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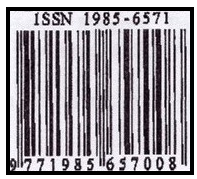

DEMYSTIFYING SHIP OPERATIONAL AVAILABILITY: AN INNOVATIVE APPROACH FOR MANAGEMENT OF IN-SERVICE SUPPORT CONTRACTS

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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.*

1. INTRODUCTION

Asset availability optimisation concepts have been introduced and studied at length and in depth in a multitude of industries for a few decades now. For industrial organisations, high asset availability has traditionally been linked to higher profits, while for the defence sectors high availability was viewed as a required performance measure or a targeted Operational Availability (A_o) (OPNAVINST 3000.12A, 2003). However, in recent years, government agencies worldwide are increasingly subjected to higher risk compliance with a reducing defence budget. This is also the case for most navies that have to strike a balance to satisfy the various stakeholder requirements. Some navies have pioneered innovative concepts such as contracting for availability as a means to delegate some of the burden to their contractors, such as the Royal Navy in the UK (Tomkins, 2012) and Italian / French Navy through the FREMM Program (Dell'Isola & Vendittelli, 2015). Other navies such as Australia are studying how to achieve the

optimum Preventive Maintenance requirements to mitigate technical risks to an acceptable level, comply with regulations and policy and provide an acceptable level of Ao at the lowest Life Cycle Cost as studied by Hamilton (2016).

The Royal Malaysian Navy (RMN) alike its counterparts world-wide also strives to achieve high Ship Availability within a set budget, whilst achieving its vision of becoming a World Class Navy (RMN, 2017). Nevertheless, even those established navies such as USN, Dutch Navy, Royal Navy UK, Australian Navy have not been able yet to formulate a strategy that can be applied either to their own fleet or universally to improve availability whilst regulatory, quality or / and cost performance measurements are being imposed. In simple terms, there appears to be no generic "best suited methodology". This is mostly due to the fact that naval vessels are complex assets and have to be viewed as system of systems with highly interlinked relationships. The term System of Systems (SoS) is used by the US Navy Research, Development and Acquisition (2006) in an Engineering Guidebook to describe an integrated force package of interoperable systems acting as a single system to achieve a mission capability.

In accordance to Reliability Analysis Centre (2004), operational availability is not just a function of design but also of maintenance policy, logistics system and other supportability factors. It can be improved by improving the design, improving the support, or both. As availability is a measure of maintenance performance (Parida & Kumar, 2009) , history has shown that efforts resulting in an increase of ship operational availability is commendable. Admiral Bowman was lauded by US Congress for his leadership in achieving an increase of 25% ship operational availability for the CVN21 aircraft carrier (US Congress, 2004). The key concept of the presented research is that Availability can be simply expressed as Uptime and can be formulated as "One minus Downtime" as derived from Hou Na *et al.* (2012). Basically, the lower the Downtime, the higher is the Availability.

Efforts in improving availability and implementing various independent strategies without identifying and understanding the underlying downtime influence factors (DIFs) could be futile as some of these DIFs may be the root cause to the resulting short, medium and long-term issues. Due to limited available data and research into naval ship DIFs, a literature review across various engineering disciplines on factors affecting Downtime and Operational Availability was carried out by the authors. The focus of the research is based around the RMN Patrol Vessels (PVs) that are currently being maintained through the In-Service Support (ISS) Contract between the Government of Malaysia (GoM) and Boustead Naval Shipyard (RMN, 2011). The ISS Contract covers Maintenance Services, Spare Parts, Training and Computer Support System for Maintenance.

This paper represents the latest instantiation of a series of evolving work by the authors, subsequent to Al-Shafiq *et al*. (2018) attempting to improve the methods and techniques used by various stakeholders worldwide in their attempt in improving their operational availability figures in general, with an immediate application to naval surface combatants. The main contributions include the consolidation of a multitude of DIFs related to human and equipment from various fields of research, the ranking of DIFs to identify the most troublesome factors, the application of multiple rounds of Delphi Methodology with Snowballing Technique to improve rigour of the study. The findings are introduced in a simplified 'bite-size' approach which can easily be appreciated by practitioners to enable them recognize their individual contribution towards improving the organization's operational availability.

2. METHODOLOGICAL APPROACH TO THE RESEARCH

2.1 Gap between Theory and Practice

The authors agree with the findings of Dekker (1996) that many papers have been written for math purposes only. Mathematical analysis and techniques, rather than solutions to real problems, have been central to many papers in maintenance optimisation models. However, the mathematical results are not appealing to practitioners. Dekker (1996) continued by stating that it is astonishing how little attention is paid either to make results worthwhile or understandable to practitioners, or to justify models on real problems or to consider data problems.

