NATO Mission Modularity Cost-Benefit Analysis

R.A. Logtmeijer[a]* MSc, J.-D. Caron[b] MSc, M. Fee[b] MSc, A.M. Rudius[c] B.Eng. Dipl.-Kfm., S.R. Otten[a] BSc, D. Manley[d]* CEng MSc FRINA RCNC, M.S. Clarke[e], J. Lin[e] MSc FSNAME

[a]Ministry of Defence, NL; [b]Defence Research and Development Canada; [c]MTG Marinetechnik GmbH, GE; [d]Ministry of Defence, UK; [e]Naval Sea Systems Command, US
*Corresponding authors. E-mail: ra.logtmeijer@mindef.nl, david.manley641@mod.gov.uk.

Synopsis

The objective of defence planning is to look well into the future and predict which force structure will be the most cost-effective in the future security environment. NATO periodically executes a defence planning process called NDPP (NATO Defence Planning Process) in order to have an effective and affordable future force structure for all 29 NATO member states combined. Defence planning delivers for a navy the future fleet structure: the types and numbers of ships required for future maritime operations.

A trend that is considered to be essential in order to remain relevant in the rapidly changing security environment is mission modularity. Mission modularity means that the mission systems of a ship are contained within modules (which can be standard shipping containers) so that the ship can adapt to changing missions and technologies more quickly. The ship has space for installing a number of mission modules and supports the modules by providing services like electricity, cooling water and data exchange. The requirements of the next mission determine which mission modules have to be installed on the ship. Reconfiguration may occur in the nearest friendly port.

In the past a number of studies have been conducted to determine the impact of this trend on the cost and operational effectiveness of the current traditional navy construct. These studies have in common that the results are based on qualitative assumptions. The NATO Specialist Teams on Total Ship Systems Engineering and Ship Costing developed an approach that combines an effectiveness model and a cost model in order to provide valuable data and insight into the cost-effectiveness of alternative fleet structures on a comparative basis. The approach includes future operational context analysis, fleet and ship concept design, concept of operations development, operations analysis, cost analysis, and data analysis and visualisation. Together with the Specialist Team on Mission Modularity, the approach was applied in a study that finished end of last year. The study validates in a rigorous, systematic and analytical context the conclusions from earlier studies about the value of mission modularity, and aids NATO and individual nations to make informed decisions on naval force planning.

Keywords: Mission modularity; Future operational context analysis; Fleet and ship concept design; Concept of operations development; Operations analysis; Cost analysis; Data analysis and visualization

1 Introduction

1.1 *Background*

It takes many years to design and build a warship. The development and production of a surface combatant typically takes more than ten years. Because of the high cost of the ship and its development and production, the aim is to operate the ship for many years. The operations and support phase of a surface combatant is typically about thirty years. History shows that the requirements of a ship will change over the course of its service life. There are two main reasons:

- The geopolitical situation changes, and consequently the global security environment.
- New technology emerges.

Authors' Biographies (Continued on next page)
Richard Logtmeijer holds the current position of Senior Staff Member Life Cycle Modelling in the Defence Materiel Organisation (DMO) of the NL Ministry of Defence. He is responsible for analysing the operational effectiveness and cost of new maritime systems. He is the NL delegate to the NATO Specialist Team on Mission Modularity and the chair of the NATO Specialist Team on Total Ship Systems Engineering. His previous experience includes three years serving as a naval officer and over twenty years working for the Royal Netherlands Navy. He has a MSc in Electrical Engineering (University of Twente, The Netherlands).
Jean-Denis Caron BSc Mathematics, Master Applied Mathematics (Université du Québec à Trois-Rivières, Canada). Defence Research and Development Canada – Center for Operational Research and Analysis. Since 2002, he has been a Defence Scientist with Defence Research and Development Canada's Center for Operational Research (DRDC CORA). He is currently the team leader of the Maritime Operational Research Team in Ottawa, providing decision-support, quantitative analysis and modeling and simulation to the Royal Canadian Navy.

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Changes in the global security environment may lead to different types of missions that will be assigned to the ship. The ship may need different capabilities in order to successfully complete these new types of missions, and consequently new mission systems have to be installed.

New technology may lead to more effective capabilities, or entirely new capabilities (for example, directed-energy weapon systems). In order to remain more effective than the peer competitor, the ship may have to upgrade its capabilities by upgrading or replacing its mission systems, or installing new mission systems.

New mission systems require space and support from the ship's support systems such as the electric power generation and distribution system and cooling system. Because of such requirements, it may be technically or economically infeasible to install new mission systems, or upgrade or replace the ship's current mission systems. It may be technically infeasible if there is not enough space for the new mission systems. It may be economically infeasible if the cost of installing the new mission systems is relatively high compared with the cost of a new warship. Or it may take a very long time to implement the changes to the ship. If because of these reasons the ship cannot be adapted to the new situation, it will not be as effective as required. This could mean that the ship is no longer relevant, and that it has to be replaced.

A solution to this problem is to design adaptable ships: ships with sufficient design margins that technically can be adapted to new situations (new missions and new technology), in relatively short time and at relatively low cost. Each adaptable warship may be more expensive than a traditional, less adaptable equivalent. So the question is: is a task group (TG) or fleet of these adaptable warships more cost-effective than a TG or fleet of traditional warships, during the entire operations and support phase of the TG or fleet? And is a TG or fleet of these adaptable warships more cost-effective than a TG or fleet of traditional warships considering both today's and tomorrow's missions and technology? These questions are relevant to NATO because the objective of the NDPP is to maintain high effectiveness of NATO maritime forces at the lowest cost possible.

