A Framework for Assessing the Impact of Integrating New Equipment onto Naval Vessels

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ABSTRACT

A nation's Defence Force has to adapt to changing geopolitical, technological and economic challenges. This particularly impacts capability systems with relatively long lifecycles such as naval ships. In Australia, government policy has meant the Royal Australian Navy (RAN) currently uses the off-the-shelf (OTS) acquisition strategy. If the RAN is to remain adaptable while using an OTS strategy, approaches to evaluate the capacity of OTS designs to integrate new equipment at various stages in the lifecycle are required. By understanding the impact of integrating new equipment onto a naval ship design, the RAN can manage the risk of not being able to respond to changing strategic and technological circumstances.

Recent research in the Maritime Division of the Defence Science and Technology (DST) Group has focused on developing methods to assess the impacts of integrating new equipment onto OTS naval ship designs. These assessments can be made throughout the capability lifecycle, including tender evaluation, when establishing potential batch-build strategies and when considering ship subsystem upgrades. To support these assessments, an Integration Impact Assessment framework has been constructed. The framework allows an assessment of the capacity of a ship design to integrate a range of equipment configurations and investigate the implications on the ship's mission performance.

This paper focuses on the use of the Integration Impact Assessment framework to assess the impact on ship designs of integrating new systems for additional military roles. The paper covers a pilot study undertaken jointly by the Naval Technical Bureau and DST to assess Multi-Role Vessel designs for their ability to accommodate new equipment in support of forecasted future roles of maritime constabulary, rapid environmental assessment and mine counter measures.

INTRODUCTION

The OTS acquisition strategy may result in the need for the Royal Australian Navy (RAN) to perform design changes to align the OTS vessel design with RAN specific requirements. Additionally, vessels typically have long service-lives and must be periodically upgraded to meet evolving RAN requirements. Consequently, there is likely to be a need for the RAN to integrate new systems and equipment during acquisition, and update or upgrade this equipment at different stages throughout the vessel service-life. The need to integrate new equipment can arise from changing geopolitical, technological and economic challenges that necessitate changes in Australian naval operational requirements [1]. The need to integrate new equipment can also arise from the maturation and uptake of suitable technologies, a current example of which are uninhabited systems [2]. Ideally, RAN vessel designs will inherently have a degree of flexibility, or adaptability built in through a range of appropriate margins. Throughout the vessel's lifecycle, these margins will be consumed as new or upgraded systems and equipment are integrated onto the vessel. Evaluating and understanding these margins and therefore the flexibility of the base platform will assist in identifying and managing capability risks and assist the RAN in making evidence-based design decisions [1].

The current Australian Chief of Navy, VADM Noonan, noted at the Defence and Industry Conference in 2018 that "*The future is not static and the context and needs of the future will continue to evolve. With it, we will be required to continually assess our capability*" [3]. In order to continually assess and manage the margins available on RAN vessels so they can adapt to these evolving needs, a methodical framework and associated tool is required. This paper covers the development and use of the Integration Impact Assessment (IIA) Framework and associated Tool that was developed to satisfy this requirement[1].

The IIA Framework provides the ability to undertake an assessment of various equipment configurations (ECs) to ascertain what integration impacts there will be on a naval vessel's margins and functional capability [4]. Integration of new equipment onto a vessel for which it was not originally designed may occur at any time in its lifecycle, including during the initial build process, major dockings or in batches of vessels being constructed using a continuous build program. This means that the IIA Framework and Tool could potentially be used to support decision-making during [4]:

1. Tender Evaluation: both tendered vessel performance and projected whole of life performance.
2. Modification of a current vessel to achieve evolving capability requirements.
3. Mid-life upgrade evaluation: what equipment will have the biggest capability increase with the smallest impact?
4. Development of batching strategies for classes of vessels in a continuous build program.
5. Life of Type Extension (LOTE) studies.
6. Exploration of Multi-Role Vessel concepts.

The IIA Framework has been developed to be flexible in application; the margins assessed could include consumable physical parameters such as space and weight, as well as measurable Key Performance Parameters (KPPs), such as stability compliance, endurance, and sprint speed. Additional analytical approaches such as the Ship Performance Modelling and Simulation Framework proposed by Dwyer and Morris [5] could be utilised to generate these KPPs, allowing the impact on more complex KPPs such as 'Percent Time Operable at Sea State 5' to be calculated and considered.