The authors further agree with Dekker (1996) that companies are not interested in publication and that many good ideas have been developed in industry, but only a small amount has appeared in scientific literature. To have academics study industrial problems, they have to be exposed to them and be rewarded if they solve them. Although academic freedom is a great thing, it does not force academics to tackle industrial problems. Therefore, companies should stimulate researchers by offering them problems and allowing them to analyse and publish their results. Dekkers (1996) also reiterated that sometimes if approaches are successful, companies are afraid of losing a competitive edge by publishing their findings. A competitor might use information disclosed in a scientific paper to develop a competing product or otherwise gain commercial advantage or to discredit the product claims of the company making the disclosure (National Research Council, 2003). Furthermore, scientific literature focuses on new aspects and thus, the tenth application of a model will not be published. Therefore, the authors have embarked on the journey of bridging the knowledge gap between academics and practise, with the hope that the published study would benefit all, academics and practitioners alike.

2.2 Identification of the Downtime Influence Factors

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 organisation structure.

All pertinent information relevant to the scope of the current ISS contract includes Planned Maintenance or Preventive Maintenance (PM), Corrective Maintenance (CM), 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. 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 was conducted.

A 7-Stage modified sequential Delphi approach into identifying the DIFs for the RMN ISS for patrol vessels (PV) was carried out as summarised in Table 1 and presented by Al-Shafiq *et al.* (2017a, b). The objective was to discover and better understand the unavailability causes and to highlight as well as to prioritise 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 the subsequent stage, five Top Management Experts as proposed via Snowballing Technique in earlier rounds were used to validate and confirm the findings.

Table 1: The seven stages of the Delphi study.

Research Stage	Phase, Expert Group & Delphi Round	Activity and Results
Stage 1 Focus Group Discussion (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.

Table 2 summarises the 50 categories of DIFs as supported by literatures from various fields and Focus Group Discussion (FGD) involving the 30 experts.

Table 2: Summary of 50 DIFs and the relevant literature.

S/No	DIFs for Ship Operational Availability	Authors of literatures from various fields
1	Equipment and Systems – Hull and Design	(GAO, 1981), (GAO, 1982), (GAO, 2014a), (GAO, 2014b), (GAO, 2014c), (Rosenberger & Pointner, 2015), (Dell'Isola & Vendittelli, 2015), (Forsthoffer, 2005), (Bloch&Geitner, 2012), (Jardine *et al*., 1993), (Allred, 1995), (IAEA, 2005), (Prasertrungruang & Hadikusumo, 2009), (Glorian & Spiegelberg, 1998), (Dhillon, 2002), (Papavinasam, 2013), (Al-Najjar, 1998), (Nepal & Park, 2004), (WEC, 1991), (Balafas et al. 2010), (Odeyinde, 2008), (Lazakis *et al.*, 2010), (Sinnasamy *et. al*, 2017).
2	Equipment and Systems – Main Propulsion	
3	Equipment and Systems – Electrical	
4	Equipment and Systems – Weapon Systems including guns and missiles	
5	Equipment and Systems – Auxiliaries	

6	Equipment and Systems – Outfittings	
7	Maintenance Policy - Priority on Type of Maintenance	(Dell'Isola & 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*., 1993), (Al-Najjar, 1998), (Marquez & Gupta, 2005), (Colosi *et al.,* 2010), (Pascual *et al*., 2006), (Park *et al.*, 2010), (Nepal & Park, 2004), (Goossens, 2015), (Jazouli & Sandborn, 2011), (Stambaugh & Barry, 2014), (Pan *et al.,* 2012), (Reliability Analysis Centre, 2004), (Boyle *et al.*, 2011), (Farajiparvar, 2012), (U.S. Navy, 2014).
8	Awareness of Importance of Maintenance / Attitude – including hiding problems from becoming official.	(Leva & McDonald, 2013), (GAO, 1982), (Bloch & Geitner, 2012), (Morris & Sember, 2008), (Jonsson, 1997), (Marquez & Gupta, 2005), (Banaitiene & Banaitis, 2012), (Attwater *et al*., 2014), (Mafini & Dubihlela, 2013), (Obeng-Odoom & Amedzro, 2011), (Zahedi-Seresht *et al*., 2014), (Chang, 1999), (Blaikie, 1993).
9	Maintenance Budget Allocation	(Dell'Isola & Vendittelli, 2015), (Sullivan, 2011), (Dhillon, 2002), (Dhillon, 2002), (Lock, 2014), (GAO, 2014), (GAO, 2014b), (Commission on Wartime Contracting, 2011), (Jardine *et al*., 1993), (Stambaugh & Barry, 2014), (Nepal and Park, 2004), (Jonsson, 1997), (Dekker, 1996), (GAO, 1982), (Walker, 2005), (Bateson, 1985), (Kazi, 2005), (Swanson, 2001), (Henry & Bil, 2015), (Garel, 2013), (Romzek & Johnston, 2002), (Apte *et al.*, 2008), (Yuan, 2016), (Atkinson, 1999), (Pascual *et al*., 2008), (Stambaugh & Barry, 2014), (Eckstein, 2016), (Erwin, 2014), (Balafas *et al.*, 2010), (Odeyinde, 2008), (Zahedi-Seresht *et al*,. 2014)
10	Information Management	(GAO, 1982), (Ford *et al.,* 2013), (Bloch & Geitner, 2012), (Jonsson, 1997), (Ljungberg, 2009), (Belkhamza & Wafa, 2012), (U.S. Congress, 1986), (RAND, 1996), (IAEA, 2005), (Jardine *et al*., 1993), (Dekker *et al*, 1998), (GAO, 2002), (Mathew *et al.*, 2006), (Harz, 1981)
11	Preventive Maintenance	(Rosenberger & Pointner, 2015), (Driessen *et al.*, 2010), (Dhillon, 2002), (Bloch & Geitner, 2012), (Edwards *et al.,* 1998), (Pecht, 2009), (Jonsson, 1997), (IAEA, 2005), (Gits, 1994), (Dell'Isola & Vendittelli, 2015), (Pogačnik *et al*., 2015), (Marquez & 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)
12	Corrective Maintenance	(GAO, 1981), (Driessen *et al.*, 2010), (Dhillon, 2002), (Jonsson, 1997), (Cooke & Paulsen, 1997), (Ross, 2009), (Dell'Isola & Vendittelli, 2015), (Pogačnik *et al*., 2015), (Kadry, 2013), (Chang, 1999), (Marais *et al*., 2013), (Schreiber, 2007), (Deris *et al.,* 1999), (Eti *et al*., 2004), (Weibull, 2017)
13	Predictive Maintenance	(Dell'Isola & Vendittelli, 2015), (Dhillon, 2002), (Bloch & Geitner, 2012), (Edwards *et al.,* 1998), (Cooke & Paulsen, 1997), (Swanson, 2001), (Marquez & Gupta, 2005), (Katsikas *et al.*, 2014), (Popovic *et al.,* 2011), (Offenbeek & Vos, 2016).
14	Emergency Repair & Docking	(Houtum & Kranenburg, 2015), (Pizam, 2010), (Telsang, 2007), (GAO, 2005), (Dhillon, 2002), (Jonsson, 1997), (Kowalski, 2002).

