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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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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.**

Index Terms— **Naval Operational Availability, Downtime Influence Factors (DIFs), Delphi method, Panel Demographic**

I. Introduction

All Navies worldwide face the same challenges of achieving high asset availability, albeit the situation is aggravated due to the complex nature of warships. The Navy Force Planning Scenarios illustrating the variety of military operations “across the spectrum of conflict”, are also complex according to the Directorate of Maritime Strategy Canada, 2001 [1]. The Australian National Audit Office confirmed in 2001 that Naval vessels are of complex design [2]. Dell’Isola and Venditelli, 2015 argue that Naval vessels itself are complex assets [3]. Pascual et.al 2006 [4] identified that Design Complexity is one of the causes of greater risk for asset downtime. In addition the various types of maintenance contracts aimed at achieving high ship availability result in an extremely complex situation for the stakeholders involved in ship maintenance.

Furthermore there is a long list of human and equipment-related downtime influence factors (DIFs) affecting ship availability that are intertwined, ambiguous and uncertain, significance and weightage [5]. The immediate questions are would be possible to reduce that complexity? Would it be possible to evaluate the DIFs’ impact to ship availability?

A few researchers have attempted to consolidate some factors to find interdependencies and also try to implement best practices in project management [2] but none have been able to consolidate them comprehensively. No literature has attempted to consolidate factors involving human and equipment combined into one study involving ships possibly due to the complexity.

There has been no research conducted using Delphi Method on Naval Ship maintenance or Operational Availability for naval ships to study the Downtime Influence Factors (DIFs). There has been some research from various other engineering industries such as Oil and Gas [6], Construction [7-11], Nuclear [12-13], Aviation and Aerospace [14], Business Intelligence (BI) [15-17], Energy [18] and Mining [19]. There has also been survey on soliciting Expert Opinion on Swedish companies in the food, timber, paper, chemical, mechanical engineering and iron industry. As the variety of industries surveyed is wide, the researcher believes that the findings would contribute to the study of downtime factors.

Since ship maintenance is also an established engineering discipline, most of the DIFs should also be applicable to naval ship maintenance. Delphi technique was chosen as the most suitable method as it covers the “Men”, “Method”, “Material” and “Machines” the 4 M’s Geitner and Block, 2012 [20] argue that reducing the probability of trouble tomorrow is one of the best reasons to spend part of today seeking the cause of yesterday's problems. Jardine et al. 1996 [21] maintained that "Industry Driven Applied Research" is motivated by the practical needs of an organization. The research problems are based on the needs of the industrial organizations, and the research results will definitely benefit the participating organizations.

A Delphi approach into the DIFs for the RMN ISS for Patrol Vessels (PV) was carried out to identify and better understand the unavailability causes and to highlight and prioritize the areas of improvement. A panel of 30 professionals directly involved in naval ship maintenance was selected and their expert opinion sought via various questionnaires. Irrespective of the advantages of Delphi studies in fields were little information is available [22], some critics may argue that Delphi study outcomes are influenced by the experts demographics or sample make up. To counter the drawbacks of Delphi this analysis identifies 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 study.

II. MAIN RESULTS

The objective of the descriptive statistics analysis in the research was to examine, describe and summarize the data collected in a meaningful and simple manner. However, as with all non-quantitative methods it was not possible to make conclusion beyond the data set or to make inference onto the population or simply put generalize the findings. 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. The list of panel members of the Delphi Study and their positions are as reflected in Table 1.

TABLE I. PANEL MEMBERS DEMOGRAPHICS BY GENDER, QUALIFICATIONS, TYPE OF ORGANIZATION, DESIGNATION & EXPERIENCE

Gender	No	Qualifications	No	Type of Organization	No	Designation	No
Male	27	O'Level, Diploma, Certificate	17	ISS Contractor	17	Technical Executive	6
Female	3	Bachelor Degree	10	Shipyard 1	5	Senior Technical Executive	9
TOTAL	30	Masters	3	Shipyard 2	1	Supervisor	1
		TOTAL	30	Shipyard 3	1	Senior Supervisor	2
				Shipyard 4	2	Assistant Manager	1
				Customer – Senior Navy Officers	4	Manager	3
						Project Manager	1
				TOTAL	30	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

At a glance it can be recognized that only 10% of the panelists are female. Whilst this may appear to be a low percentage, there are very few female staffs or officers from either organizations that are involved in the RMN ISS Contract Management. Regarding the panelists Working Experience 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 ensure the validity of this Phase of Delphi research. The majority of respondents were from the ISS Contractor organization type, a minority of the panel is made up of Naval Officers. Regarding the panelists designation 50% of the panelists were either technical executive or senior technical executives, 20% of the panelists were Supervisors and Managers and 10% are Commanding Officers from the RMN. All respondents were requested to assess the "Impact" and "Likelihood of occurrence" of a DIF. The outcome of Impact multiplied by the Likelihood was labeled as "Weightage of Severity" (WOS) of a DIF.