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[1] Initial development of the Integration Impact Assessment Tool was conducted by Frazer-Nash Consultancy, under the direction of the Defence Science Technology (DST) Group, to assess the impacts of integrating various technologies and subsystems on board the base platform for the SEA2400 project (Survey Vessel Hydrographic & Oceanographic). Subsequent development was conducted in a collaboration between the Navy Engineering Branch and DST.

This paper introduces the IIA Framework and covers a test implementation in a spreadsheet-based tool. The test implementation investigates the integration of a range of equipment configurations onto a Multi-Role Vessel (MRV) base platform. The paper concludes with some observations on the utility of the tool.

THE INTEGRATION IMPACT ASSESSMENT FRAMEWORK AND TOOL

Due to the nature of the activities that lead up to the integration impact assessments, the steps required to execute the IIA Framework could conceivably be implemented in any particular order the user deems fit. However, a general approach to the steps involved in the IIA Framework is depicted in Figure 1.

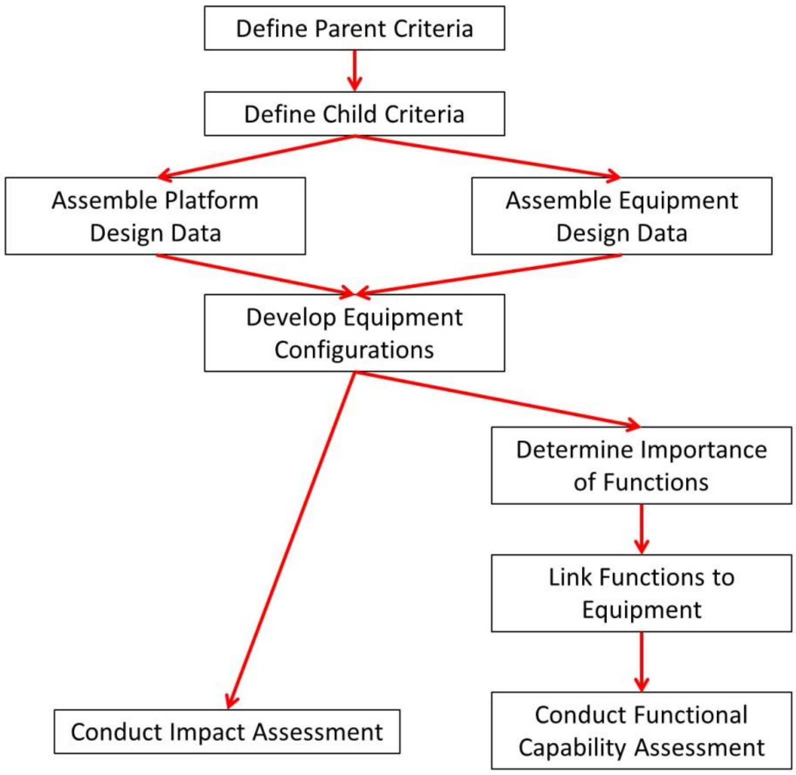

Figure 1: Overview of steps involved in the Integration Impact Assessment Framework.

Impact Assessment

The integration impact assessment component of the IIA Framework provides a qualitative assessment of the impact of integrating new equipment on a vessel's margins. The parent and child criteria are the metrics of the IIA Framework. They should represent the remaining vessel margins, over and above the original design, which the newly integrated equipment will consume.

Five common parent margin categories that are important for current and future naval vessels were identified by Schank *et al.* [2], they are; power, cooling, support for personnel, space and bandwidth margins, as well as the well-established weight and stability margins [2]. A summary of the expected impacts on these margins from emerging naval technology trends according to Schank *et al.* [2] is shown in Figure 2.

	Power	Cooling	Personnel	Space	Bandwidth
Unmanned systems	Little change	No change	Increase	Unclear	Increase
Electromagnetic weapons	Increase	Increase	Little change	Increase	No change
Long-range targeting	Increase	Increase	Little change	Increase	No change
Increasing Networking	Increase	Increase	More technical	Unclear	Increase

Figure 2: Effect of some key technology trends on vessel margins [2].