An interesting and promising method for making a warship adaptable is mission modularity (Manley *et al.* 2016, Manley 2018, Logtmeijer *et al.* 2019). A warship with mission modularity has spaces in which mission modules can be installed. Mission modules are standard shipping containers, or other standard packages, that contain mission systems (e.g., weapon systems) or support systems (e.g., diesel generators). The spaces in which mission modules can be installed are called mission bays. A standard defines the interface between the mission bays and the mission modules (Cole and Alvarez 2019, NATO Standardization Office 2020a, NATO Standardization Office 2020b).

Authors' Biographies (Continued)

Michèle Andrée Fee BASc Chemical Engineering, MASc Chemical Engineering (University of Ottawa, Canada). Defence Research and Development Canada – Center for Operational Research and Analysis. Since 2017, she has been working as a junior Defence Scientist with Defence Research and Development Canada's Center for Operational Research (DRDC CORA). She currently supports the Royal Canadian Navy, providing decision-support through quantitative analysis, modeling and simulation.

Michael Rudius B.Eng. Industrial Engineering (University of Applied Sciences Hamburg), Dipl.-Kfm. Economics (University of Hamburg). He works as a project manager for techno-economic studies in early stage naval projects providing decision support for the German MOD / German Navy and has around 15 years of experience as a cost engineer. He supports the German Delegate to NATO ST-TSSE / ST-SC since more than 5 years.

Siebe Otten holds the position of Staff Member Life Cycle Modelling at the Defence Materiel Organisation (DMO) of the NL Ministry of Defence. He has over 15 years of experience in naval ship requirements definition, project engineering and ship costing, and is co-chair of the NATO Specialist Team on Ship Costing. He holds a BSc degree in Marine Technology from the Delft University of Technology.

David Manley holds the current position of Naval Authority Group Deputy Head, Ships Division in the UK Ministry of Defence. He is responsible for the development and management of the MOD's maritime combat safety programme as well as the Royal Navy's Survivability Strategy. His previous experience includes twenty years working in maritime survivability and nearly thirty years working in the MOD. He is the UK delegate to the NATO Ship Design Capability Group and the co-chair of the NATO Specialist Team on Mission Modularity. He is a DE&S Defence Engineering Senior Fellow, a Fellow of the Royal Institution of Naval Architects and a member of the Royal Corps of Naval Constructors.

Jennifer Lin is the Deputy Ship Design Manager for Unmanned Surface Vehicles/Vessels and Surface Ship-launched Unmanned Undersea Vehicles in the Surface Ship Design and Systems Engineering Group at the US Naval Sea Systems Command. She has nearly 15 years of experience as a Ship Systems Engineer, 6 years as the U.S. Delegate to the NATO Ship Design Capability Group, and has been the co-chair of the NATO Specialist Team on Mission Modularity since its establishment. She holds a B.S. in Aerospace and Ocean Engineering, M.S. in Ocean Engineering (Virginia Polytechnic Institute and State University), and is a Fellow of the Society of Naval Architects and Marine Engineers.

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The purpose of mission modularity is to quickly adapt the ship to new missions and new technology by swapping out mission modules, which can be done in a friendly port. Modularity decouples the design and build phase of the ship from that of the modular capability. For example, in the design and production phase of the ship the mission modules can be designed and produced at a location away from the shipyard. Likewise, in the operations and support phase of the ship the mission modules can be maintained and modernized at a location away from the port or shipyard.

Making warships adaptable through mission modularity is a growing trend: many navies require that their new surface combatants have one or more mission bays (Figures 1 to 4).

Figure 1 Royal Navy Type 26 (Royal Navy 2020)

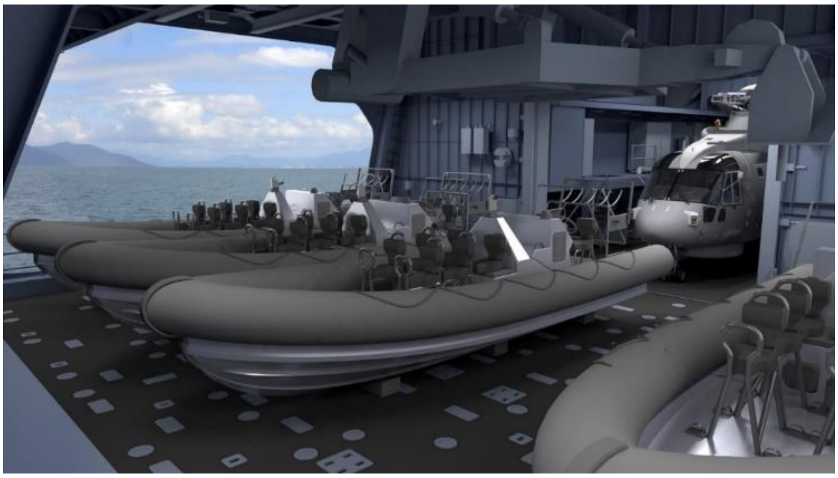

Figure 2 Royal Navy Type 26 mission bay (Royal Navy 2020)

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Figure 3 Italian Navy Pattugliatori Polivalenti d'Altura (Logtmeijer *et al.* 2019)