15	Equipment Technology / System Complexity	(Dell'Isola & Vendittelli, 2015), (McNamara *et al.,* 2015), (Jonsson, 1997), (Psenka, 2008), (Ross, 2009), (Pecht, 2009), (Kobbacy & Murthy, 2008), (Dean, 2003), (Walsh, 2014), (Darnall & Preston, 2010), (Deris *et al.,* 1999), (Glorian & Spiegelberg, 1998), (Xia *et al*., 2012), (Ford *et al.,* 2013), (Dhillon, 2002), (Blaikie, 1993), (Marquez & Gupta, 2005), (Mavris, 2007)
16	Scheduling Issues	(Persson & Stirna, 2015), (Wilson, 2015), (Wilson, 2014), (Peters, 2014), (Bawa, 2009), (Kerzner, 2013), (Burford, 2012), (Banaitiene & Banaitis, 2012), (Badiru, 2009), (Colosi *et al*., 2010), (Park *et al.,* 2010), (Odeh & Battaineh, 2002), (Darabaris, 2006), (Deris *et al.,* 1999), (GAO, 1981), (Xia *et al*., 2012), (Dhillon, 2002), (Miau &Holdaway, 2013), (Pogačnik *et al*., 2015), (Atkinson, 1999), (Marquez & Gupta, 2005), (Nepal & Park, 2004), (Pan *et al.,* 2012), (Jonsson, 1997), (Marais *et al*., 2013), (Dekker *et al,* 1998), (Swanson, 2001)
17	Maintenance of Special Tools, Test Equipment	(Dell'Isola & Vendittelli, 2015), (Pecht, 2009), (Dhillon, 2002), (GAO, 1982), (Atkinson, 1999), (Staub-French & Nepal, 2007), (Harz, 1981), (Mathew *et al.*, 2006)
18	Availability of Facilities	(Dell'Isola & Vendittelli, 2015), (Rosenberger & Pointner, 2015), (Banaitiene & Banaitis, 2012), (GAO, 1981), (Denman, 1999), (GAO, 2015b), (IAEA, 2005), (Dhillon, 2002), (GAO, 1982), (Deris *et al.,* 1999), (Henry & Bil, 2015), (Pogačnik *et al*., 2015), (Nepal and Park, 2004), (Harz, 1981), (Balafas *et al.*, 2010), (Darabaris, 2006)
19	Spares Availability	(McNamara *et al.,* 2015), (Dell'Isola & Vendittelli, 2015), (Rosenberger & Pointner, 2015), (Banaitiene & Banaitis, 2012), (Driessen *et al.*, 2010), (Gits, 1994), (RAND, 1996), (Denman, 1999), (Dhillon, 2002), (GAO, 1982), (GAO, 1981), (Jardine *et al*., 1993), (Marquez & Gupta, 2005), (Colosi *et al*., 2010), (Nepal and Park, 2004), (Harz, 1981), (Balafas *et al.*, 2010), (Sandborn, 2013)
20	Obsolescence Issues	(Allman, 2015), (Dell'Isola & Vendittelli, 2015), (Mequignon & Haddou, 2014), (Moir & Seabridge, 2012), (Finch, 2012), (Bartels *et al.,* 2012), (Clavareau & Labeau, 2009), (Adriaansen, 2004), (National Research Council, 1993), (Driessen *et al.*, 2010), (Stambaugh & Barry, 2014), (Colosi *et al*., 2010), (Nepal and Park, 2004), (Ladetto, 2015), (Sandborn, 2013), (Berkok *et al.*, 2013), (Freeman & Paoli, 2015), (Benedetto, 2014b), (Erkoyuncu *et al.*, 2015), (Rojo *et al.,* 2009)
21	Design and Design Change Issues	(Rosenberger & Pointner, 2015), (Dell'Isola & Vendittelli, 2015), (Papavinasam, 2013), (Xia *et al*., 2012), (Dhillon, 2002), (GAO, 1982), (Abowitz & Toole, 2010), (Bloch & Geitner, 2012), (Jonsson, 1997), (Dekker, 1996), (Pecht, 2009), (Coles *et al.*, 2003), (Smith, 2005), (Temple & Collette, 2013), (Sullivan, 2011), (Australian National Audit Office, 2001), (Psenka, 2008), (Al-Najjar, 1998), (Stambaugh & Barry, 2014), (Ridgway *et al*., 2009), (Marquez & Gupta, 2005), (Pascual *et al*., 2006).