The researcher formulated initial hypothesis that panellist's gender would impact WOS. The researcher also formulates the null hypothesis that panelists 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 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 1.

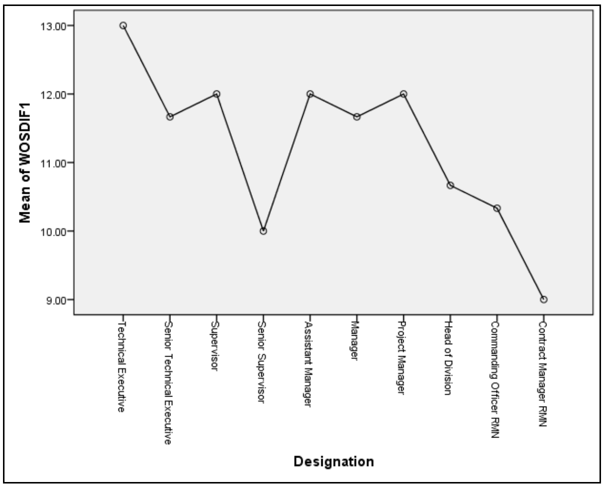

Fig. 1. Means of Plot WOS DIF1 vs. Designation

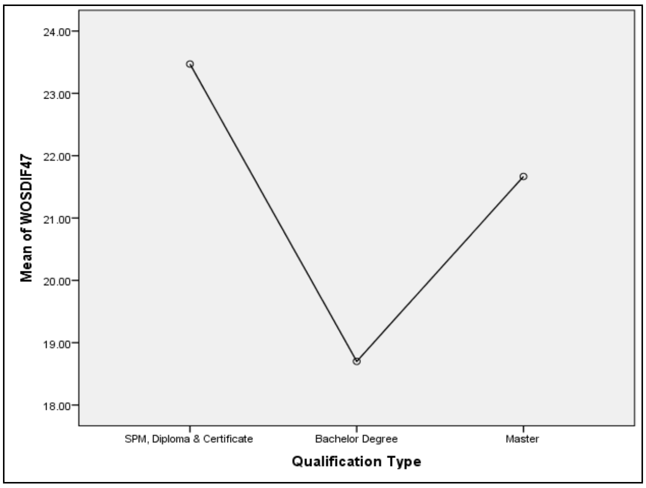

Fig. 2. Means of Plot WOS DIF47 vs. Designation

Nevertheless based on subsequently performed Pearson's chi square test there was no significant evidence to show a relationship between WOS & Designation, simply put there was no evidence that the rating is impacted by Designation for WOS DIF1 Equipment and System - Hull & 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 2.

TABLE II. SPSS OUTPUT CHI-SQUARE TEST

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	49.130ª	36	.071
Likelihood Ratio	30.882	36	.710
Linear-by-Linear Association	3.162	1	.075
N of Valid Cases	30		

Whilst cross tabulation 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 is 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 2 below.

One-way analysis of variance was conducted to evaluate the Null Hypothesis that there is "no difference" in how panelists rate WOS for DIF47 (Impact of Parallel Contracts by Qualification) (N=30). The independent variable, qualification type included 3 groups:

1. SPM, Diploma and Certificate (M = 22.94, SD= 5.02, n=17)
2. Bachelor Degree (M=21.20, SD=3.61, n=10)
3. Masters (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 is 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 panelist 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.

TABLE III. POST HOC TEST PAIRWISE COMPARISON QUALIFICATIONS FOR WOS DIF47

Multiple Comparisons

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.

III. CONCLUSIONS

Based on the statistical analysis conducted for the 30 Delphi Expert panelists 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.

Further Delphi rounds would be conducted to obtain agreement of Experts on the WOS and these rounds should be targeted at understanding particular trends in responses by the panelists. Additionally other types of analysis may be conducted in future compare with the results of this study and to determine further underlying statistical patterns where applicable.

