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SEVERITY OF DOWNTIME INFLUENCE FACTORS IMPACTING NAVAL SHIP OPERATIONAL AVAILABILITY - A FIVE-STAGE DELPHI CONSENSUS PROCEDURE WITH SNOWBALLING TECHNIQUE

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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.

INTRODUCTION

Achieving targeted operational availability of equipment and systems can be an arduous task for any organization. Navies worldwide face the same challenges of achieving high asset availability, albeit the situation is aggravated due to the complex nature of warships including the variety of military roles [1]. The variety of military operations according to "across the spectrum of conflict" is illustrated in Navy Force Planning Scenarios. Operational availability of naval ships, which reflects the number of days the warships are available for operational tasking in a year as stated in GAO 2015 [2], is therefore a complex problem [3]. 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 [2]. It is interesting to note that availability is still a problem in modern navies including the United States Navy even lately [4].

Given the complexity of the naval vessel itself as an asset due to advanced ship designs[3] and the various intricate maintenance contracts under which the vessels belong to[5], the race to maximize their operational availability or uptime is hampered by the simple fact that there exists a long list of possible contributing factors creating downtime. There have been several availability calculations through Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR) [6, 7] However, there has been limited literatures pinpointing to the root cause of the various downtime. These factors are called Downtime Influence Factors (DIFs)as described in Alshafiq *et al.* [8]. Most studies are limited to a single factor such as obsolescence or spares availability in Sandborn [9] and Koehn *et al.* [10], or two or three factors at most. Therefore, new knowledge could be gained if DIFs are studied holistically. This research aims to simplify the complexity surrounding naval ship availability. A holistic study on combined human and equipment related Downtime Influence Factors (DIFs) enables the various stakeholder levels to achieve better understanding of factors and their severity in affecting operational availability.

Due to issues of achieving high availability targets as expected by some customers, nowadays providers of complex engineered equipment are often encouraged to offer outcome or availability-based contracts or performance-based contract (PBC), where the provider guarantees the uptime and availability of the product[5, 11-13]. As availability is also a measure of maintenance performance, the availability is guaranteed to minimize the risks faced by customers, such as in the process industry, whereby machine downtime in the shop floor is one of the main issues for maintenance

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productivity [14]. Maintenance activities are mostly non-repetitive in nature resulting in all maintenance personnel and managers facing new problems with each breakdown or downtime of the plant or system. Due to the conflicting multi-objectives issues, multi-skill levels are needed [14] and retention of these special skills is also a common problem in maintenance [15-19].

It is well agreed among researchers that Delphi method is preferred as a research instrument for incomplete knowledge about a problem or phenomenon [20-23] or in the case of limited experts in the field are available [20, 24]. Grisham [25] emphasized that the method is 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. The scientific methodology provided by the Delphi is well suited to issues that require the insights of subject matter experts. The method works especially well when the goal is to improve the understanding of problems, opportunities, solutions or to develop forecasts [20]. On the implementation and enhancement of the Delphi method, various studies provided further details. Exclusively, Rowe and Wright[26] presented a framework for conducting the necessary Delphi research and how to enhance the use of the Method including improving expert recruitment via snowballing and other methods of retention over Delphi rounds. Specifically, Baker and Edwards [27] 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[28] 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. Other researchers have similarly used expert opinions to study maintenance downtime distribution which reflects availability of systems [29]. Therefore the researcher has selected a 5-Stage Sequential Modified Delphi Approach with Snowballing Technique for this study.

MAIN RESULTS

Delphi studies are mainly concerned with eliciting expert opinions in fields where little or no literature is available [30]. Lavrakas [31] states that some non-probability samples are useful, as long as they are not used to make inference to a larger population. Qualitative research “samples” some members from a population of interest so as to gather information from or about them [32]. 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

The population of interest is described in this study as experienced, knowledgeable Malaysian Naval In-Service Support (ISS) Experts that have direct involvement in the Patrol Vessel (PV) ISS Contract. The total number of experts complying with these criteria is 46. Subsequently, the researcher applied judgemental sampling based on the accessibility of these experts. The final sample size for Stages 1-3 was 30 Experts from the total population of 46. For Stages 4 and 5, Snowballing Technique as described next is applied to identify 5 Top Management Experts. The total number of interviewed experts throughout the 5-Stage sequential modified Delphi was 35.