22	Knowledge Management incl Training, Knowledge and Skills	(Dell'Isola & Vendittelli, 2015), (GAO, 2014a), (Bloch & Geitner, 2012), (Pecht, 2009), (Ross, 2009), (Dollschnieder, 2010), (152), (Dhillon, 2002), (Swanson, 2001), (Najjar, 1998), (Glorian & Spiegelberg, 1998), (Jonsson, 1997), (U.S. Congress, 1986), (GAO, 1982), (Lock, 2014), (Goh & Yip, 2014), (Comission on Wartime Contracting, 2011), (GAO, 2002), (Glorian & Spiegelberg, 1998), (Al-Shammari, 2009), (Henry & 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*., 2006), (Bianchetti, 2012)
23	Availability of OEM Expert Support	(Dell'Isola & Vendittelli, 2015), (IAEA, 2005), (Dhillon, 2002), (U.S. Congress, 1986), (Stackley, 2009).
24	Availability of Local vendor support	(Dell'Isola & Vendittelli, 2015), (More, 2013), (IAEA, 2005), (Dhillon, 2002), (Denman, 1999), (GAO, 1982), (Palvia *et al.*, 1996), (Karampelas, 2005).
25	Complexity and efficiency of existing contract	(Xia *et al*., 2012), (USN 2012), (McNamara *et al,*. 2015), (Pecht, 2009), (Pascual *et al*., 2006), (Offenbeek & Vos, 2016), (Balafas *et al.*, 2010), (Price, 2013), (Wiggins, 1985), (Stackley, 2009).
26	Capability of Customer performing Maintenance	(Dell'Isola & Vendittelli, 2015), (Banaitiene & 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 & Kittony, 2008), (Harz, 1981), (Morris & Sember, 2008), (Obeng-Odoom & Amedzro, 2011).
27	Morale & Attitude of Customer involved in Maintenance	
28	Morale & Attitude of Contractor involved in Maintenance	(Jonsson, 1997), (GAO, 1982), (U.S. Congress, 1986), (Leva & McDonald, 2013), (Bloch & Geitner, 2012), (Morris and Sember, 2008), (Banaitiene & Banaitis, 2012), (Obeng-Odoom & Amedzro, 2011), (Attwater *et al*., 2014), (Odeh & Battaineh, 2002), (Rendon, 2009), (Rendon & Snider, 2008).
29	Efficiency of Processes, Procedures and reporting structure include Finance	(Dell'Isola & Vendittelli, 2015), (Sullivan, 2011), (Dillon, 2002), (Lin *et al*, 2015), (Thai, 2004), (Burford, 2012), (Odeh & Battaineh, 2002), (Foerst, 2010), (Goh & Yip, 2014), (McIntosh, E&Y, 2003), (Bloch & Geitner, 2012), (Jardine *et al*., 1993), (Edwards *et al.,* 1998), (GAO, 1982), (Harz, 1981), (Bianchetti, 2012).
30	Ship Operational/sailing schedule	(RAND, 2006), (House of Commons Defence Committee, 2006), (Popovic *et al.,* 2011), (Marais *et al*., 2013)
31	Non-Commonality of Equipment issues	(Driessen *et al.*, 2010), (Chang, 1999)
32	Non-Redundancy of Equipment	(Driessen *et al.*, 2010), (Dekker, 1996), (U.S. Congress, 1986), (Rosenberger & Pointner, 2015), (Nannapaneni *et al*., 2014), (Lin *et al*, 2015), (Staub-French & Nepal, 2007), (More, 2013), (Marquez & Gupta, 2005), (Pascual *et al*., 2006)
33	High Turnover of maintenance supervisors.	(Chitram, 2008), (Dhillon, 2002), (Tan *et al*., 2002), (Lowry *et al.*, 2006), (Mathew *et al.*, 2006), (Mokaya & Kittony,