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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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***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.**

***Index Terms*—Naval Ship Availability, Downtime Influence Factors (DIFs), Severity Index (SI)**

I. INTRODUCTION

Since the 1980's there have been efforts in studying availability improvement concepts to military assets [1]. Various maintenance concepts had been applied by diverse industries worldwide ever since with different degrees of success. The operational availability of warships and the requirements to improve ship availability has been rejuvenated as of late as studied by Dell'Isola and Vendittelli, 2015 [2], especially due to, firstly, the criticality of achieving the balance between availability and life cycle cost (LCC) of warships and, secondly, focusing on proper design process, methods, models and tools to help achieve this. Further recent studies in operational availability improvement of Naval Vessels for the Royal Netherlands Navy pointed out that the operational availability was below the requirements [3]. The most important factor highlighted by Dell'Isola and Vendittelli (2015) [2] was the fact that an 'availability-based' contract needs to be formulated and long enough to ensure return on investment for the contractor. This is true for the European Multi-Mission Frigates (FREMM) of the French and Italian Navies and also to some countries like UK and Australia that have moved towards 'availability-based' contracting.

However, this is not the case for the many navies globally which adhere to their traditional contracts in maintaining their naval vessels in accordance with their existing policies. The Royal Malaysian Navy (RMN) to date remains with the existing conventional policy of 'per-repair' contracts similar to most navies around the world including US Navy. Similar with other assets, a naval ship or platform requires day-to-day operations and maintenances. However, 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. 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.

Blanchard and Fabrycky, 1998 [4] and Inozu, 1996 [5] defined availability is as the probability that the ship is available and capable of performing the intended function at any random point in time. Availability which is also commonly known as 'Uptime' can be formulated as one minus downtime as stated in Hou Na et al., 2012 [6] or known as unavailability, with the resulting mathematically implication that the more the unavailability or 'downtime', the lesser the availability yielded. Ship operational availability is also described as the number of days the warships are available for operational tasking in a year (US Government Accountability Office, 2015) [7].

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In previous studies, extensive Literature Research was conducted by the authors [8-9] to identify the Downtime Influence Factors (DIFs) that affect naval downtime for the Patrol Vessel (PV) in Malaysia. Focus Group Discussions (FGD) and a 5-stage Delphi was conducted to identify a list of 50 DIFs and to rank these based on their severity. Delphi was chosen as a suitable method in line with Skulmoski et al., 2007 [10] to explore new concepts within and outside the existing body of knowledge in the field and as stated in Franklin and Hart, 2007 [11] since the complexity of Naval Ship Availability involved an institutional or environmental phenomenon without previous history, a quickly changing event that outdates the literature, and a very complex phenomenon that truly requires experts for understanding it.

This research continued from previous research where Experts subsequently prioritized and rated these DIFs based on Risk Assessment methodology as described in the Methodology Section. A Severity Index formula was developed based on the prioritized severe DIFs. This research also aimed to understand the interrelationship of the DIFs applying the statistical analysis software SPSS. Finally the SI index was adjusted to take into account these interrelationships as described in the Results and Discussions section. The Conclusion section described that the resulting adjusted SI shall assist PV ISS contract stakeholders to pinpoint and focus on human and equipment factors that are the main causes of downtime.

II. METHODOLOGY

A 5-Stage Delphi was conducted by the authors in previous research [9]. Two groups of experts with in-depth knowledge of Contract Management and In-Service Support (ISS) Maintenance for PV were selected. The first group consisted of 30 knowledgeable professionals directly involved in the PV ISS for Stage 1 to Stage 3 of the Delphi. The second group was identified via snowballing sampling technique as stated by Giannoarou and Zervas, 2014 [12] to make up a group of Senior or Top Management experts. These panelists were surveyed in Delphi Stage 4 to Stage 5.

Both panelist groups were requested to identify and rank the DIFs by severity by assigning a value to the probability of the DIF occurring during the contract duration and the Impact the DIF had onto the Availability of Naval Vessel for the ISS Contract by means of a 5 point Likert Scale as per Tables 1 and 2 below. 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.

TABLE 1: IMPACT OF THE DIF ONTO AVAILABILITY OF THE NAVAL VESSELS FOR THE ISS CONTRACT 5 POINT LIKERT SCALE

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

TABLE 2: PROBABILITY OF DIF OCCURRING THROUGHOUT THE CONTRACT DURATION, 5 POINT LIKERT SCALE

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

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".