The majority of Delphi studies involve 15-20 respondents [33]. Moreover, with a homogeneous group of experts, good results can be obtained even with a panel as small as 10-15 individuals [21].

The 5-stage sequential modified delphi approach

The steps of the 5-stage Sequential Modified Delphi approach could be summarized in Table-1.

Stage 1 - Focus group discussion

Based on AlShafiq *et al*. [8], the first stage commenced with a Focus Group Discussion (FGD) with a group of 30 Experts from contractor and customer’s organizations who were directly involved in the In-Service Support (ISS) Contract with sufficient working experience or knowledge in the ship maintenance field. The 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.

The 30 Expert members identified and consolidated the variables from various interpretations and carefully pooled into 50 agreed categories called Downtime Influence Factors (DIFs) that impact ship availability.

Table-1. 5-Stage sequential modified delphi approach summary.

Research stage	Phase, Expert group	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 2 - Delphi Round 1

From AlShafiq *et al.* [8], Stage 2 commenced with the design and development of questionnaire. The questionnaire was constructed using 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 the next stage for further identification and confirmation by the Expert group. All 30 Experts confirmed the 50 DIFs brought forward from Stage 1.

The Expert members were subsequently asked to select the DIFs that have impact on ship availability via Risk Assessment Matrix. 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 [34]. In engineering, the definition of risk is:

RISK = (Probability of Incident/Accident) x (Losses per Incident/Accident) [34]

The probability and impact matrix illustrates a risk rating assignment for individual risk factors. It reflects the combination of impact and probability that in turn yields a risk ranking or risk priority. Risk ranking is based on a matrix whose axes are the ranks of consequences and probabilities [34]. The likelihood of occurrence and consequences of scenarios as the result of their pairing is called a Risk Assessment Matrix [35]. Typical Risk Assessment Matrices vary with organizations, however Ludwig[34] concludes that the most common type of matrices contain 3x3, 4x4, 5x5, 5x4 and 6x4 likelihood and consequences categorizations. The best suited Risk Assessment Matrix chosen for the study was as a 5x5 Matrix, as did the US Navy on ship maintenance [36].

Consensus among the expert group members regarding the importance of each of the 50 DIF was achieved. The DIFs were ranked and the Weightage of Severity (WoS) of the various DIFs was obtained. Based on Risk Analysis, a DIF with a total value or median of 16 was defined as “Severe” and confirmed as important.

Stage 3 - Delphi Round 2

Based on Alshafiq *et al.* [8], in Delphi Round 2, Expert members were asked to re-assess the DIF ratings in the light of the consolidated results obtained previously. New questionnaires similar to previous ones were issued for feedback. The subsequent processes of computing DIFs severity and performing risk analysis were similar to Stage 2. After re-assessment of the DIFs severity in Delphi Round 2, the agreement level among the Expert members had improved based on the CV values.

The 30 Experts were asked to provide their recommendation for the Top Management Experts for the subsequent rounds of Delphi, based on Snowballing Technique. In any case ‘knowledgeable persons’ could be identified either through Literature Research or recommendation from institutions and other experts, demanding techniques of purposive and snowballing sampling [37]. Giannarou and Zervas[38] indicates that an expert endorsement or recommendation can help in identifying other experts.

The researcher here enlisted the assistance of the participating panellists to pinpoint those professionals recognised in their fields to have high levels of expertise and authority. The 30 Experts from Stages 1 to 3 were requested to list down the top management experts from either Royal Malaysian Navy or Prime ISS Contractor that have extensive experience in ISS Contract Management.

