirah Al-Shafiq, Arifah Ali & Keizo Kitagawa

Ministry of Defence Malaysia

SCIENCE & TECHNOLOGY RESEARCH INSTITUTE FOR DEFENCE (STRIDE)

DEMYSTIFYING SHIP OPERATIONAL AVAILABILITY: AN INNOVATIVE APPROACH FOR MANAGEMENT OF IN-SERVICE SUPPORT CONTRACTS

Al-Shafiq Abdul Wahid[1*], Mohd Zamani Ahmad[2], Khairol Amali Ahmad[3], Joshua P. Taylor[4], Aisha Abdullah[5], Al-Athirah Al-Shafiq[6], Arifah Ali[7] & Keizo Kitagawa[8]

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ABSTRACT

Asset availability optimisation concepts have been studied in a multitude of industries for a few decades now. The defence industry is no exception, whilst traditionally navies worldwide were concerned in achieving targeted ship availability, nowadays budget and regulatory restrictions increase the burden for all stakeholders. Most concepts developed are applied to systems that do not have many interlinked and parallel operating sub-systems. Nevertheless, navy ships are complex assets and it appears no generic framework has yet been developed that is universally applicable. A key drawback is that historically, proposed efforts remained placed on complex mathematical calculations and estimates, which required not only sophisticated programmes but also limited the understanding to a few highly skilled professionals able to implement them. This has never been appealing to most practitioners as well as the majority of stakeholders who continuously complain about the gap between theory and practice. This paper proposes an innovative 4-step approach by demystifying ship operational availability involving both human and machinery/systems related factors. These factors called downtime influence factors (DIFs) are presented in a simplified 'bite-size' form for better understanding of the practitioners to enable them to appreciate their individual contribution towards improving the common goal achieving higher Ship Operational Availability.

Keywords: *Demystifying ship availability; human and equipment factors; downtime influence factors (DIFs); severe DIFs; 4- step availability improvement.*

International Journal of Engineering & Technology, 7 (2.29) (2018) 940-946

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Measuring Severity of Downtime Influence Factors to Naval Ship Operational Availability: A Delphi Study

Al-Shafiq Bin Abdul Wahid[1]*, Mohd Zamani Bin Ahmad[2], Sunarsih[3], Mohd Najib Bin Abdul Ghani Yolhamid[4], Mohamad Abu Ubaidah Amir Abu Zarim[5], Aisha Binti Abdullah[6], Nur Hanani Bt Ahmad Azlan[7]

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Abstract

Rapid development of shipbuilding and ship repair industry in recent years has been increasingly transforming the way organizations apply the long term strategic thinking of "cradle to grave" maintenance approach in order to maximize their growth in a dynamic marine industry. With increased ship complexity, size and revolutionary design, organizations strive to balance ideal maintenance philosophies against on-going efforts of cost reduction whilst maintaining high availability of vessels. Despite aspiration and efforts to improve the ship availability, the Royal Malaysian Navy [RMN] vessels which are currently maintained under the In Service Support [ISS] Contracts are hardly tackling the human and equipment related aspects due to limited knowledge and available data on ship Downtime Influence Factors [DIFs]. The current research carried out an explorative study across various engineering disciplines to generate RMN ship maintenance DIFs and their severity measures via a 3-Stage Modified Delphi approach. 30 Experts experienced in daily implementation of naval ship maintenance contracts were involved. In the first stage, Focus Group Discussions [FGDs] amongst Experts were conducted to produce the DIFs, followed by questionnaire distribution to measure the severity of the DIFs in the second stage. In the third stage, the Severe DIFs were confirmed and ranked based on a Risk Assessment method. The study revealed 50 DIFs to RMN ship availability and deduced the top 15 Severe DIFs pinpointing the key problem areas to prioritize efforts in improving RMN ship availability.