34	High Turnover of maintainers	2008), (Thomas, 2013), (Mafini & Dubihlela, 2013), (GAO, 2014c), (Belkhamza & Wafa, 2012), (Price, 2013), (Parliament UK, 2008), (Wang *et al*., 2010)
35	Different location of ships	(RMN, 2011), (Dhillon, 2002), (GAO, 2015), (Golding & Griffis, 2003), (Lu *et al*., 2010), (Skoko *et al,* 2013).
36	Statutory requirements	(IAEA, 2005), (WEC, 1991), (Goh & Yip, 2014), (Marquez & Gupta, 2005), (Glorian & Spiegelberg, 1998), (Lock, 2014)
37	Cashflow Shortages	(Banaitiene & Banaitis, 2012), (IAEA, 2005), (GAO, 1982), (GAO, 1981), (GAO, 2014a), (GAO, 2014c), (Denman, 1999), (U.S. Navy, 2012), (Lock, 2014), (GAO, 2014b), (Glorian & Spiegelberg, 1998), (IAEA, 2005)
38	Government Requirements and Policies (i.e. EEP, Offset etc),	(MOF, 2011), (TDA, 2010-2017), (Berkok *et al.*, 2013), (Bil & Mo, 2013), (Rendon, 2009), (Lee & Dobler, 1971), (Moe, 1984), (Romzek & Johnston, 2002)
39	Variation Order and Contract Change	(Banaitiene & Banaitis, 2012), (Lock, 2014), (Apte *et al.*, 2008), (Carter, 2015), (Odeh & Battaineh, 2002), (Rendon, 2009), (Thai, 2004), (Rendon & Snider, 2008), (GAO, 2009), (Rendon, 2009), (Rendon, 2009b), (Humbert & Mastice, 2014), (Price, 2013), (Romzek & Johnston, 2002).
40	Ageing /Aging of Equipment	(Mathew *et al.*, 2006), (Ladetto, 2015), (Glorian & Spiegelberg, 1998), (Colosi *et al*., 2010), (Garel, 2013), (Marquez & Gupta, 2005), (Keller *et al.*, 2002), (Stambaugh & Barry, 2014), (Pascual *et al*., 2006), (Park *et al.,* 2010), (Mafini & Dubihlela, 2013), (Offenbeek & Vos, 2016), (Davis, 2014), (Boonstra *et al.*, 2008), (Bianchetti, 2012), (Rendon, 2009), (Nepal and Park, 2004), (Chang, 1999), (Rendon & Snider, 2008)
41	Force Majeure	(RMN, 2011), (IAEA, 2005) (Nepal & Park, 2004),
42	Accidents & Hazards	(IAEA, 2005), (Reuvid, 2012), (Driessen *et al.*, 2010), (Twigge-Molecey and Price, 2013), (Banaitiene & Banaitis, 2012), (Bawa, 2009), (U.S. Bureau of Mines, 1998), (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, 2011), (Stambaugh & Barry, 2014), (Sawyer, 1997), (Rendon & Snider, 2008)
43	Extraordinary Price Escalations (Spares, Consumables, Equipment)	(Banaitiene & Banaitis, 2012), (Lock, 2014), (Driessen *et al.*, 2010)
44	Pilferage, Theft & Fraud & Cheat	(McAfee & Champagne, 1994), (Hayes, 2014), (Doig, 2012), (Taska & Barnes, 2012), (Foerst, 2010), (U.S. Congress, 1986), (McIntosh E&Y, 2003), (Commissioning on Wartime Contracting, 2011), (GAO, 2015).

45	OLM, ILM, DLM - Overlap of maintenance duties (contractual) and impact if not performed	(U.S. Navy 2012), (Xia *et al*., 2012), (Jonsson, 1997), (GAO, 1982), (Henry & Bil, 2015), (Balafas *et al.*, 2010), (Ford *et al.,* 2013), (Deris *et al.,* 1999), (Crane & Livesey, 2003), (Lim *et al.*, 2013), (Offenbeek & Vos, 2016), (Sword, 2010).
46	Contract Management across a wide range of stakeholders with conflicting interests	(Lock, 2014), (Gracht, 2012), (Wilkinson, 2009), (Chermack & Nimon, 2008), (Aven & Korte, 2003), (Rendon, 2009), (Price, 2013), (Kwak & Smith, 2009), (Nasab *et al.*, 2015), (Zahedi-Seresht *et al*., 2014), (Jardine *et al*., 1993), (Ford *et al.,* 2013), (U.S. Navy, 2012), (Pogačnik *et al*., 2015), (Atkinson, 1999), (Davis, 2014), (263), (Boonstra et al., 2008), (Xia *et al*., 2012), (Taska & Barnes, 2012), (Rendon & Snider, 2008), (Offenbeek & Vos, 2016)
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)
48	Supporting of the Vessel outside of home ports (e.g. issue on mob, availability of materials etc.)	(Dell'Isola & Vendittelli, 2015), (GAO, 2015), (Golding & Griffis, 2003), (Lu *et al.,* 2010), (Skoko *et al,* 2013).
49	Exogenous factors (i.e. company profit margin, administrative costs, peripheral costs, support cost)	(Dell'Isola & Vendittelli, 2015), (Banaitiene & Banaitis, 2012), (IAEA, 2005), (Henry & Bil, 2015), (Staub-French & Nepal, 2007), (Darnall & Preston, 2010), (Mathew *et al.*, 2006)
50	Exogenous factors - Contract Concept (Total Maintenance Package against segregated orders without interrelationships) and based on recommendations	(Dell'Isola & Vendittelli, 2015), (RAND, 1996), (Keller *et al.*, 2002), (Rusi Defence System, 2012)