Through recommendation by the 30 Experts based on a selected Fulfilment Criteria, 7 very senior position panellists were selected after fulfilling the following selection criteria in Table-2.

Table-2. Panel members fulfilment criteria for stage 4 and 5.

Stage	Delbecq's criteria [39]	Expert criteria to be fulfilled	Fulfilment
4 to 5 4 to 5	Have pertinent information to share; Are motivated to include the Delphi task in their schedule of competing tasks;	Having extraordinary working experience or extraordinary knowledge in the ship maintenance field; and the requirements of the PV ISS Contract.	Yes, all of the panellists possess extraordinary knowledge, skills and years of experience on ship maintenance. They are also either currently engaged or had previously engaged in the implementation of the PV ISS Contract.
	Feel personally involved in the problem of concern to the decision makers;	Working in relevant organizations in the naval ship maintenance field.	Yes, they are also either currently engaged or had previously engaged in the naval ship maintenance field.
	Feel that aggregation of judgement of a respondent panel will include information, which they too value, and to which they would not otherwise have access.	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.	Yes, they are stakeholders that hold very top management positions either as the customer or the contractor.

However, from a list of 7 Top Management Experts short listed and approached, 5 agreed to participate in the study. The list of panel members and their positions for Stage 4 and 5 are as reflected in Table-3.

Table-3. List of the panel members for Stage 4 and 5.

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 possess extraordinary knowledge and experience in ship maintenance, project management, financial management, maintenance philosophies as well as policies and procedures, and are positioned in their respective organizations to ensure that their organizations benefit from the results of the study. All experts possessed on average 35 years of working experience in the naval ship maintenance industry. Their selection provides a fair and balanced top level view for the Delphi study. All the panel members have fulfilled the criteria requirements of Delphi.

Stage 4 - Delphi Round 3

Stage 4 commenced by providing the results of Stage 3 to the group of Contract Management Experts (Top Management) to confirm their agreement to the list of 50 variables that influence ship's downtime. All the Top Management Experts confirmed the list of 50 DIFs were valid as the DIFs had direct impact to the ship's operational availability. Similar to Stage 2, the 5 Top Management Experts were asked to conduct a Risk Assessment of the DIFs that were brought forward from Stage 3, based on ranking conducted by the 30 Experts. A new ranking list was generated.

Stage 5 - Delphi Round 4

Similar to Stage 3, Top Management Experts were asked to re-assess the DIF ratings in the light of the consolidated results obtained in Stage 4. All of the Top Experts remained with their earlier assessment in Stage 4. The result after 5 Stages are as described in Table-4.

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Table-4. Results of delphi after 5 stages.

RESULTS after stage 2 and 3, Consensus reached (n=30)			Results after stage 4 & 5 (n=5)		Combined (n=35)	
List of severe DIFs	**Mean**	**Rank**	**Mean**	**Median**	**Mean**	**Rank**
Corrective Maintenance	24.5	1	25	25.0	24.57	1
Spares Availability	23.4	2	25	25.0	23.62	2
Impact of Parallel Contracts to Schedule, Genuinity of Spares, Professionalism of Repair Team etc.	22.8	3	23	25.0	22.82	3
Cashflow Shortages	22.63	4	21.2	20.0	22.42	4
Knowledge Management incl. Training, Knowledge, Skills and System	20.2	5	20	20.0	20.17	5
Equipment and Systems - Main Propulsion	20.03	6	20	20.0	20.03	6
Maintenance Policy - Priority on Type of Maintenance	19.13	7	20	20.0	19.26	7
Availability of OEM Expert Support	17.43	8	18.4	20.0	17.57	8
Maintenance Budget Allocation	17.37	9	16	16.0	17.17	9
Awareness of Importance of Maintenance/ Attitude-including hiding problems from becoming official	17.23	10	16	16.0	17.06	10
Availability of Facilities	17.1	11	16	16.0	16.94	11
Availability of Local vendor support	17	10	16	16.0	16.86	12
Complexity and efficiency of existing contract	16.97	13	16	16.0	16.83	13
Scheduling Issues	16.83	14	16	16.0	16.71	14
Equipment and Systems - Auxiliaries	16.33	15	16	16.0	16.29	15

The level of concordance or agreement between Experts was measured with the help of Kendall's coefficient of concordance in Minitab and SPSS. Out of 15 measures the Experts agreed on 12 (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 $p < 0.001$. The 15 most severe DIFs as evaluated with a high level of consensus by the Top Management experts can be viewed in Figure-1.