The final step of the Impact Assessment in the IIA Tool involves a comparison between the margins available on a vessel and those consumed by integrating an equipment configuration, to calculate an impact score for each criterion. An overall impact assessment score is calculated using a Multi-Criteria Decision Making (MCDM) method that combines the scores from all of the parent and child criteria. While this can be useful, testing of the IIA Framework has highlighted that the overall score should never be used without investigating all individual parent and child criteria to check whether individual criteria, or margins on the vessel are over consumed. These aspects are covered in more detail in Morris *et al*. [4], as well as in the test implementation covered later in this paper.

Functional Capability Assessment

The functional capability assessment provides an estimate of the functional capability provided by an equipment configuration. The estimate is based on a weighted summation of the number of required functions that an equipment configuration can perform. The functions that a vessel is required to perform must be defined and their importance estimated as shown in Figure 1. Once this has been done, the functions need to be linked to the equipment that could perform them. For the vessel to achieve a functional capability contribution of a function, all pieces of equipment required to perform the function must be present in an equipment configuration; e.g. if an equipment configuration contained a davit without a seaboat, it would not be able to perform boarding party functions. The functions can be defined in a top-down manner based on the content typically provided in an Operational Concept Document.

The functional capability assessment component of the IIA Framework should only be considered with reference to the impact assessment. This is to ensure that functional capability assessments are conducted with an understanding of the equipment configurations that can be feasibly integrated onto a vessel.

Further details on the IIA Framework and Tool can be found in Morris *et al.* [4]. This paper focuses on a test implementation of the IIA Framework using the current version of the IIA Tool to investigate its utility.

TEST IMPLEMENTATION – IMPACT OF INTEGRATING EQUIPMENT ONTO MULTI-ROLE VESSELS

This test implementation involves the use of the IIA Framework and Tool to explore Multi-Role Vessel (MRV) concepts. The MRV concept in this case is a vessel that is to perform the military roles of Rapid Environment Assessment (REA), Mine Countermeasures (MCM) and Maritime Constabulary (MC). It is assumed that the vessel will spend 60 % of its time at sea undertaking MC operations, 30 % of its time at sea undertaking REA and 10 % performing MCM activities. In the test implementation, the IIA Framework is applied to three assessments:

1. Assessing the impact of including various Equipment Configurations (ECs) associated with the onto three candidate MRV designs.
2. A comparison of the three candidate MRV designs.
3. An assessment of the functional capability achieved by the ECs.

Background

The MRV concept has been gaining momentum in recent years, with many Navies developing MRV programs to combat the increasing number of tasks a naval vessel is required to perform [6]. An increasing amount of time is spent on military operations other than war such as; humanitarian relief after natural disasters, border protection, piracy interdiction, search and rescue. The single-mission navy vessel can be seen as an expensive and rigid solution, which requires expensive mid-life upgrades to keep up with competing technology advances. The modular concept of reconfigurable payloads has the potential to reduce the cost of mid-life upgrades and allows the vessel to be reconfigured to perform different roles as required [2, 7]. The interoperability of the same base platform and systems potentially reduces training requirements and cost of ownership while increasing operational efficiency [7, 8].

The roles of REA, MCM and MC were identified in an initial capability description for the SEA1180 MRV project in 2011. It was planned to replace the existing RAN Patrol, Hydrographic and MCM force, comprised of 26 vessels across four classes, with a single, multirole class [8]. This concept was not realised for SEA1180 at the time, however this concept has been used as the basis for the test implementation.

The test implementation uses the IIA Framework to investigate the impact of integrating various subsystems onto three MRV concepts and the associated functional capability provided with each EC. It is worth noting that the impact of placing additional equipment on the vessel on the centre of gravity has not been assessed in this test implementation and it is assumed that the vessel stability and structural strength will not limit the Equipment Configurations (ECs). In a full implementation of the IIA Framework, the impact on the vessel centre of gravity could be included as a criterion.