The Weightage of Severity (WOS) is obtained by multiplying for each DIF individually the Impact onto Availability X the Probability of occurrence throughout the contract duration. Therefore, the mean scoring was considered from Delphi Stage Three (n=30) and Delphi Stage Five (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 1.

$$W_{SMi} = \frac{M_{SMi}}{\sum_{1}^{15} S_{SMi}} \quad (1)$$

Where:

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

$MSMi$ 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 following formula in Equation 2. Once the Severity Index had been defined, the Project Management and Contract Management KPI score was quantified for each of the severe DIFs.

$$SI = W_{SM\,(DIF1)} + W_{SM\,(DIF2)} + W_{SM\,(DIF3)} + W_{SM\,(DIF4)} + W_{SM\,(DIF5)} + W_{SM\,(DIF6)} + W_{SM\,(DIF7)} + W_{SM\,(DIF8)} + W_{SM\,(DIF9)} + W_{SM\,(DIF10)} + W_{SM\,(DIF11)} + W_{SM\,(DIF12)} + W_{SM\,(DIF13)} + W_{SM\,(DIF14)} + W_{SM\,(DIF15)} \quad (2)$$

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) [13] (Weisberg, 2005) [14].

A guide as provided by Cohen and Manion (1994) [15] was referred to interpret the linear correlations. The suggested size of coefficient is given as in Table 3 below.

TABLE 3: 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

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.

III. RESULTS AND DISCUSSIONS

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 below.

TABLE 4: MEAN, RANKING AND IMPORTANCE WEIGHTINGS

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 / 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 mentioned in Methodology.

Only two instances of linear correlation or multiplier effect were found. These were singled out and adjusted in the Severity Index as described next.

The relevant DIFs were analyzed with the help of scatterplot graphs and a linear regression line to indicate the relationship. Figure 1 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 2 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.

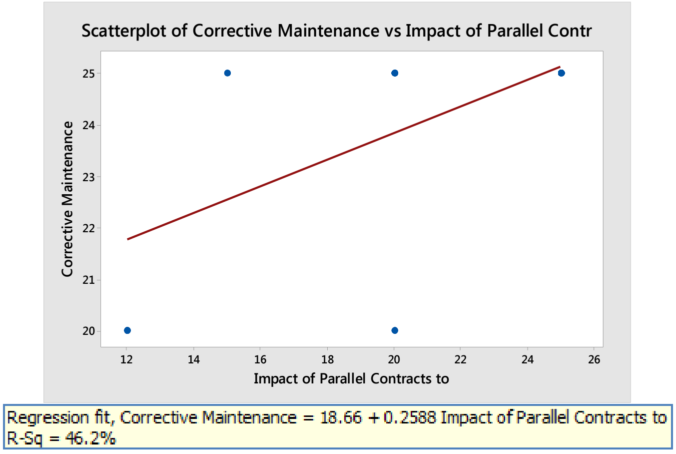

Figure 1: Scatterplot Corrective Maintenance vs. Impact of Parallel Contracts

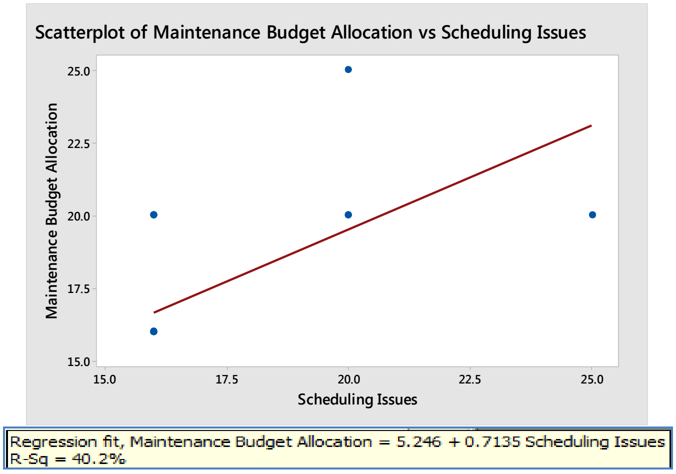

Figure 2: Scatterplot Maintenance Budget Allocation vs. Scheduling Issues

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 $M_{SM1}+M_{SM3}$ is 0.164.
ii) The relationship of 0.2588 as per Figure 1 above 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}+ M_{SM14} is 0.118.

ii) The relationship of 0.7135 as per Diagram XY above is applied to MSM14 resulting in MSM14 0.7135 x MSM9= 0.7135 x 0.060

iii) The adjusted value for MSM9 is 0.075

iv) The adjusted value for MSM14 is 0.118 – 0.075 = 0.042.