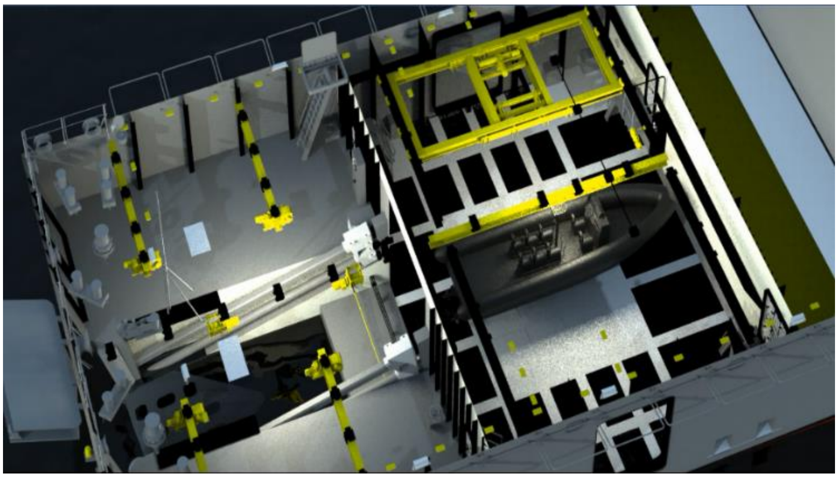

Figure 4 Italian Navy Pattugliatori Polivalenti d'Altura mission bay (Logtmeijer *et al.* 2019)

1.2 *Motivation*

The NATO Specialist Team on Mission Modularity (ST-MM) coordinates NATO's internal research on mission modularity. In December 2013 the ST-MM held a workshop at the NATO HQ in Brussels, which was called the 'Payloads and Platforms Workshop'. One of the outcomes of the workshop was that NATO should conduct a cost-benefit study on mission modularity for the NATO maritime forces. The reason for conducting a cost-benefit study is that opinions of naval operators and other experts vary widely on how mission modularity will change the cost and operational effectiveness of NATO maritime operations.

After the Payloads and Platforms Workshop, the ST-MM tasked the Specialist Team on Total Ship Systems Engineering (ST-TSSE) and the Specialist Team on Ship Costing (ST-SC) to conduct the cost-benefit study. ST-MM, ST-TSSE and ST-SC all fall under the Ship Design Capability Group (SDCG) of the NATO Naval Armaments Group (NNAG).

1.3 *Scope*

In order to bound the study a number of assumptions have been made. The types of missions do not change over time. Also, the frequencies at which missions of these types occur over time are constant (although there is randomness in the way the actual sequence of missions is generated). The scope of the study is thus limited to an operational demand that is constant over time (i.e., the same scenario frequencies and expected durations are used in the Monte Carlo simulation). Note that the same assumption covers both the traditional TG and the modular TG, so the approach is consistent. Mission modularity can have advantages when the operational demand changes

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over time, for example when the mission type frequencies change over time (e.g., more ASW missions and fewer MCM missions), when new types of missions have to be conducted, or when new technology emerges. In these cases the set of mission packages can be adapted to reflect the new operational situation. It will be much easier to adapt a set of mission packages on a modular TG than a group of traditional warships with dedicated and integrated mission systems. This study focuses on the less obvious situation for which the operational demand is constant over time.

1.4 *Research Question*

The main research question is:

- Is a modular TG more cost-effective than a traditional TG?

This study focuses on estimating the operational effectiveness and cost of a TG that conducts NATO maritime operations. A modular TG consists of modular warships and mission packages:

- A modular warship has capabilities which can be adapted relatively quickly by installing and removing mission packages.
- A mission package consists of mission modules and additional crew members who have been trained to operate and maintain the mission package throughout deployment. A mission package adds a specific capability to a warship when it is installed on board (e.g., an ASW capability).

A traditional TG consists of traditional warships with capabilities assumed to be unchangeable (i.e., organic to the ships).

An essential requirement for any approach to answering the main research question is that the comparison must be fair, which means that either the effectiveness or the cost of the two TGs should be equal.

1.5 *Objective*

The objectives of the cost-benefit study are (1) to inform NATO, in particular the SDCG and the ST-MM, of the differences in cost-effectiveness between a modular TG and a traditional TG, and (2) if a modular TG is found to be more cost-effective than a traditional TG, to advise NATO nations on how to implement mission modularity in a cost-effective way.

The first objective is achieved by conducting a cost-benefit analysis (CBA), provided in this paper. The second objective can be achieved by including new mission modularity-related capability codes into the NDPP. The NDPP translates changes in the global security environment and new technological developments into capability requirements for the allied maritime forces (NATO 2020a). The capability requirements are grouped into capability codes (NATO 2020b). The maritime capability codes represent different ship types (e.g., Warship Capable) and operational capabilities (e.g., Anti-Surface Warfare). Currently there are no capability codes that represent mission modules (with the exception of the harbour protection capability code) or ships with mission bays. By including mission modularity-related capability codes that are derived from the study results, NATO can provide guidance to member nations on how to implement mission modularity in a cost-effective way. For example, suppose the study results show that a modular TG is more cost-effective than a traditional TG under the condition that the modular ships each have a minimum capacity of *x* mission modules. In that case a new modular ship capability code can be created. One of its capability statements will state the minimum capacity: ‘Capable of hosting at least *x* mission modules’.