***Keywords**: Naval vessels; navy ship maintenance; operational availability; Downtime Influence Factors [DIFs]; Delphi method.*

JOURNAL OF ENGINEERING SCIENCE AND TECHNOLOGY

Journal of Engineering Science and Technology
Vol. 13, No. 12 (2018) 4326 - 4346

DEMYSTIFYING SHIP OPERATIONAL AVAILABILITY – AN ALTERNATIVE APPROACH FOR THE MAINTENANCE OF NAVAL VESSELS

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Abstract

Asset availability improvement has been the focus of many studies by various industries for a few decades now, and the defence industry is no exception. To date, there exists no simple and inexpensive high availability solution for the complex naval ships consisting of many interdependent systems and subsystems working in parallel. Any given approach must strike a balance between true needs and economics, an ever-increasing decision-making burden to stakeholders. Nevertheless, there are many ways to approach the problem. In the past, availability has been viewed as complex mathematical calculations and estimates involving defective equipment. The applied approach has not been fully understood nor appealing to most practitioners as well as the majority of stakeholders who continuously complain about the gap between theory and practice. This paper aims to demystify the complex naval ship availability issue, simplified for easy understanding of operators, maintainers and logisticians as well as other stakeholders involved in the maintenance of naval vessels. The step-by-step approach begins with the identification of severe factors involving both human and machinery affecting downtime of naval vessels culminating into the generation of an availability-oriented model, summarized to a simple four-step approach to availability improvement. Practitioners are now able to appreciate their individual contribution towards improving ship availability.

Keywords: 4-steps availability improvement, Demystifying ship availability, Downtime influence factors (DIFs); Human and equipment factors; Severe DIFs.

INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING

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DOI: https://doi.org/10.30880/ijie.2018.10.05.025

Contract Management Control and Monitoring System for the Royal Malaysian Navy – Post Survey Validation via Top Management Experts

Al-Shafiq bin Abdul Wahid*

Faculty of Mechanical Engineering, Universiti Teknologi Malaysia (UTM), 81310 Skudai, Malaysia.

Received 2 August 2018; Accepted 13 August 2018; Available online 30 October 2018

Abstract: The improvement of naval ship operational availability remains a critical aspect to navies worldwide. Despite sophisticated methodologies and complex In-Service Support Contracts in place to achieve high operational availability, even the most advanced navies are still struggling to strike a balance between availability targets, budget and regulatory restrictions. This situation is also applicable to the Royal Malaysian Navy. A Contract Management Control and Monitoring System (ConCaMS) was developed to target both human and machinery related factors affecting naval availability or so-called Downtime Influence Factors. These factors are identified and prioritized based on their severity based on Delphi methodology. The resulting system is validated via top management experts that concluded in unison the benefits of ConCaMS especially in improving availability.

Keywords: Improving naval availability, Downtime Influence Factors, Contract Management Control and Monitoring System (ConCaMS), Post-Survey Validation, top management experts.

APPENDIX E

Appendix E - ConCaMS Brief User Guide

Monitor Ao & share visibility

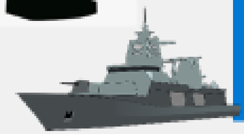
CONCAMS offers great visibility of Availability for individual vessels but also for the fleet of vessels.

2. Monitor Actual vs Target Ao and share Ao Status

- You've got an ISS contract and you need to regularly work together with stakeholders including your customer.
- Invite selected stakeholders to access CONCAMS and provide visibility of Ao status.
- Update downtime on a daily basis and see at a glance Actual Ao vs Target Ao.
- The availability indicator will immediately alert whether you are in the red, yellow or green zone compared to target.
- The Recovery Ao will provide the steps to improve Ao by reducing downtime.

CONCAMS makes it easy to monitor unavailability, even for those less experienced personnel.

Severe DIFs



CONCAMS offers you an approach to recover Ao by prioritizing the Downtime Influence Factors you need to improve to achieve your target Ao.

2. Focus on improving Severe Downtime Influence Factors (DIFs)

Understand which DIFs are causing the majority of the downtime by looking at the severe DIFS and their description in table and chart format.