Based on these findings, the initial Severity index (SI) was adjusted as in Equation 3 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 as in Equation 3 as a composite indicator to evaluate severity of the DIF for a particular contract or project.

$$
\begin{aligned}
\boldsymbol{SI} = {} & 0.142 \ X \ \textit{Corrective Maintenance} \\
& + 0.082 \ X \ \textit{Spares Availability} \\
& + 0.022 \ X \ \textit{Impact of Parallel Contracts} \\
& + 0.078 \ X \ \textit{Cashflow Shortages} \\
& + 0.070 \ X \ \textit{Knowledge Management} \\
& + 0.069 \ X \ \textit{Equipment and Systems: Main Propulsion} \\
& + 0.067 \ X \ \textit{Maintenance Policy} \\
& + 0.061 \ X \ \textit{Availability of OEM Expert Support} \\
& + 0.075 \ X \ \textit{Maintenance Budget Allocation} \\
& + 0.059 \ X \ \textit{Awareness of Importance of Maintenance \& Attitude} \\
& + 0.059 \ X \ \textit{Availability of Facilities} \\
& + 0.058 \ X \ \textit{Availability of Local Vendors} \\
& + 0.058 \ X \ \textit{Complexity and efficiency of existing contracts} \\
& + 0.042 \ X \ \textit{Scheduling issues} \\
& + 0.056 \ X \ \textit{Equipment and Systems: Auxiliaries}
\end{aligned} \qquad (3)
$$

The adjusted SI has not had a major impact on the ranking, as shown in Table 5 below.

TABLE 5: 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
Cashflow Shortages.	4	3	0.078	0.078
Knowledge Management.	5	4	0.070	0.070
Equipment and Systems – Propulsion.	6	5	0.069	0.069
Maintenance Policy and Priority.	7	6	0.067	0.067
Availability of OEM Expert Support.	8	7	0.061	0.061
Maintenance Budget Allocation.	9	8	0.060	0.060
Awareness of Importance of Maintenance / Attitude.	10	9	0.059	0.059
Availability of Facilities.	11	10	0.059	0.059
Availability of Local Vendor Support.	12	11	0.058	0.058
Complexity and Efficiency of Existing Maintenance Contract.	13	12	0.058	0.058
Scheduling Issues.	14	13	0.058	0.058
Equipment and Systems – Auxiliaries	15	14	0.056	0.056
TOTAL			1.000	1.000

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. The SI formula application is best demonstrated via a short illustration using example figures. First the Target Ship Operational Availability (Ao) is required. Assuming that our ship Ao 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 Ao stands at 71% translating to 259 days full days. Therefore the downtime in days is 70 days. For the purposes of this illustration only and for simplification of the example we follow 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 per Figure 3.

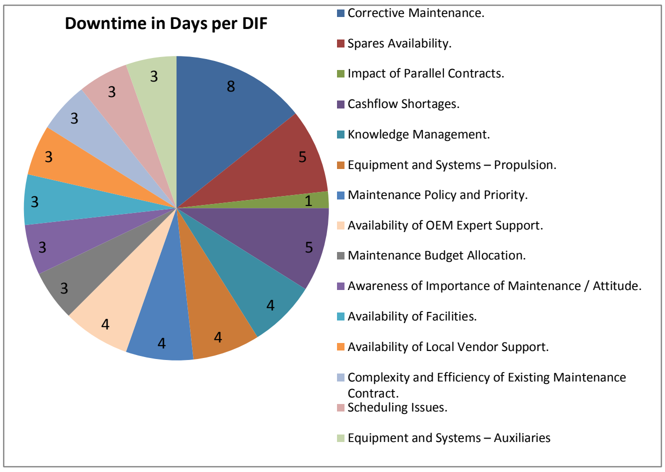

Figure 3: Distribution of DIFs and corresponding days for sample

At a glance it can be seen that Corrective Maintenance with a total of 8 days downtime to improve should be focused on as a priority as opposed to Impact of Parallel Contracts which has a total of 1 day downtime only. The remaining efforts would be distributed rather equally in the example above.

An aspect that has not been critically considered in improving the Naval Ship Availability is the impact on contract management objectives and project management constraints. These could be a performance indicator and would help to better understand whether the overall availability improvement impact on cost, quality and time is positive, neutral or negative. These criteria could be viewed as a "filter" or designated as an Impact Assessment criteria as in Figure 4.