1.6 *Approach*

The approach adopted by the study group starts with the definition of the operational demand, and subsequently the definition of the traditional TG. The operational demand is a sequence of missions randomly generated from a set of vignettes. It is assumed that the traditional TG is capable of meeting a high enough fraction of the total operational demand with regard to the types of missions, the number of missions of each type, mission locations, etc., so the definition of the traditional TG follows from the operational demand.

After generating an operational demand, the cost and effectiveness of the traditional TG set the baseline for comparing cost and effectiveness. Several different modular TG definitions are used, because at this point it is unknown which modular TG definitions have the same effectiveness as the traditional TG, or cost the same as the traditional TG. To ensure a fair comparison in costing and capability, the ships used in both traditional and modular TG configurations were not based on existing designs, but were representative of the types of ships that could be

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expected to serve in a typical NATO navy. The main difference between the modular designs is how many mission modules they can carry (so they differ in size). The set of mission packages is derived from the vignettes and the mission systems of the ships in the traditional TG. Each modular TG definition included in the study defines the types and numbers of modular ships and mission packages.

After setting up (a) the operational demand, (b) the traditional TG, and (c) the set of modular TGs, the cost and effectiveness of each TG (traditional and modular) are estimated by running two simulation models. Important factors of the simulations are which measures of effectiveness (MOEs) are used, and which types of cost are included in the cost estimate. Three different, yet simple MOEs are used, and the cost estimates include the cost of operation and support.

Finally, the output data of the models are analysed in order to answer the main research question: Is a modular TG more cost-effective than a traditional TG? In order to test the robustness of the answer, more variations in the operational demand and the definitions of the traditional and modular TGs have been analysed.

2 Methodology

2.1 *Operational Demand*

The operational demand was defined for a notional fleet consisting of two TGs operating in the area highlighted in Figure 5. The first, called TG West (TGW), covers a standing zone in the West Mediterranean corresponding to Zone 3 in Figure 5. The second TG, noted TG East (TGE), operates near the Horn of Africa included in Zone 1 in Figure 5. Each TG has a standing task to complete—protecting sea lanes for TGW and counter piracy for TGE.

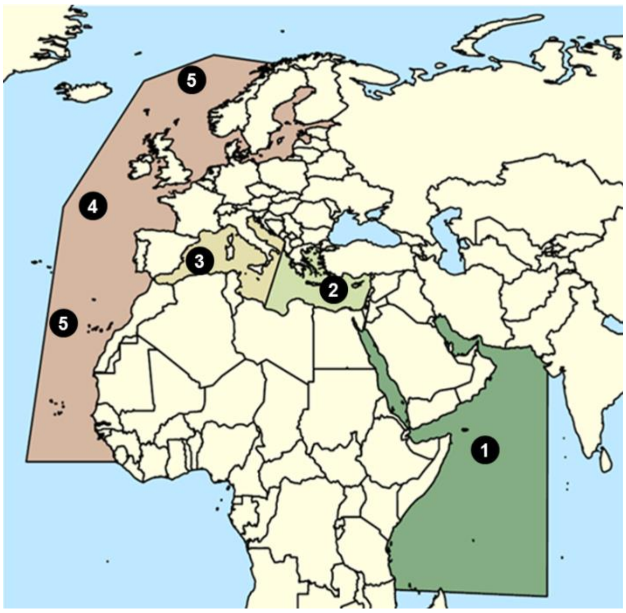

Figure 5 Area of operation for the notional scenario

In addition to their respective standing task, it is assumed that each TG may respond to emerging events that arise within the area of operation. More specifically, TGW is responsible for Zones 2 to 5 and TGE for Zones 1 and 2, with events in Zone 2 preferring a naval response from TGW whenever possible. These emerging events are described by a set of vignettes listed in Table 1. Vignettes 1 to 3 in the table describe events occurring outside the corresponding standing zone.

The vignettes, which drive the operational demand put on the TGs, are characterized by type (random or scheduled), frequency, duration, and response time. An impact category, ranging from '1 – Minor' to '5 – Severe', is also associated with each vignette. The impact category is an indication of the importance of the vignette and is used in this study to define the measures of effectiveness. Higher impact categories refer to most critical vignettes usually assigned to higher intensity missions. Lower impact categories are associated to low end warfare vignettes, like disaster relief and humanitarian assistance.

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Acceptable responses in terms of platforms and modules also have to be specified for each vignette but they may vary depending on the TG configuration. For example, a traditional naval force may require a mine countermeasures vessel for a particular event while, for the same event, a modular naval fleet would take a small modular ship with a Mine Warfare (MW) mission package.

Table 1 List of vignettes used in the CBA

ID	Vignette	Impact Category*	Event Type	Frequency (Event per Year)	Duration (days)	Response Time (days)
1	Counter Piracy	4	Random	1.25	2-3	4
2	Protecting Sea Lanes (CARGO)	2	Random	3.125	7-10	7
3	Protecting Sea Lanes (QUICK)	2	Random	1.25	7-10	4
4	Humanitarian Aid and Disaster Relief	3	Random	0.625	7-14	4
5	Search and Rescue	3	Random	15	2-3	1
6	Non-Combatant Evacuation Operation	3	Random	0.25	21-28	7
7	Track and Follow Under water	4	Random	3.75	7-10	4
8	Track and Follow Above water	4	Random	3.75	7-10	4
9	High Value Asset Escort	5	Random	7.5	7-10	4
10	Assisting Forces Ashore	5	Random	0.375	21-28	14
11	Full Task Group Training	2	Scheduled	2	30	15
12	Partial TG Training (HVA)	1	Scheduled	6	3-5	15
	Partial TG Training (TAF-UW)	1	Scheduled	2	3-5	15
	Partial TG Training (TAF-AW)	1	Scheduled	2	3-5	15

* 1 - Minor; 2 - Measurable; 3 - Significant; 4 - Critical; 5 - Severe

2.2 *Traditional and Modular Task Group*

For the purpose of the CBA, the traditional TG configurations considered, noted Traditional Baseline (BT), were composed of Destroyers, Frigates, Mine Countermeasures Ships (MCMs), Offshore Patrol Vessels (OPVs) and Joint Support Ships (JSSs).