2.3 Ranking of the Severe Downtime Influence Factors

The simplified DIF model as shown in Figure 1 portrays the relationship between Uptime and Downtime (and availability) as well as the various DIFs that make up the Downtime, for the benefit of all levels of stakeholders.

Nevertheless, the sizes of the individual DIFs are yet to be determined at this stage. Figure 2 graphically represents the ranking of DIFs from most to least severe based on Delphi rounds. This new perspective introduced by the authors clearly shows 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.

Further research is expected to focus on prioritisation of DIFs based on Risk Assessment methodology and reducing the 50 identified DIFs to those DIFs classified as “High Impact” and “Likely” to occur. In addition, each severe DIF is allocated a Severity Index (SI) that will enable contract managers and project managers to prioritise efforts, as exemplified in Figure 2.

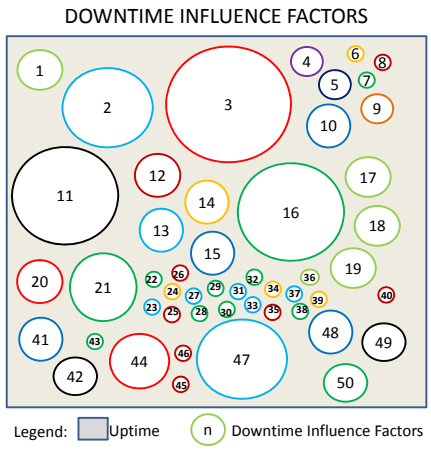

Figure 1: Conceptual diagram of the 50 DIFs.

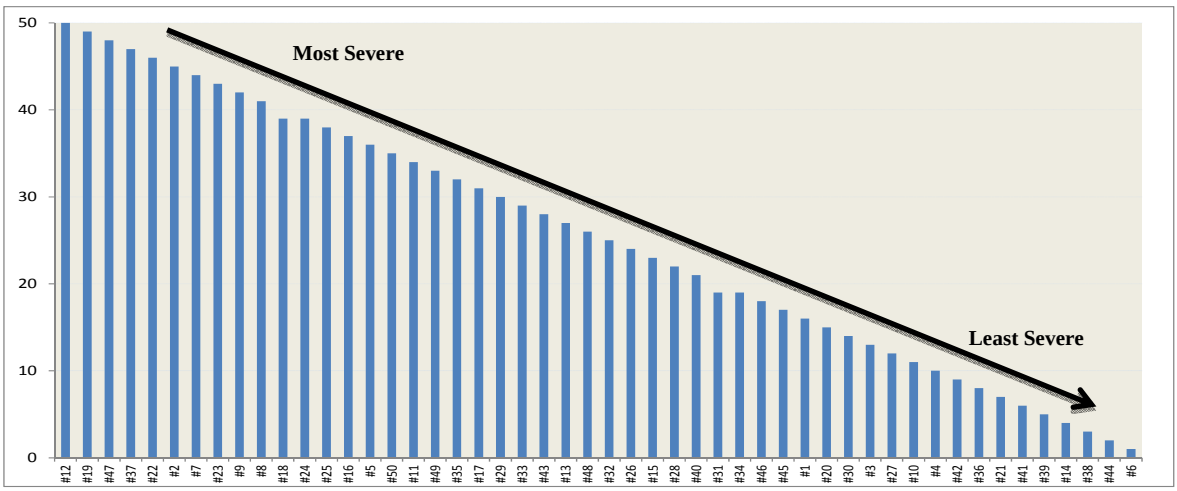

Figure 2: the 50 Severe DIFs ranked from Most to Least Severe.

2.4 Ranking of Downtime Influence Factors

A total of 15 DIFs were found to be severe based on the Risk Analysis as described in Table 1. An illustration of the derived 15 Severe DIFs impacting RMN Ship Operational Availability and the resulting reduced size of DIFs (improved availability) following improvement efforts by the various stakeholders is reflected in Figure 3.

The size of the sphere for each of the 15 Severe DIFs is proportionate to their Severity Index (SI) as presented in Al-Shafiq *et al*. (2017c). The higher the index, the bigger is the sphere and the more severe the DIF. For example, focusing attention and efforts on the most severe DIF which is "corrective maintenance" in order to reduce the size of this DIF, would result in a sizeable overall improvement in Uptime. An illustration of targeted efforts to improve availability for severe DIFs. "that are easily understood and relatable to any reader" are in Figures 4 and 5 respectively.