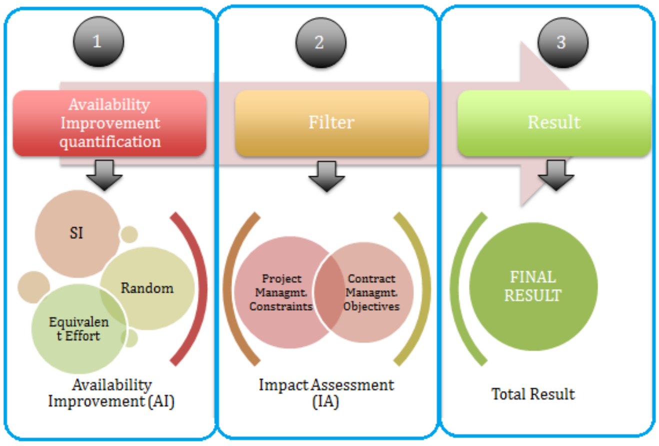

Figure 4: Conceptual Impact Assessment SI

IV. CONCLUSIONS

Compared to traditional Ship Availability approaches most of which 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 Improvement of Ship Availability based on DIFs Severity Index is expected to assist stakeholders of various levels and backgrounds to understand better on how the DIFs impact the ship availability and most importantly have a better grasp on how individually they are involved on a daily basis in reaching the ship availability target.

The overriding advantage of the proposed formula is that Stakeholders, especially Policy Makers, are able to achieve a tangible improvement with a transparent measurement by focusing improvement efforts with prioritization placed on each DIF based on the proposed formulae.

The model assists in demystifying the Ship Availability concept and allowing ISS Contract Managers, who in practice may not to have an engineering background, to proactively structure ISS Contracts that will result in improved Ship Availability

A further step beyond the conceptual model is the development of the Impact Assessment Severity Index into a dashboard that can be used to monitor the recovery Availability, i.e. the availability required for the remaining contract period in order to achieve the targeted Ship Availability.

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Contract Management Control and Monitoring System for the Royal Malaysian Navy – Post Survey Validation via Top Management Experts

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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.

1. Introduction

The Royal Malaysian Navy (RMN) alike its counterparts worldwide strives to achieve high Ship Availability whilst accomplishing its vision of becoming a World Class Navy [1]. Operational availability (Ao) of naval ships is defined as the number of days the warships are available for operational tasking in a year. It also reflects the sustainability of the naval force in showing off presence and deterrent capability [2]. Upon handover of ships to the navies the In-Service Support (ISS) phase begins [3]. The ISS contract is to perform the management, logistic services, engineering and training required to support the naval vessels in order to operate and perform its function through its lifecycle. The ISS phase of a naval vessel will typically constitute 70% of the through-life cost of the vessel [4], therefore it is an important area to be attended to. In addition, [5] presented an indicative value of losses due to downtime, stating that for a ship valued at USD500mil and 30-year target service life, would lose the navy approximately USD50k/day if the ship is not operational.

A compelling study by [6] recently in 2015 resurfaced more recent interest in naval ship Ao by explaining that warships are complex in nature and that studying availability of naval ships would require consolidation of all factors from concept to ISS phase. The author recommended a new design concept based on Ao of warships with the associated support systems to achieve the best balance between Ao and life cycle cost (LCC) along the vessel's operational life. LCC studies are life cycle costing has long been recognized as one of the essential techniques for sustainable development [7]. An example of the LCC Tree as disclosed by the author is displayed in Fig. 1.

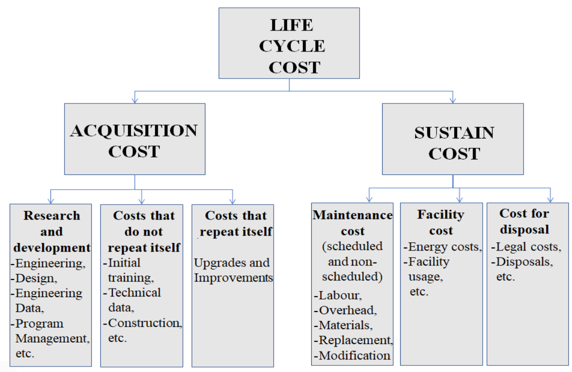

Fig.1 Life Cycle Cost [7]

All ISS contracts have Ao targets to achieve. Even established navies such as United States Navy (USN), Dutch Navy, Royal Navy United Kingdom (RN), and Royal Australian Navy (RAN) have successfully devised and implemented strategies that improved their fleet availabilities whilst regulatory, quality and cost performance measurements are being imposed [3].