Define Integration Impact Criteria

The five parent criteria defined for this test implementation are: Space – non tank, Space – tank, Weight, Heating Ventilation Air-conditioning and Cooling (HVAC) and Power. The criteria and weightings were developed by DST researchers acting as defence stakeholders. Child level integration criteria were developed for each parent criteria. For each criterion, the margin available on a vessel is typically applied as the upper threshold, and a value of zero applied as the lower threshold. The equipment configuration's value for that criterion is then marked as a percentage of these thresholds. For the test implementation, all criteria were assigned an increasing value curve. This means that a lower integration impact score results in a lower utilisation of the available margins. As the vessels used in the test implementation are concepts, i.e. in the early design stage, a lower utilisation of margins is preferable as reserve margins may be required for future upgrades and remediation when the vessel is in service.

Assemble Platform and Equipment Characteristics

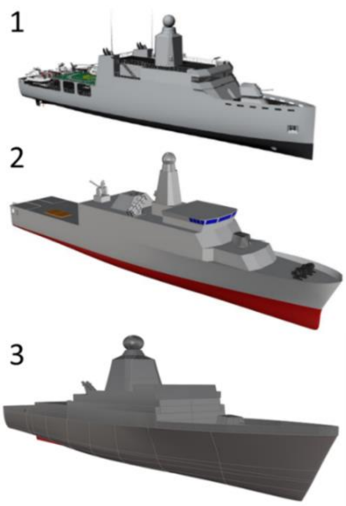

Figure 3: Candidate Vessel Designs

The three vessels used in this test implementation were final year projects by students at the Australian Maritime College, developed under direction from DST and are depicted in Figure 3.

These vessels were designed as multi-role vessels, with slightly varying requirements and particulars. Computer Aided Drawing (CAD) models, general arrangements and ship specification documents were supplied with each vessel and have been used to assemble the platform design data required to populate the IIA criteria thresholds.

The Equipment required for the roles was developed using a top-down mapping of the equipment required to achieve the operational functions described in Morris [9] in combination with engineering knowledge. The data required to populate the criteria values for the equipment was then sourced and the functional capability that the equipment could achieve were recorded using a traceability matrix, an example of which is provided in Reference [4].

Equipment Configurations

Twenty-two ECs were developed using the open literature sources and engineering knowledge. Three levels of EC were developed for each vessel role, representing a minimum, medium and maximum performance level. Combinations of these role-specific ECs were also generated, to identify any potential integration impact savings by utilising the same equipment across multiple roles. The hydrographic equipment configurations were developed with the assistance of data from Hayes and Webb [10]. The three equipment configuration levels generated were formed as:

1. Minimum performance level: shipborne sensors and a small specialist crew.
2. Medium performance level: minimum performance level equipment + towed sensors and a medium specialist crew.
3. Maximum performance level: Minimum + medium performance level equipment + off-board, UUV and UAV sensors with a maximum specialist crew.

As an example, the MCM role ECs are shown in Table 1.

Table 1: Mine Counter Measure Equipment Configuration levels

MCM Minimum	MCM Medium	MCM Max
UUV (Double Eagle Mk II)	MCM Min Plus	MCM Min + MCM Med Plus
Three MCM Crew	UAV (Camcopter s-100)	Two MCM Crew (7 total)
Small Deployable Survey Kit	UUV (Seafox Mine Disposure)	Clearance Divers (6)
Deployable Meteorological Kit	Two MCM Crew (5 total)	Clearance Diver RHIB
LARS A-frame (Seaview) Max1.5t	LARS Crane (SAAB Seaeye)	Transportable recompression Chamber
Ceremonial: Flags etc.	RHIB MCM (J3)	Davit (Clearance Diver RHIB)
Towing Gear	Davit (RHIB PRH 100 AP)	
Mooring Gear		

Link Functions to Equipment

The functional capability assessment within the IIA Framework is based on the number of functions the equipment within the EC can perform, and does not involve the candidate vessel; it is merely a weighted measure of the functions that can be performed by an EC. Hence, it should not be used in isolation from the Impact Assessment.