The availability dashboards illustrate the overall impact of the improvement based on cumulative efforts. The figures illustrate a small subset of efforts undertaken by the various stakeholders to improve the severe DIFs that encompass a multitude of possibilities that need to be carefully studied.

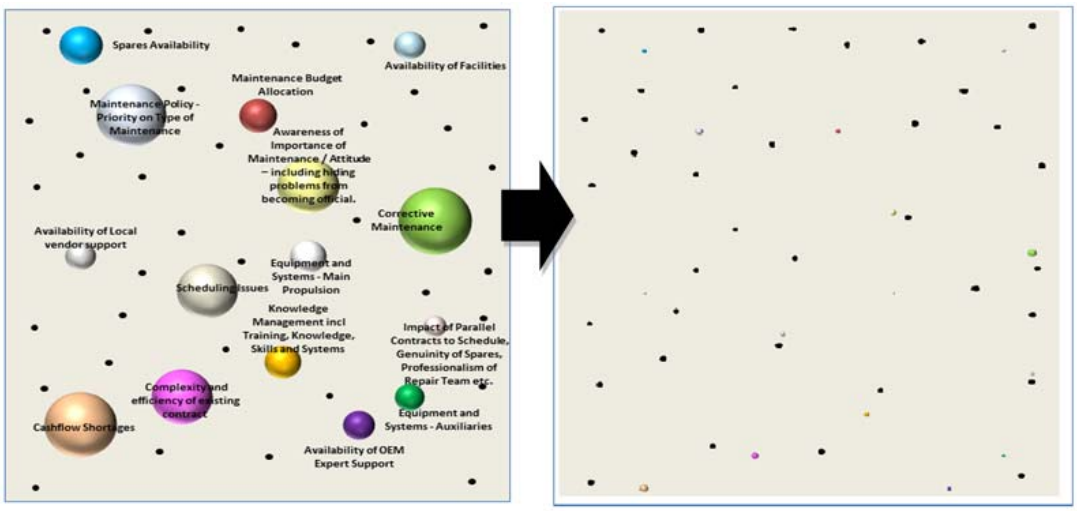

Figure 3: Example of reduction of severe DIFs.

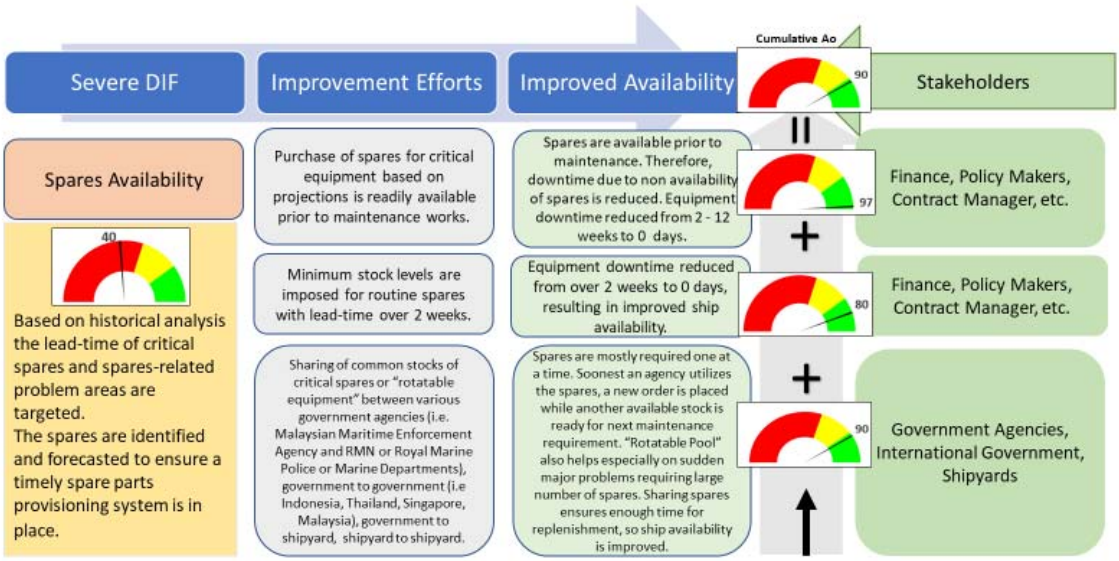

Figure 4: Illustration of Severe DIF "Spares Availability" Improvement Efforts by Stakeholders