In simple terms, to date there appears to be no generic "best suited methodology" in place. In accordance to Reliability Analysis Centre, Operational Availability (Ao) is not just a function of design but also of maintenance policy, the logistics system, and other

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supportability factors [8]. A Contract Management Control and Monitoring System (ConCaMS) is a decision-making support tool to continuously track, manage and control the In-Service Support (ISS) contracts with the necessary feedback and recovery information enabling faster decision making, assist maintainers and store keepers as well as trainers and all other stakeholders to have a better appreciation of their individual contribution towards improving availability figures. This ConCaMS tool may also be used internationally to compare contract performance [3]. A display of the ConCaMS input and output is reflected in Fig.2.

Fig.2 ConCaMS display input and output

The recommended ConCaMS mechanism for collection of daily data on availability is reflected in Fig.3. The actual availability is compared to the targeted availability to reflect the current contract performance on a daily basis. Where the actual availability is lower than the targeted availability, a recovery availability is automatically calculated for the benefit of the contract manager.

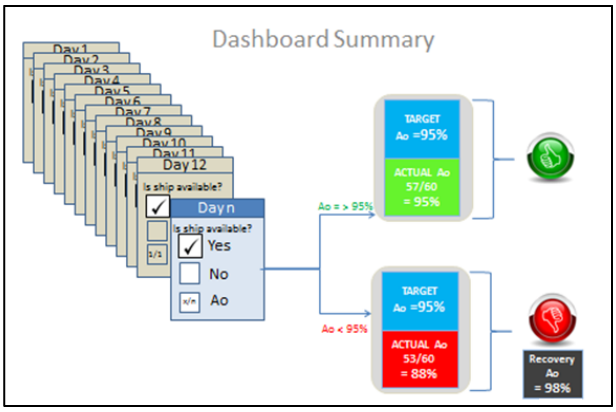

Fig.3 ConCaMS display input and output (Dashboard)

The key concept of the proposed ConCaMS is that Availability can be "simply" expressed as Uptime and formulated as "One minus Downtime" as derived from Hou Na et al [9]. In a nut shell, availability is increased when downtime is reduced. Downtime is caused by a list of human and machinery related factors. These factors are called Downtime Influence Factors (DIFs). Hence, holistic efforts should be placed on improving the DIFs [10].

The application of the ConCaMS is centered around the improvement of 15 severe DIFs identified via a 7-stage Delphi study [11]. The severe DIFs ranked from most to least severe are reflected in Table 1.

Table 1: Severe DIFs ranking.

Severe DIFs	Rank
Corrective Maintenance	1
Cashflow Shortages	2
Maintenance Policy - Priority on Type of Maintenance	3
Awareness of Importance of Maintenance / Attitude – including hiding problems from becoming official.	4
Complexity and efficiency of existing contract	5
Scheduling Issues	6
Spares Availability	7
Maintenance Budget Allocation	8
Knowledge Management incl Training, Knowledge, Skills and Systems	9
Equipment and Systems - Main Propulsion	10
Availability of Original Equipment Manufacturer (OEM) Expert Support	11
Availability of Facilities	12
Availability of Local Vendor Support	13
Equipment and Systems - Auxiliaries	14
Impact of Parallel Contracts to Schedule, Genuinity of Spares, Professionalism of Repair Team etc.	15

This paper summarizes findings of the Post-Survey Validation conducted with leading maritime top management experts in Malaysia that did not take part in the early Delphi rounds, as the final phase to conclude the complete research on availability improvement for the RMN ISS contract.

2. Post-Survey Validation Method

A post-survey validation questionnaire was developed to independently confirm the findings of this newly developed availability-oriented contract management model designated as ConCaMS. The methodology was adapted from Ramasamy [12] where a post-survey expert validation took place to confirm the final framework produced.

Other common validation methods in the engineering field consists of analysis and evaluation of physical data measured on site [13]. This method could be applied to measure equipment readings onboard the navy vessel, however would not offer an all-encompassing approach in measurement on human-related factors. In addition, the method could not assist in understanding the inter-relationships between equipment and human-related factors. A post-survey validation was selected to be applied due the fact that the new discovery of factors in this exploratory study is ahead of the technology to decipher them. There has not been any data collection on these newly discovered factors in the past, and there is no existing knowledge and experience on data collection method and mechanism on these DIFs to date. It requires a new technology and a shift in the mindset to enable collection of quality and purposeful data on the severe DIFs, which has only recently been introduced with the development of ConCaMS and its associated dashboards. Categorization of downtime to be recorded daily in accordance to the newly discovered severe DIF categories such as unavailability due to lack of knowledge and training, due to complexity of existing contract or caused by maintenance policy requires a different technological approach and mechanism that has not existed to date in the RMN and local ISS industries.