To compare different TG configurations, a fleet with 8 ships (1 Destroyer, 3 Frigates, 1 MCM, 2 OPVs and 1 JSS) per task group is used in this study as a reference configuration. In Table 2, the row corresponding to the reference configuration is highlighted in orange.

Five other BT configurations of 7 to 9 ships per TG were created from the reference configuration by varying the number of Frigates and OPVs. The resulting list of BT configurations is presented in Table 2.

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Table 2 List of Traditional Baseline configurations considered. The reference configuration is highlighted in orange

Name	Single TG Composition					Total Ships
	Destroyer	Frigate	MCM	OPV	JSS	
BT-12121	1	2	1	2	1	14
BT-13111	1	3	1	1	1	14
BT-13121	1	3	1	2	1	16
BT-12131	1	2	1	3	1	16
BT-13131	1	3	1	3	1	18
BT-14121	1	4	1	2	1	18

The modular TG configurations are divided into the two following sub-alternatives:

- Baseline Modular (BM): TGs composed of modular Medium Surface Combatants (MSCs), modular Small Surface Combatants (SSCs) and a JSS. The MSCs are equipped with limited Anti-Air Warfare (AAW) capabilities, organic to the ship. The MSCs and SSCs can carry up to 16 and 8 Twenty-Foot Equivalent Unit (TEU) mission modules, respectively.
- Small Modular (SM): TGs consisting of small modular OPVs, small AAW-variant OPVs and a JSS. The small OPV class has space for 8 TEU-sized modules, while the AAW-variant has limited organic AAW capabilities and room for 4 modules.

In total 28 modular fleet compositions were evaluated and are listed in Table 3.

Table 3 List of modular configurations considered – a. Baseline Modular and b. Small Modular

a. Name	Single TG Composition			Total Ships
	MSC	SSC	JSS	
BM-241	2	4	1	14
BM-331	3	3	1	14
BM-421	4	2	1	14
BM-511	5	1	1	14
BM-601	6	0	1	14
BM-251	2	5	1	16
BM-341	3	4	1	16
BM-431	4	3	1	16
BM-521	5	2	1	16
BM-611	6	1	1	16
BM-701	7	0	1	16
BM-261	2	6	1	18
BM-351	3	5	1	18
BM-441	4	4	1	18
BM-531	5	3	1	18
BM-621	6	2	1	18
BM-711	7	1	1	18
BM-801	8	0	1	18

b. Name	Single TG Composition			Total Ships
	OPV (MOD)	OPV (AAW)	JSS	
SM-421	4	2	1	14
SM-511	5	1	1	14
SM-431	4	3	1	16
SM-521	5	2	1	16
SM-611	6	1	1	16
SM-441	4	4	1	18
SM-531	5	3	1	18
SM-621	6	2	1	18
SM-711	7	1	1	18
SM-631	6	3	1	20

Seven Mission Packages (MPs) were derived from the set of vignettes. A MP is composed of several TEU-sized modules. The list of MPs is shown in Table 4.

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Table 4 List of Mission Packages

Number	Name	Full Name	Size (TEU)
M01	ASW	Anti-Submarine Warfare	7
M02	ASuW	Anti-Surface Warfare	4
M03	MW	Mine Warfare	12
M04	CP	Counterpiracy	7
M05	Medic	Medical	2
M06	HP	Harbour Protection	14
M07	HADR	Humanitarian Aid and Disaster Relief	20

Changes to the vignettes were made to account for ships picking up modules before traveling to the event location. For all emerging vignettes, except the SAR, an additional preparation time of one day was added to account for the time required to load MP on board. Due to the urgent nature of the SAR vignette, it was deemed reasonable to assume that any modules necessary would already be on board. Also, picking up modules in port is taken into account in the travel distances covered when responding to an event. Friendly NATO ports were selected along the paths covered by traveling between zones. For example, a modular TGW could respond to an event emerging in Zone 4 by passing from Zone 3 through the port in Rota, Spain to pick up mission packages.

2.3 *Assumptions*

As any model is at best an approximation of reality, several assumptions were made over the course of this study:

- Ship attrition during operation is not taken into account.
- Vignettes represent peacetime threat level that has been consistent for years. The analysis does not include any scenarios representing an escalation to a full war posture.
- No maintenance periods are modelled for the operational benefit estimates since it is assumed that nations are providing full time availability by replacing the ships in the TG when long-term maintenance is needed.
- Operational benefit assumes fully available task group (includes only in theatre actions, 365 days/year), while a valid cost comparison requires inclusion of rotational and out-of-theatre assets.
- A mission is modelled as successful if a response is dispatched. No measure of the quality of the response is included (all responses modelled are assumed to meet mission requirements).
- Fleets include only current or near-term state-of-the-art: no new technology is required to make this implementation of mission modularity feasible.
- Assumptions are applied consistently to both the modular and traditional fleet to ensure consistency in the analysis and comparison.