For the MRV test implementation of the IIA Tool, A previous study [9] into the functions required to be performed by an MRV was utilised. Morris' [9] list of 96 parent functions and 135 children functions has been refined, with functions that are performed by the base platform such as Transit and Seakeeping not being considered in this functional capability assessment. The remaining functions were segmented by role and assigned an importance, or weight based on the total 'time spent in role' defined in the vessel requirements: 60 % for MC, 30 % REA and 10 % MCM.

The importance or weight of a function is calculated by dividing the percentage of time the MRV will spend in the role by the number of functions within it. Furthermore, if a function contributes to a capability more than once, the importance was multiplied by the number of times that function occurred within the role. An example of this is the shallow water function within the MC role. Shallow water functions were present in many of the missions identified for MC role such as Littoral warfighting, Border protection and Counter terrorism, which resulted in its high contribution to capability. These functions are listed in Tables 2, 3 and 4 by each role respectively.

Table 2: Functions and their contribution to MC Functional Capability

Role	Top-Level Function	Second-Level Function	Contribution (%)
MC	Border Protection Functions	Boarding Party Functions	6.92%
	Launch, Recover and Stow	Boats	6.92%
		UAV	2.31%
		UUV	2.31%
		USV	2.31%
	Sensor Functions	Above Water Sensors	4.62%
		Underwater Sensors	2.31%
		Visual Surveillance and Detection	2.31%
	Shallow Water Functions	Shallow Water Functions	13.85%
	Counter Piracy Functions	Sensor Functions	4.62%
		Special Forces Functions	2.31%
	Counter Terrorism Functions	Littoral Warfighting Functions	4.62%
		Offshore Warfighting Functions	4.62%

Table 3 Functions and their contribution to REA Functional Capability

Role	Top-Level Function	Second-Level Function	Contribution (%)
REA	Bathymetric Mapping Functions	Shallow Water Functions	4.0%
		Sensor Functions	2.0%
		Deep Bathymetric Mapping	2.0%
		LRaSF.1-Boats	4.0%
		LRaSF.2-UUV	4.0%
		LRaSF.3-UAV	4.0%
		LRaSF.4-USV	4.0%
	Sensor Functions	Underwater Sensors	2.0%
		Above Water Sensors	2.0%
	Subsearch Functions	Hydrographic Survey Functions	2.0%

Table 4 Functions and their contribution to MCM Functional Capability

Role	Top-Level Function	Second-Level Function	Contribution (%)
MCM	Clearance Diver Functions	LRaSF.1-Boats	0.71%
	Ceremonial Functions	Ceremonial Functions	0.71%
	Minehunting Functions	LRaSF.1-Boats	1.43%
		LRaSF.3-UAV	1.43%
		LRaSF.4-USV	1.43%
		LRaSF.6-UUV	1.43%
	Sensor Functions	SF.1.2-Underwater Sensors	1.43%
	Minehunting Functions	ShF- Shallow Water Functions	0.71%
	Sensor Functions	SF.1.1-Above Water Functions	0.71%

Impact of Integrating Equipment Configurations onto Vessels

The impact assessment results for integrating the 22 ECs onto each of the three candidate MRV designs is summarised in Table 5. This provides only a high-level overview of the overall impact assessment that is calculated as a weighted value using an MCDM technique. An impact result of 100 % represents a vessel margin being completely consumed. An impact result greater than 100 % means the EC cannot be feasibly integrated within the vessel's margins and indicates some equipment may need to be removed or design changes made to the base platform.

As previously discussed, it is vital that the overall impact assessment criteria are not viewed in isolation from the individual parent and child integration impact criteria. For example, the child criteria results of EC10 provide a useful demonstration of this as the overall integration impact results for vessels one and two are less than 100 % (red cells highlighted in Table 5). However, when viewing the individual child-level integration impact criteria results for EC10 shown in Figure 3 (also see the blue highlighted cells in Table 5), it can be seen that six of the criteria are greater than 100 % for Vessel 1 and five of them are greater than 100 % for Vessels 2.

Table 5: Results Summary of the Integration Impact Assessment for the MRV Test Implementation [4].