2.1 Post-Survey Expert Selection Criteria

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 [14]. Other researchers have similarly used expert opinions to study maintenance downtime distribution [15]. Size of sample and the appropriate number of experts was decided according to Baker and Edwards [16] who provide guidance and advice on sampling size for qualitative interviews based on a set of succinct "expert voice" contributions.

Adler and Adler [17] 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 (PSE) 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.

2.2 Post-Survey Expert Demographics

The participants were selected from Top Management of Shipyards, RMN and Malaysian Maritime Enforcement Agency (MMEA) fields 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 (SME). Table 2 contains the participant's demographics.

Table 2: Post-Survey Experts Demographics.

No	Organisation Type	Working Experience	Designation/ Job Function
1	RMN	28 years	First Admiral/ Head of Engineering
2	Shipyard	24 years	Executive Director Shipyard
3	Shipyard	42 years	Managing Director Shipyard
4	RMN	34 years	Rear Admiral/ Chief of Strategic Management
5	MMEA	40 years	Rear Admiral/ Director of Maritime Safety and Surveillance

2.3 Research Questions

The questionnaire administered was subdivided into three sections consisting of Section A, a 25 minutes demonstration of the ConCaMS, Section B, a 10 minutes feedback on the demonstrated model and implementation considerations and Section C, further feedback. These sections were aimed at answering a list of research questions and research objectives as contained in Table 3.

Table 3: List of Research Questions towards achieving Research Objectives.

Research Questions (RQ)	
RQ1a	What are the human and equipment related downtime influence factors (DIFs) affecting ship availability?
RQ1b	How can the DIFs affecting ship availability be-ranked and prioritized?
RQ2a	How do the DIFs impact the contract and project management elements of the "iron triangle of cost, time, quality and scope"?
RQ2b	Is it possible to improve ship operational availability by improving DIFs?
RQ2c	What areas can be improved when faced with budget constraints, if RQ2b is positive?
RQ3	Is it possible to develop an index based on ranking of the DIFs to indicate the severity of the DIFs?
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

Research Questions (RQ)	
	better?
RQ5a	How can the developed model assist the various organizations in their ultimate effort for improving the ship availability?
RQ5b	How can the model assist contract managers in managing their contracts better?
RQ5c	How can the model assist policymakers, maintainers and logisticians, as well as other stakeholders to contribute better in improving ship availability?
RQ5d	How can this model and associated research findings specifically benefit other navies implementing ISS contract, and generally benefit other engineering industries as well?

3. Results and Discussion

The results obtained from the Post-Survey Validation are summarized in Table 4.

Table 4: Post-Survey Validation Questionnaire.

No.	Question
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 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.
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?
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, 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?
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.

The answers of the experts are graphically displayed in Fig. 4. 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.

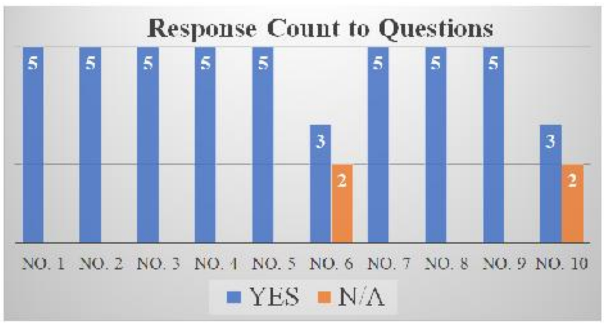

Fig.4 Response count to Question 1 to 10

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 summarized as follows:

i. This study is a new approach in determining 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.

4. Summary

Results of the Post-Survey Expert Validation points out with 100% consensus that the proposed ConCaMS model addresses the research questions and is therefore a valid system to improve ship availability for the RMN. It is important to point out that all RMN and MMEA top management experts believe in the advantages of the proposed model and it would assist not only in improving ship operational availability but also assist contract managers to manage the contract better. Policymakers, maintainers and logisticians could contribute better in improving availability. They agreed that accountability would be improved and the availability-oriented contract management model (ConCaMS) would ultimately improve Navy's overall preparedness and readiness. It is also worth pointing out from their individual remarks 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 current research has also proven the suitability and validity of the Post-Survey Validation method especially on exploratory study as other conventional validation methods using measured data are not befitting.

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