2.4 *Modelling and Simulation*

To quantify the cost-benefit of the traditional and modular naval fleets, Modelling and Simulation (M & S) tools are needed to generate estimates of the total fleet cost and operational effectiveness. For this, two separate inter-connected models were developed and refined. The first model, the Platform Capacity Tool (PCT), was produced by Defence Research and Development Canada (DRDC) to quantify operational effectiveness of the fleets (Fee and Caron 2018, Valois *et al.* 2019). The second model, called FleetCo, was created by MTG Marinetechnik GmbH (Germany) to estimate acquisition and operating costs of the fleets (Rudius 2017).

2.5 *Effectiveness Model*

The PCT estimates the operational effectiveness of a given fleet by matching the supply of resources, such as ships and modules, to the operational demand.

Three measures of effectiveness (MOE), MOE-1, MOE-2 and MOE-3 are calculated from the data generated by the tool to express the performance of each TG configuration. They are:

- MOE-1: It consists of the fraction of events of all Impact Categories (1 to 5) completed: the percentage of events for which a timely and appropriate response was provided, both in terms of numbers of platforms and, when relevant, mission modules.
- MOE-2: Similarly to MOE-1, it corresponds to the fraction of events completed, for events of Impact Categories 4 and 5 only. This MOE was added in order to evaluate whether TG configurations are well suited to fulfil the most critical vignettes (i.e., the higher intensity missions).
- MOE-3: This measure consists of the fraction of events completed for events of Impact Categories 1, 2 and 3. This MOE was added to evaluate TG configurations that may be more suited for low end warfare vignettes.

2.6 *Cost Model*

The FleetCo model evaluates the cost of ships based on design specifications and includes considerations for acquisition, operations, and maintenance costs (crew, fuel, etc.). In addition to the design specifications and crewing levels of the ships, the model requires state distribution (i.e., fraction of time each ship spends in the following four stages: Standing Task, Emerging Task, Transiting, and In Port) and module utilization information, which is provided as an output to the PCT.

The FleetCo model is based on basic formulas for estimating acquisition costs from the well-known and accepted Product-Oriented Design and Construction Cost model (PODAC). Because these formulas do not cover non-recurring costs or life-cycle costs, the model is extended based on MTG's knowledge and experience. FleetCo is Microsoft Excel-based and makes use of Visual Basic for Applications (VBA) as well as a commercially available add-in called @Risk.

2.7 *Comparing Alternatives*

The two models are used to generate the cost-benefit metrics needed to quantitatively compare the modular and traditional TGs outlined in Tables 2 and 3. The interactions between the models are shown in Figure 6, where the FleetCo model requires the input of the number and type of modules used in the PCT as well as the state distribution of the ships over the course of their operations. While more inputs are needed in each model than are shown, those highlighted in Figure 6 are expected to change for each the TG configuration considered in this study.

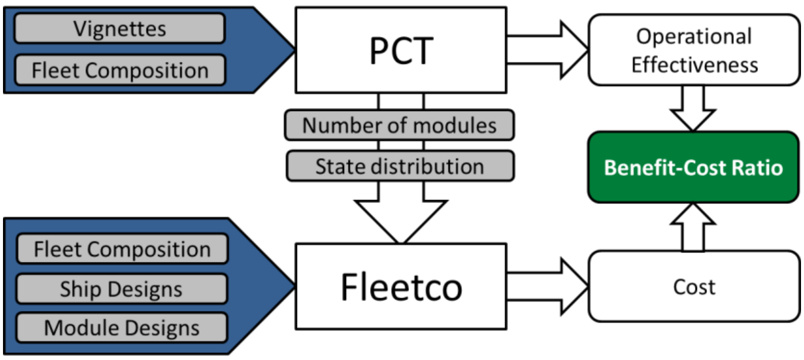

Figure 6 Model interaction diagram

The general steps used to conduct the CBA are as follows:

1. Run the PCT model for each of the 34 TG configurations.
2. Extract the number and types of modules used and the state distribution from the PCT outputs.
3. Run the FleetCo model for each TG configuration.
4. Compare the TG configurations using the Benefit-Cost Ratio (BCR).

The BCR is an expression of the benefit gained through expenditure of a billion Euro. With this metric, the results can be compared along lines of equal BCR, with higher ratios corresponding to greater cost effectiveness.

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3 Results

3.1 *MOE-1*

The goal is to achieve at least an average absolute effectiveness greater than or equal to the 'BT-13121', which is approximately 80.1% for MOE-1. This value is therefore used as a minimal acceptable threshold—fleet configurations with an MOE-1 value less than 80.1% are left out. Figure 7 shows a plot of the effectiveness for MOE-1 as a function of the cost for the 22 fleet configurations that meet the minimum acceptable benefit threshold of 80.1%. Because the objective here is to have relative comparison between the fleet configurations, the error bars, which are 90% confidence intervals, on the graph are small given the large number of runs done with both models (100 for the PCT and 1,000 for FleetCo).

Lines of constant BCR with slopes of 1.00, 1.05, 1.10, 1.15 and 1.20, represented in grey in Figure 7, were added to provide a visual means for differentiating the fleets from a cost-effectiveness point of view. For example, all the points on the line 'BCR = 1.2' represent an infinite number of alternatives for which there would be a gain of 1.2% in operational effectiveness for every Billion Euro. In this case, 'SM-621', 'BM-511' and 'BM-421' are located to the left of the 'BCR = 1.2' line meaning that they are more cost-effective (i.e., BCRs are all greater than 1.2).