- **Downtime due to other DIFs** — 11 days
- **Severe Downtime Influence Factors** — 43 days

11 days + 43 days = 54

Description:	Severity Index	Downtime days
Corrective maintenance	0.142	7 days
Spares availability	0.082	4 days
Cashflow shortages	0.078	4 days
Maintance budget allocation	0.075	3 days
Knowledge manag. incl training, knowledge, skills and systems	0.070	3 days
Equipment and systems - Propulsion	0.069	3 days
Maintenance policy and priority on type of maintenance	0.067	3 days
Availability of OEM expert support	0.061	3 days
Awareness of importance of maintenance & attitude	0.059	3 days
Availability of Facilities	0.059	3 days
Availability of local vendor support	0.058	2 days
Complexity and efficiency of existing maintenance contracts	0.058	2 days
Equipment and systems - Auxiliaries	0.056	2 days
Scheduling issues	0.042	1 days
Impact of parallel contracts	0.022	0 days
TOTAL	1.000	43 days

Recovery Ao

CONCAMS will calculate the recovery Ao for the balance of the contract period and focus attention on the maximum number of downtime days per DIF.

3. The Recovery Ao

CONCAMS will calculate the Recovery Ao required to be achieved in the balance contract period to meet the target availability.

Recovery Ao

Description:

Contract Period	1095	in days
Balance contract	915	in days
Target Availability	93%	in %
Uptime target	851	in days
Max Downtime	64	in days
Max SDIF downtime	51	in days
Already lost due to sSIF	43	in days
Max balance	8	in days
Recovery Ao	99%	balance

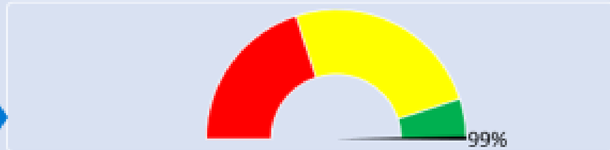
Description:

Corrective maintenance	2	in days
Spares availability	1	in days
Cashflow shortages	1	in days
Maintance budget allocation	1	in days
Knowledge manag. incl training, knowledge, skills and systems	1	in days
Equipment and systems - Propulsion	1	in days
Maintenance policy and priority on type of maintenance	1	in days
Availability of OEM expert support	0	in days
Awareness of importance of maintenance & attitude	0	in days
Availability of Facilities	0	in days
Availability of local vendor support	0	in days
Complexity and efficiency of existing maintenance contracts	0	in days
Equipment and systems - Auxiliaries	0	in days
Scheduling issues	0	in days
Impact of parallel contracts	0	in days
MAX DOWNTIME	8	in days

The maximum balance downtime per severe DIF will focus stakeholders attention on areas of highest priority.

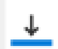
The overall Recovery Ao is displayed to guide users on efforts required to achieve target availability.

Recovery Ao



To achieve a Target Ao of 93% the Recovery Ao is 99% for the balance contract period

Please contact author for a DEMO version of the CONCAMS.



4. Compare performance across the Fleet

With CONCAMS, you can also track status of your vessel compared to other vessels in the fleet.

5. Limitations of CONCAMS

Whilst CONCAMS is a simple and user friendly availability oriented contract management model it has its limitations and shortcomings as follows:

Can Do

- Model is customizable.
- Monitor Vessel vs Fleet Ao.
- Recovery Ao is indicated.

Can't Do

- Model requires to run (past data) for at least 6 months.
- Model calculates full days only.

For more information, kindly email shafiq@enigmatechnicalsolutions.com

APPENDIX F

APPENDIX F

Testimonials from Asset Management Software Companies

Atos Services (M) Sdn Bhd
1st Floor, 2310 Century Square
Jalan Usahawan
63000 Cyberjaya, Malaysia
T +60 3 8316 0288
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atos.net

To whoever it may concern

4th June 2018

Dear Sir,

LETTER OF TESTIMONIAL FOR: AL-SHAFIQ BIN ABDUL WAHID
INTEGRATED LOGISTICS SUPPORT SERVICES FOR THE ROYAL MALAYSIAN NAVY

Atos is an international information technology services company, delivering hi-tech IT and LS, transactional services, consulting, systems integration and managed services with an annual revenue of € 11 billion with almost 95,000 business technologists worldwide in 72 countries. For further details please visit www.atos.net.