ID	Equipment Configuration Description	Vessel 1		Vessel 2		Vessel 3	
		Impact (%)	No. Criteria > 100%	Impact (%)	No. Criteria > 100%	Impact (%)	No. Criteria > 100%
EC1	Base (nothing)	0	0	0	0	0	0
EC2	Rapid Environmental Assessment (REA) Minimum	40	2	32	2	74	4
EC3	REA Medium	59	3	51	4	105	5
EC4	REA Maximum	74	7	62	5	154	7
EC5	Mine Countermeasures (MCM) Minimum	7	0	9	2	25	3
EC6	MCM Medium	38	1	33	3	73	4
EC7	MCM Maximum	56	3	46	5	95	5
EC8	Constabulary (MC) Minimum	51	4	38	4	77	5
EC9	MC Medium	57	5	42	5	82	5
EC10	MC Maximum	76	6	57	5	128	5
EC11	REA + MCM Minimum	45	2	40	4	84	6
EC12	REA + MCM Medium	95	6	81	5	161	7
EC13	REA + MCM Maximum	120	9	101	9	224	9
EC14	REA + MC Minimum	100	7	77	6	154	6
EC15	REA + MC Medium	125	9	99	9	190	7
EC16	REA + MC Maximum	146	10	115	9	245	10
EC17	MC + MCM Minimum	68	5	54	7	106	6
EC18	MC + MCM Medium	93	7	73	7	139	6
EC19	MC + MCM Maximum	118	9	91	8	186	7
EC20	REA + MC + MCM Minimum	106	8	84	8	164	8
EC21	REA + MC + MCM Medium	149	9	120	9	227	10
EC22	REA + MC + MCM Max	170	13	137	10	278	12
Totals			125		126		137

These individual criterion results are useful as they provide suggestions for vessel design changes. For example, from Figure 3 it can be seen that for the child-level integration impact criteria 1.5, Machinery Space, EC10 has consumed only 31 % of the machinery space available on Vessel 2. This means there could be potential to install more auxiliary machinery on Vessel 2, thereby resolving some of the over allocated criteria such as HVAC (criteria 4.1) and power generation (criteria 5.1).