CONCLUSIONS

This study concludes with 15 severe DIFs from a range of more than 50 possible factors impacting the operational availability of naval vessels, and the severity of each DIFs. This research may be the most comprehensive study of its nature in consolidating the DIFs specifically in the naval ship domain, but also in the maintenance engineering field in general. The findings of this paper would assist organizations in prioritizing their efforts in controlling specific downtime factors which greatly impact their organizations. Further focused research on individual factors and especially on various combinations of factors may shed more light on 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 facing continuous inter-related issues in improving their operational availability.

The authors believe that Project Managers and Contract Managers shall be able to manage their contracts better with these identification of constraints and interdependencies, which they will endeavour to implement best practices [40] . The current research has proven the reliability of Delphi method in tackling the complex problem of naval ship operational availability involving combined factors of human and equipment. 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.

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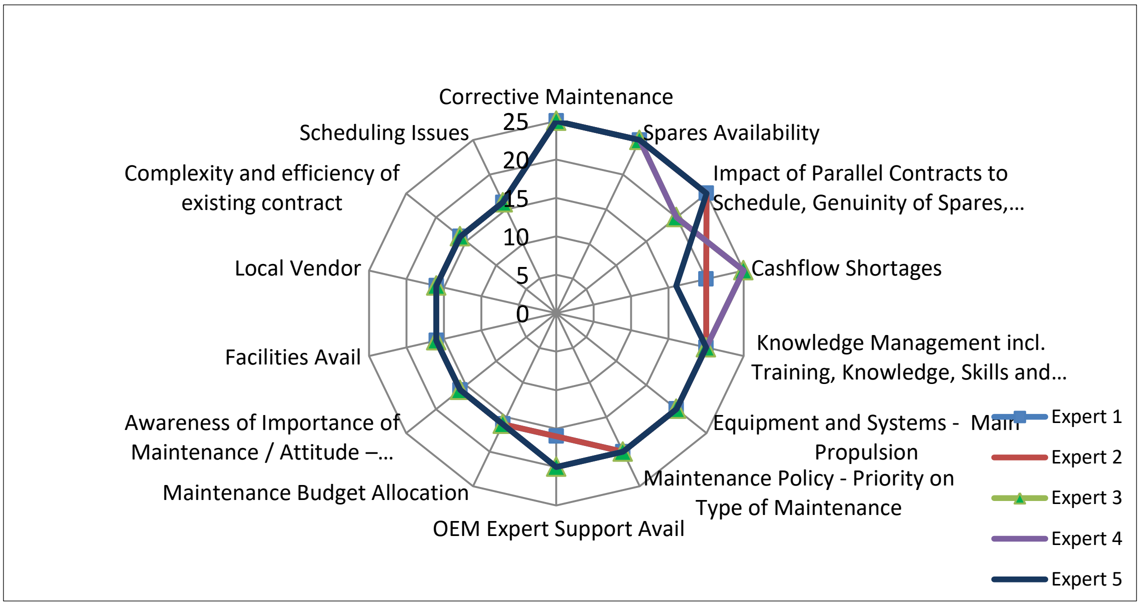

Figure-1. Radar chart of the top management identified severe DIFs.

Equally important, the current research has set a fundamental basis of an availability-oriented contract management framework/model as new knowledge towards improving naval ship operational availability. The study is a pivotal step in enabling a Severity Index (SI) to be produced in future research to assist navies to compare indexes of various types of contracts implemented globally on naval ship maintenance.

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