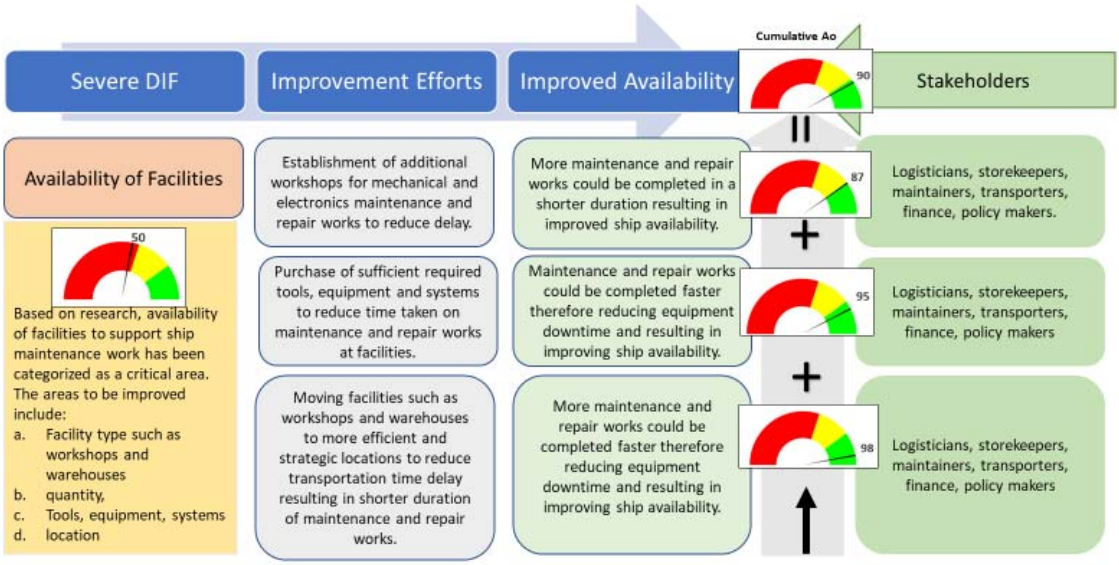

Figure 5: Illustration of Severe DIF "Availability of Facilities" Improvement Efforts by Stakeholders

3. RECOMMENDED 4-STEP AVAILABILITY IMPROVEMENT

Following the various graphical illustrations and introduction of a new simple perspective of the relationship between DIFs and Availability described above, the authors hereby summarize the simplified approach through the introduction of the "4-Steps to Availability Improvement" as described in Figure 6.

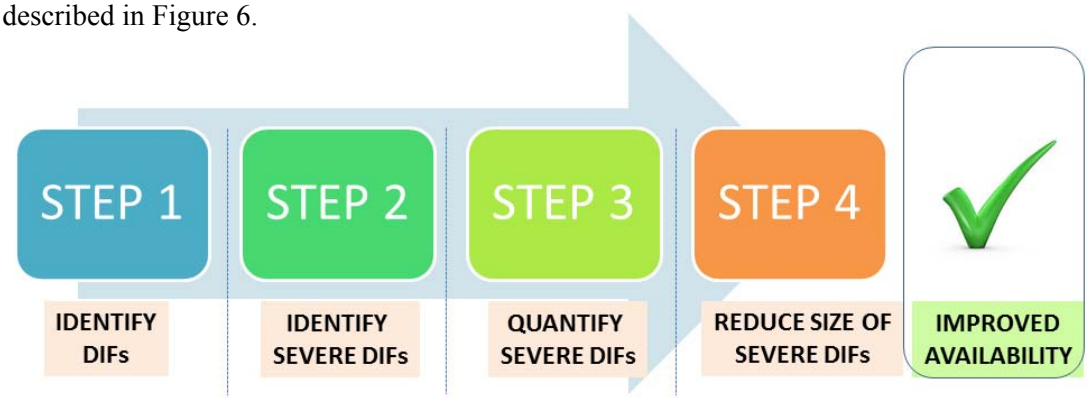

Figure 6: Four steps towards Availability Improvement.

4. CONCLUSION AND RECOMMENDATION FOR FUTURE STUDIES

Complex Systems could reasonably be replicated or simulated in a controlled environment i.e. in laboratory with an ascertained INPUT, a pre-determined PROCESS and a precisely measurable OUTPUT. But in open systems environment it becomes extremely complicated to manage. This is especially true for dynamic systems like naval ships whereby many systems operate simultaneously with interdependencies in series and in parallel as well as redundancies, on a floating and moving platform. The obvious answer is that there has not been any model successfully developed and proven to resolve the issues involving complex assets such as the

naval vessels, simply because if there has been any breakthrough, it would have been published and shared globally to be implemented. To date, models and simulations remain on small equipment and systems with many presumed conditions and assumptions which have not reached a stage to be implemented on complex systems.

The proposed 4-Step Availability Improvement philosophy focuses on the systematic reduction of DIFs based on severe or priority DIFs. The authors embarked on a journey to broaden the horizon on available knowledge by progressively evolving from the exhaustive screening of more than 700 literatures to identify the DIFs, until the introduction of a simplified "bite-size" approach for practitioners and stakeholders in general. From the extensive research, the authors have not found any previously-discovered "one-size fits all solution" towards this complex naval ship availability issue.

Nevertheless, it is evident on the valuable contribution of the authors in guiding stakeholders to place the appropriate efforts on tackling the identified DIFs with the aim of improving Naval Ship Availability. However, due to the time, resources and financial constraint involved in this exploratory but highly specialized research in naval ship maintenance which has spanned over 5 years, and in order for the results to remain current for the partial fulfillment of the Doctorate in Mechanical Engineering, the authors have concluded this exploratory research by evidently paving the way for more focused future research in all of the areas covered by the 50 DIFs individually and combined, including the 15 identified Severe DIFs.

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