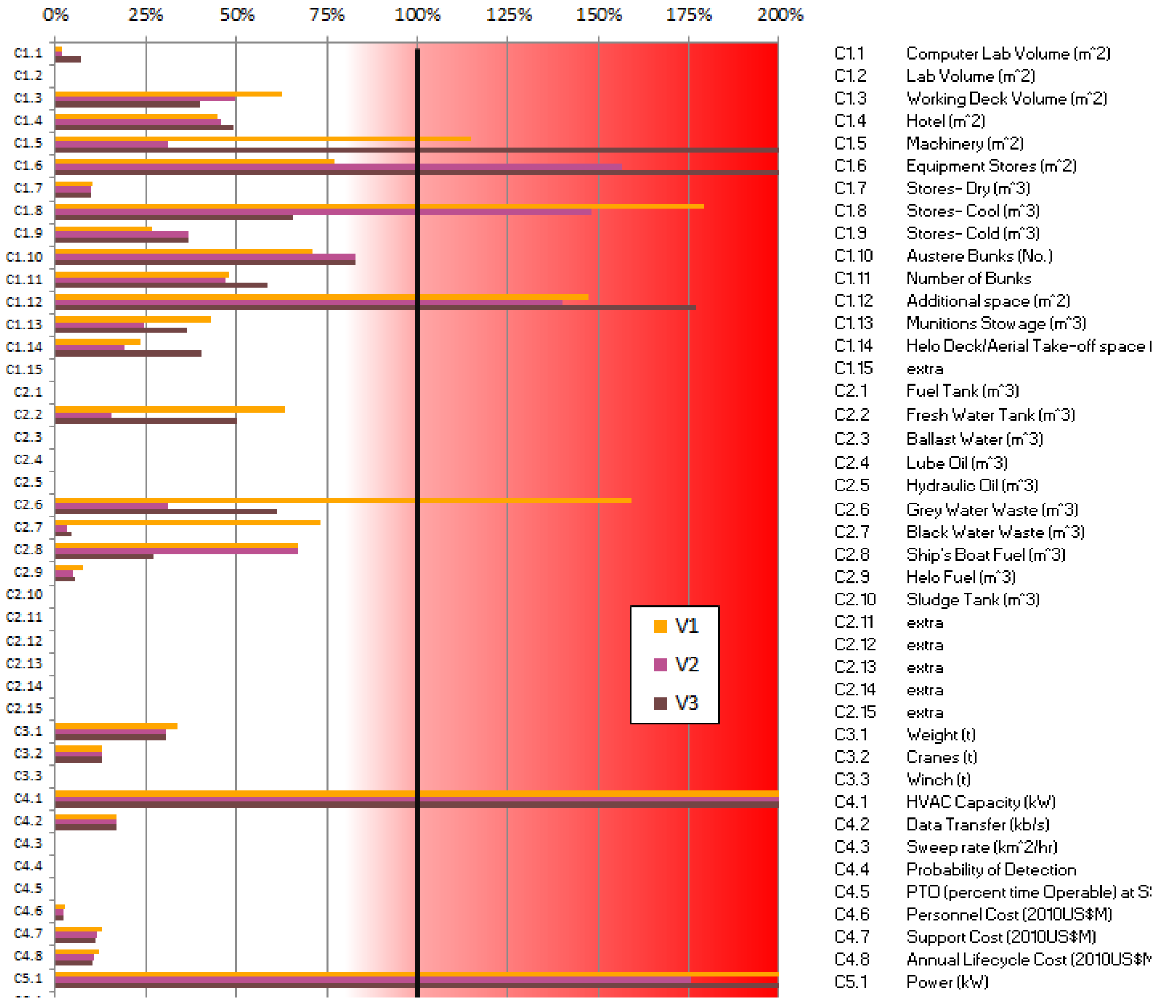

Figure 3: Child-level Integration Impact Criteria Results for EC10 [4].

Evaluating Vessels

A simple way of comparing the three vessels investigated for this test implementation is to sum the total number of over allocated (i.e. over 100 %) integration impact criteria for all of the ECs. In this case, by adding up the number of criteria greater than 100 % for each vessel as shown in the final row in Table 5, it can be seen that Vessel 1 has a total of 125 over allocated criteria across all ECs, Vessel 2 has 126 and Vessel 3 has 137. Again, this does not provide a full understanding of which vessel is preferable, as this will be dependent on the EC that is of most value to the capability stakeholders. Once this is known, the vessel evaluation will need to be conducted in light of all integration impact criteria.

Evaluating Functional Capability

The functional capability assessment component of the IIA Framework is based on the ECs and is independent of the vessels being evaluated. It is therefore important to remain cognisant of which ECs can be feasibly integrated onto any vessel under evaluation when conducting the functional capability assessment. Using the weightings of the importance of the functions for the functional capability given in Table 1, the relative capability of each of the ECs were calculated with the results shown in Table 6.

To achieve a functional capability score in the IIA Tool, all equipment required to perform the function must be present in the EC. One piece of equipment may be included in multiple functions. As a number of equipment pieces are typically required for each function, and these may not be coincident with a single EC, an EC may have a low capability score due to not including one specific piece of equipment; e.g. a RHIB, which contributes to the capability 'Shallow Water Functions', but only if there is a davit to 'Launch, Recover and Stow Boats'. Conversely, items such as RHIBs are included in several functions and the inclusion of a RHIB in an EC will typically increase the capability of that EC. Such items of equipment, when included in an EC can increase overall functional capability with neutral impact, as their impact is only counted once, but their contribution to capability may span across several functions. This can be seen in EC17, where the individual capability scores of MC Min (EC8) = 0.461 and MCM Min (EC5) = 0.19. However, due to the combination of equipment in these two ECs, an overall capability for EC17 is 0.664 because the equipment in the EC can also be used to perform some of HS role functions. This demonstrates the potential benefits of the multi-role vessel and shared equipment and the ability of the tool to highlight these benefits.

Table 6: Summary of the relative functional capability provided by each EC [4].