The following general observations can be made:

- The most cost-effective fleet configurations that can cover the whole spectrum of missions considered (i.e., MOE-1) are: (1) Baseline Modular (BM) with 7 or 8 ships, or (2) Small Modular (SM) with 9 or 10 ships.
- The reference configurations and the other Baseline Traditional fleet configurations are not the most cost-effective options with respect to MOE-1.
- Out of the 34 fleet configurations considered, 22 of them provide and effectiveness greater or equal than 'BT-13121', the reference configuration. Of those, ~77% (17/22) are more cost-effective than the reference configuration.

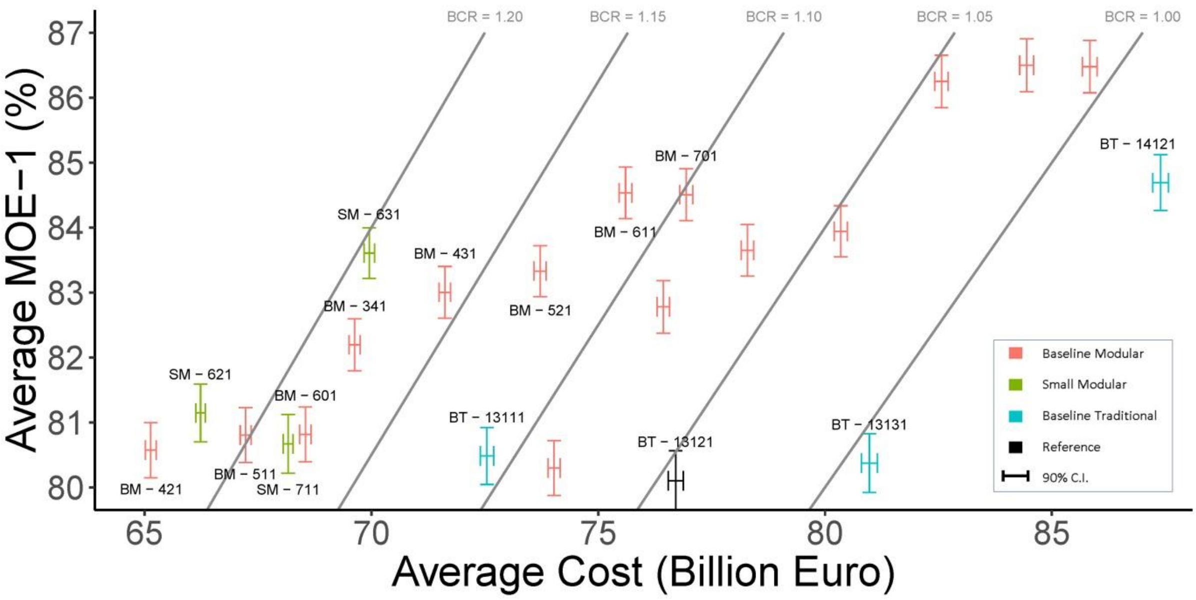

Figure 7 Visualization of cost-benefit analysis results for MOE-1, with only TG configurations meeting minimum acceptable effectiveness threshold

 https://doi.org/10.24868/issn.2515-818X.2020.018

3.2 *MOE-2*

MOE-2 was created to compare the cost-effectiveness of fleet configurations responding to higher intensity missions (Impact Categories 4 and 5). Figure 8 shows a plot of the benefit as a function of cost for MOE-2 for the eight fleet configurations that exceed the minimal acceptable threshold of 73.8%. Lines of constant BCRs were also added for slopes of 0.90, 0.95 and 1.00 to provide a visual means for comparing the configurations left.

The following general observations can be made:

- The reference configuration ('BT-13121') is well-suited for Impact Categories 4 and 5 missions offering the third best BCR value.
- Larger modular fleets (i.e., BM configurations) of 8 and 9 ships are cost-effective for high-intensity missions, achieving similar levels of performance to BT configurations.
- Only 8 out of the 34 fleet configurations considered in this analysis met the minimal acceptable threshold for MOE-2.
- SM fleet configurations do not appear to be cost-effective options in conducting high-intensity missions.