With reference to the above, we wish to confirm that Atos Services (M) Sdn Bhd has engaged Mr Al-Shafiq Bin Abdul Wahid as our ILS Project Consultant since 2014. He has been leading our ILS Team to successfully deliver all the ILS deliverables for the Royal Malaysian Navy Training Vessels (RMN TRV) KD GAGAH SAMUDERA and KD TEGUH SAMUDERA. The ships have been delivered with all ship maintenance documentation and data pre-loaded onto Atos's Asset Maintenance and Planning System (AMPS). Mr Al-Shafiq has successfully conducted crew training and handing over of the complete system to the RMN.

Mr Al-Shafiq has also been working closely with our team on the development of his availability-oriented CONCAMS model as part of his PhD research, alongside ATOS team's development of AMPS version 7. I truly believe that his knowledge and experience in ship construction and maintenance, and his competency in AMPS has helped him successfully develop the CONCAMS, based on data gathered from the top management of the RMN and shipyards. The CONCAMS ability in identifying the actual problem areas affecting operational availability is ground-breaking, and so is his pioneering introduction of the Recovery Availability concept. These new concepts have been introduced to AMPS design team for discussions on future developments of AMPS systems. We have been closely monitoring his published work and we look forward to possible co-authoring future publications with him.

Should you require further information, please feel free to contact us. Thank you.

Yours faithfully,
ATOS SERVICES (M) SDN BHD

Magnus Alvarsson
Head of Malaysia
Atos Services (M) Sdn Bhd

CWORKS

17th July 2018

To whoever it may concern

Dear Dato/Tuan/Puan,

LETTER OF TESTIMONIAL

As the Chief Executive Officer of CWorks Sdn Bhd, I would like to take this opportunity to provide our undividing support to Mr Al-Shafiq Bin Abdul Wahid who has been our Asset Management and Integrated Logistics Support (ILS) Consultant for all our projects with the Malaysian Maritime Enforcement Agency (MMEA).

He has been an instrumental leader in the technical document development, data harvesting, configuration, training and subsequently the delivery of our Cworks Asset Management System to the MMEA for the 6 New Generation Patrol Crafts (NGPC). 4 NGPC have been delivered to date and 2 NGPC are expected to be delivered within the next 6 months. Due to the success in the delivery of 4 NGPCs, we have been awarded with the contract for the development of Cworks for 3 MMEA Offshore Patrol Vessels that has recently commenced construction. The new development would integrate the Cworks onboard all the vessels to the MMEA Headquarters in Putrajaya.

Our team has participated in many discussions with Mr Al-Shafiq on his operational availability studies, and have considered many of his ideas and concepts into our future development of Cworks system especially for the marine industry. At the moment, we have managed to sell millions worth of Cworks licences worldwide, and some customers have requested for customized versions of our best-selling generic product.

The feedback received from the top management of MMEA and also Royal Malaysian Navy received from Al-Shafiq are invaluable to us as system developers. As the founder of Cworks, I am very interested in his CONCAMS system as we have not encountered anything of that sort in many years of my system development and implementation works. We are familiar with generic 'availability calculations' in asset management but it is amazing to see his detailed list of factors that impact availability of the vessels. The 'recovery availability' concept is also very simple and meaningful for asset managers, but has never been introduced by anyone previously.

Mr Al-Shafiq has been working closely with the Cworks team since 2016 and we look forward to many more years of collaboration with him, professionally and in published work.

Thank you.

Regards
Cworks Sdn Bhd

HjAbdulRaniAchmed
Chief Executive Officer

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LIST OF PUBLICATIONS

Scopus Indexed Journal

1. **Al-Shafiq, A.W.,** Zamani, M., Sunarsih, Mohd Najib, B.A.G.Y., Ubaidah, A.A.Z, Abdullah, A. & Nurhanani, A. (2018). Severity of downtime influence factors impacting naval ship operational availability: A five-stage delphi consensus procedure with snowballing technique, *ARPN Journal of Engineering and Applied Sciences*, 13(3), 939-946.

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