EC Number	EC	Functional Capability			
		Overall	Role 1	Role 2	Role 3
			MC	HS	MCM
EC1	Base (nothing)	0.000			
EC2	REA Minimum	0.190	0.023	0.160	0.007
EC3	REA Medium	0.266	0.023	0.200	0.043
EC4	REA Maximum	0.403	0.046	0.300	0.057
EC5	MCM Minimum	0.190	0.046	0.080	0.064
EC6	MCM Medium	0.398	0.139	0.160	0.100
EC7	MCM Maximum	0.398	0.139	0.160	0.100
EC8	MC Minimum	0.461	0.392	0.040	0.029
EC9	MC Medium	0.654	0.531	0.080	0.043
EC10	MC Maximum	0.654	0.531	0.080	0.043
EC11	REA + MCM Minimum	0.374	0.069	0.240	0.064
EC12	REA + MCM Medium	0.472	0.092	0.280	0.100
EC13	REA + MCM Maximum	0.700	0.300	0.300	0.100
EC14	REA + MC Minimum	0.728	0.485	0.200	0.043
EC15	REA + MC Medium	0.952	0.600	0.280	0.071
EC16	REA + MC Maximum	0.966	0.600	0.280	0.086
EC17	MC+ MCM Minimum	0.664	0.439	0.140	0.086
EC18	MC + MCM Medium	0.897	0.577	0.220	0.100
EC19	MC + MCM Maximum	0.897	0.577	0.220	0.100
EC20	REA + MC + MCM Minimum	0.857	0.531	0.240	0.086
EC21	REA + MC + MCM Medium	0.980	0.600	0.280	0.100
EC22	REA + MC + MCM Maximum	1.000	0.600	0.300	0.100

By comparing the functional capabilities for each EC in Table 6 with their impact in Table 5, an indication of the ECs that can be potentially integrated onto the vessels and achieve the most functionality can be identified. From the perspective of functional capability in Table 6, ideally, ECs 20, 21 and 22 would be integrated onto the MRV. However, from Table 5 it can be seen that the overall impacts for these ECs are greater than 100 % except for on instance. The number of individual criterion with an integration impact over 100 % is also significant, which indicates it is unlikely to be possible to integrate these ECs on these vessels.

CONCLUSIONS

The Integration Impact Assessment (IIA) Framework and associated spreadsheet-based Tool has been developed to build understanding of the impact of integrating new equipment onto a naval vessel. The IIA Framework and Tool builds this understanding by investigating the various vessel margins, such as space, weight, power and HVAC, that will be consumed by integrating an equipment configuration (EC). The IIA Framework and Tool can be used at various stages in a vessel's lifecycle including; tender evaluation, mid-life upgrades, life-of-type extension studies, and to assist with batching strategy development in continuous build programs.

The test implementation provided several key insights into the utility of the IIA Framework and Tool. Gathering and entering the design data of the vessels and equipment to be assessed within the IIA Tool can be time consuming. However, the ability to reuse parent and associated child-level criteria in subsequent assessments is a strength of the IIA Tool as it means this process does not need to be repeated. Furthermore, equipment and ECs can be reused, thereby significantly reducing the effort involved in conducting follow-on assessments. Hence, for a particular platform type the useability/efficiency of the IIA Tool improves with each subsequent study. This would be advantageous for a class of ship, which may be investigated for its capacity to integrate new equipment at various stages in its lifecycle. The test implementation also demonstrated the ability of the IIA Tool to highlight when vessel margins were being over utilised and underutilised by an EC. Investigating the impact of ECs on child criteria demonstrated how potential design changes could be identified in order to potentially increase critical margins.

Other insights provided by the test implementation include the need for engagement with appropriate Subject Matter Experts when developing ECs and the importance of the functions the vessel is required to perform. The IIA Tool itself requires an 'intelligent' user so that the data used in the impact and functional capability assessments is appropriate. The results of any assessment based on incorrect or inappropriate data is likely to yield untrustworthy results.

A final key conclusion, which was clearly demonstrated during the test implementation, is that the individual child and parent-level integration impact criteria need to be investigated as part of any integration impact assessment. This is because the rolled up, overall weighted values of the integration impact calculated using the Multi-Criteria Decision Making method can potentially hide key impacts and other insights. These insights can be used to identify potential equipment trade-offs and design changes. Overall, the IIA Framework and associated Tool has been demonstrated to provide useful insights for investigations into the impact of integrating new equipment onto a platform.

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