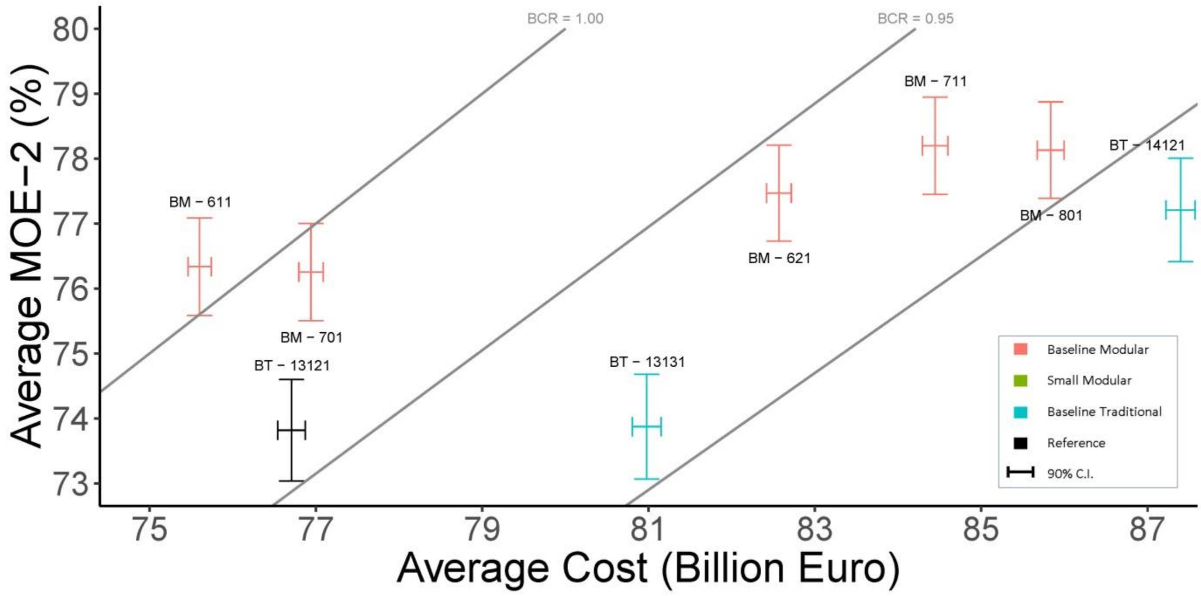

Figure 8 Visualization of cost-benefit analysis results for MOE-2, with only TG configurations meeting minimum acceptable effectiveness threshold

 https://doi.org/10.24868/issn.2515-818X.2020.018

3.3 *MOE-3*

The cost-effectiveness for a response to low end warfare is measured using MOE-3 (vignettes of Impact Categories 1, 2 and 3). Figure 9 shows a plot of the benefit as a function of cost for MOE-3 for the 30 fleet configurations that meet the minimal acceptable benefit threshold of ~83.4%. Lines of constant BCRs with slopes of 1.1, 1.2, 1.3, 1.4 and 1.5 were included in the graph.

The following general observations can be made:

- BT fleet configurations are not the best options for responding to lower impact category missions.
- Amongst all the fleet configurations considered in this study, those composed of SM ships (7 ships + JSS) are the most cost-effective options for low-intensity missions.
- A majority of the fleet configurations considered in this study obtained an absolute MOE-3 value greater than the reference configuration and were more cost effective.

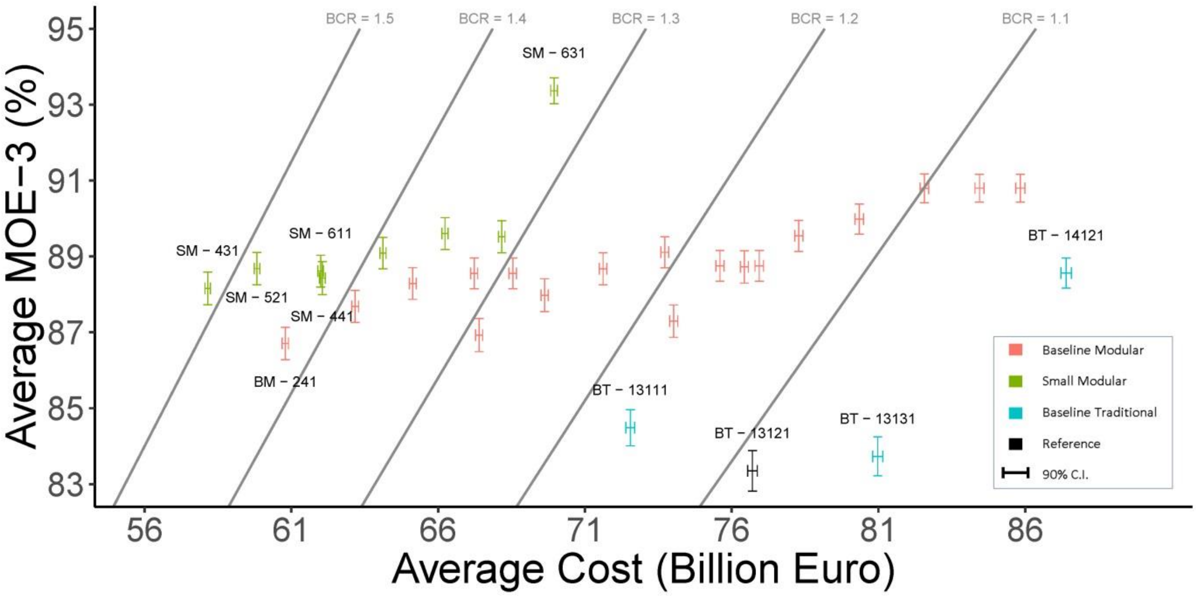

Figure 9 Visualization of cost-benefit analysis results for MOE-3, with only TG configurations meeting minimum acceptable effectiveness threshold

 https://doi.org/10.24868/issn.2515-818X.2020.018

4 Conclusions

- For high end warfighting the modular and traditional fleets are similar in performance. Unsurprising since the baseline fleet is designed against a high end warfighting requirement.
- For low end warfighting and 'peacetime' roles the modular fleet options are more cost-effective.
- For overall fleet effectiveness, and noting that navies spend more of their time at the lower end of the operating spectrum, the modular fleet offers the best overall option. The choice of Small Modular or Baseline Modular depends on the navy's expected operational profile. For navies that expect to operate at the lower end of the operating spectrum the Small Modular fleet is more effective. For those operating at the higher end the Baseline Modular fleet is the more attractive option.

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