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Operation platform design for modular adaptable ships: Towards the configure-to-order strategy

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ABSTRACT

Modular adaptable ships have received growing attention in recent decades as a promising approach to handling uncertainty in future operating contexts. A modular adaptable ship can be used for multiple purposes by changing its module configuration. This configuration change is based on the ship's operation platform, which is used as a common basis for multiple module configurations. The design of an operation platform is a multi-objective problem in which designers have to deal with the conflicting requirements of multiple missions and carefully determine the interfaces that affect the configurability and flexibility of the modules. In this paper, we present an optimization model for the design of an operation platform. This determines the optimal platform design that best meets the desired capabilities of multiple missions while considering its expected lifecycle cost. A platform's capabilities are evaluated based on its multiple module configurations for individual missions. The evaluation of lifecycle cost uses operation scenarios due to its sensitivity. We implemented the model in a case study involving an offshore support vessel, for which an operation platform was designed to compete with inflexible multi-purpose ships. The results give insights into the platform design problem with opportunities for further improvement of the design.

1. Introduction

Modular adaptable ship (MAS) design is an approach to designing value-robust ships that can maintain their value throughout the lifecycle. MASs can change their configuration based on modularity, which is ‘a particular structure, in which tasks and parameters are interdependent within modules and independent across them’ (Baldwin and Clark, 2000). Modules can be combined and separated efficiently, which provides decision makers with strategic options for handling contextual uncertainty. One example is the option to delay investment decisions until the need for particular modules is realized in a future operating context. This is referred to as ‘evolutionary acquisition’, which has been applied to the ship acquisition process of the US navy (Abbott et al., 2008). Another option is flexible mission selection. Because MASs can change their functions through ship reconfiguration, decision makers can use them for multiple purposes to maximize profit. More related research works can be found in other works (Abbott et al., 2008; Doerry, 2014; Choi and Erikstad, 2017; Choi et al., 2017; Rehn et al., 2018). Fig. 1 illustrates the concepts of evolutionary acquisition and mission flexibility.

MAS design can have potential synergy with the configure-to-order (CTO) strategy. The CTO strategy is a bottom-up development approach in which a design team creates prototype designs by configuring predeveloped standard modules. This allows for reduced development time and cost, as well as improved design reliability with proven technologies. Moreover, rapid prototyping allows for better communication with customers, which is essential for defining the appropriate key performance indicators for projects.

In ship design, the standard modules comprise ship modules and task-related modules (Erikstad and Levander, 2012). For instance, ship modules include the main hull, deckhouse, bridge, and tanks and voids, which serve basic functions for ship operation, such as buoyancy, transition, storage, and accommodation. Examples of task-related modules include weapons and sensor systems in navy ship design, as well as topside modules such as well intervention towers, cranes, remotely operated vehicles (ROVs), and saturated systems in offshore support vessel (OSV) design. In the CTO strategy, ship design projects can be defined by module configuration, evaluation, and selection to best meet individual customers' needs. Fig. 2 illustrates the process of ship design projects based on the CTO strategy.

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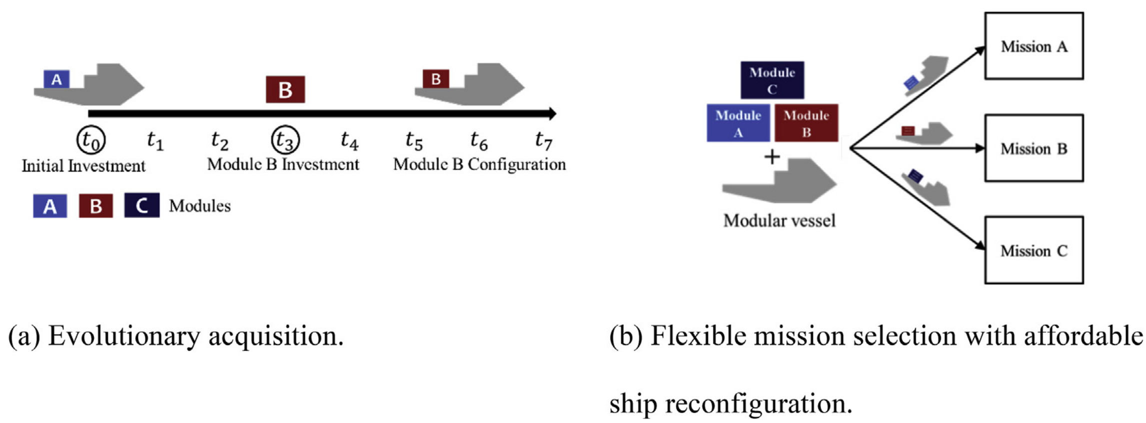

Fig. 1. Operational flexibilities provided by modular adaptable ships.

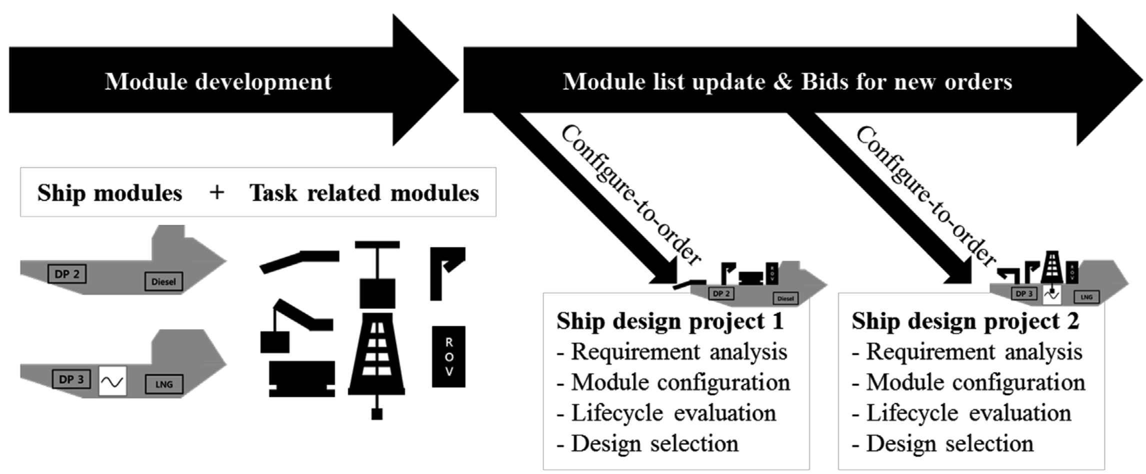

Fig. 2. Ship design projects based on the configure-to-order strategy.

There are standard task-related modules available for ship designers that are provided by third-party vendors. This enables ship designers to focus on the design of ship modules and the configuration of standard modules. There are also approaches to module configuration and evaluation for MASs. The design building blocks (Andrews, 2011) and packing approach (Van Oers, 2011) are available design synthesis approaches for MASs. These approaches create design alternatives using independent chunks, which are referred to as 'blocks' and 'objects', respectively. Sødal et al. (2008) present an evaluation method for flexible ships and compare the economic value of a multi-purpose carrier with that of specialized carriers. Page (2012) uses a Monte Carlo simulation for evaluating the lifecycle cost of flexible naval ships. Pettersen and Erikstad (2017) present a lifecycle evaluation model for flexible offshore construction vessels and estimate the value of flexibility by benchmarking the flexible designs against inflexible designs. Choi and Erikstad (2017) focus on integration of module configuration and lifecycle evaluation and present an optimization model that determines the optimal initial module configuration based on the lifecycle value. The lifecycle value in evaluations is defined by the net present value (NPV), which includes the economic value of operational flexibility resulting from modularity. This is the value of evolutionary acquisition and mission flexibility.

Along these lines, Choi et al. (2017) present a hybrid method for considering contextual uncertainty in a module configuration. This approach uses both optimization and simulation. The optimization determines the initial module configurations (designs), and the simulation evaluates them based on contract scenarios. The simulation proceeds in a rolling horizon manner, in which contextual information is gradually revealed during the simulation run, and operational decisions are made in response to the information. Doerry and Koenig (2017) present a framework for the design of MASs that also considers contextual uncertainty in MAS design. The main difference between this method and the hybrid method by Choi et al. (2017) is the way that uncertainty is modeled. While the hybrid method represents uncertainty as a set of deterministic scenarios, Doerry and Koenig's (2017) framework represents uncertainty as a Markov chain in a discrete time domain.

Compared with the standardization of task-related modules, the standardization of ship modules has received less attention in the commercial sector. There can be several possible explanations, but one of the prime reasons could be the failure case of Japanese shipyards. In the 2000s, major Japanese shipyards focused on ship standardization. However, in the context of high oil prices, customers were more interested in maximizing revenue rather than minimizing costs, so they preferred customized ships for individual projects. This caused the Japanese shipyards to lose their market share to major Korean shipyards, which focused on high-end customized ships (Park and Hong, 2015). However, since 2014, the sharp drop in oil prices has changed the market situation. In the context of low oil prices, the low break-even point makes the reduction of capital expenditure and operating expenditure more important. As a result, there is growing interest in the standardization of ships and even offshore production units, which are generally considered as high-end customized products (Agussol and Lavagna, 2017; Wyllie et al., 2017).

The ship modules of a MAS serve as an operation platform. In the general context of engineering systems design, the term 'platform' (or 'product platform') indicates common parts, components, and modules from which a stream of derivative products can be created efficiently