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Proactive vs. reactive order-fulfillment resource allocation for sea-based logistics

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ABSTRACT

We study proactive and reactive sea-based order-fulfillment decisions for a set of SKUs. In such systems, a proactive strategy may be more costly than a reactive strategy and variable marginal costs change with respect to an activity profile. We derive the optimal sets of SKUs and their quantities to handle prior (proactive strategy) or after (reactive strategy) demand materializes. Counterintuitive results show the proactive set may not necessarily include the high-demanded SKUs. This work extends the newsvendor model by analyzing negative marginal shortage costs. The model is illustrated with historical data from a sea-based logistics military application.

1. Introduction

In military operations, sea-bases consist of a set of ships to “rapidly tailor, deploy, and employ credible, self-sustained forces to respond to a crisis” (US Marine Corps, 2017). This work focuses on the logistics tasks of providing sustainment and resupply materials to troops on the ground from cargo stored in the holds of ships. This scenario, also known as a “Tailored Resupply Packages” scenario, is a proposed approach. While not currently being implemented, it has the advantage to reduce the need to build up logistics assets ashore and can facilitate a more flexible, agile, and responsive supply network for the military operations on the ground (Pazour and Shin, 2016; US Marine Corps, 2017). However, this requires new operational capabilities to transform a set of ships into floating distribution centers capable of conducting order-fulfillment operations from a ship. Similar to the role of an e-commerce fulfillment center, a Tailored Resupply Packages scenario requires fulfilling personalized (tailored) requests for cargo to be delivered quickly to troops on the ground only when requested. That is, emergent requests trigger specific Stock Keeping Units (SKUs) of cargo to be identified, retrieved, and transported from storage area (holds) of ships to the flight deck of these ships. The cargo is then transferred to a receiving vehicle that transports the tailored requests to military operations on the ground. For ease of communication, in this work, we use the term delivery ship to denote the ship that contains the inventory to be requested by the receiving vehicle, which is a connector and can be either other ships or aerial vehicles.

In a sea-based environment, the fulfilment of personalized stochastic requests with little warning are operationally challenging and complex. This is because internal cargo flow processes of the delivery ship require selective offloading of SKUs from very high dense storage environments. Moreover, the ships currently considered as delivery ships (e.g., T-ESD, T-AKR, and T-AKE ships) were not designed specifically for efficient order-fulfillment operations. As displayed in Fig. 1, the T-AKE ship is divided into different levels, connected via elevators, and multi-purpose cargo holds that store a variety of cargo. T-AKE ships have the largest cargo-carrying capacity and the largest flight decks of any combat logistics ship afloat and are designed with large open flight decks, which can support aerial delivery and have large areas that can be used to prestage cargo (US Marine Corps, 2017). Material handling

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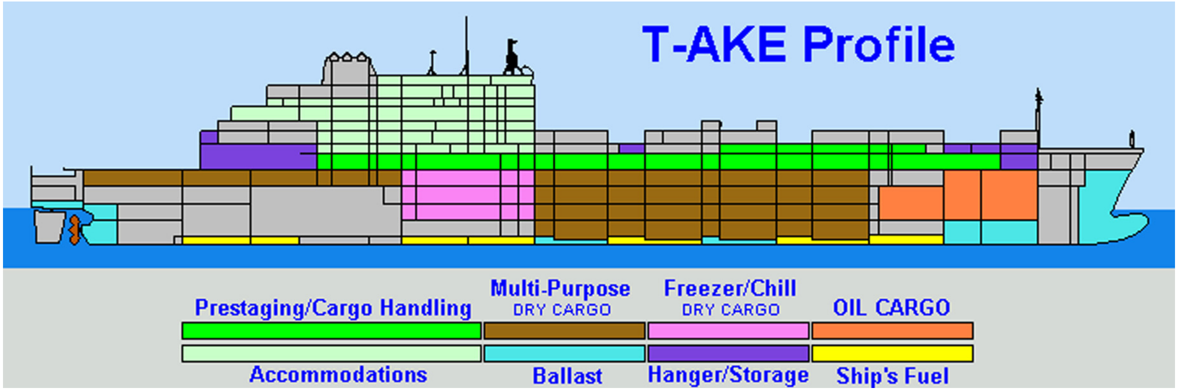

Fig. 1. A side-view of T-AKE Dry Cargo Ship; retrieved from http://navy.memorieshop.com/T-AKE/.

processes on the ships are human-intensive, and require manually storing, retrieving, and relocating pallets and containers using forklifts or pallet jacks. Very high density storage requirements in the holds create tight spaces with minimal maneuvering areas and the requirement that some SKUs may need to be moved out of the way to gain access to more deeply stored SKUs. As a result, retrieval efforts in the holds of the ships have degraded performance and are not identical for all SKUs; instead, the retrieval efforts vary for each SKU based on its popularity.

SKU popularity measure is a commonly used criteria in activity profiling (also known as an ABC analysis) of warehouse operations (Bartholdi and Hackman, 2011). In storage system design, SKUs may be stored based on their popularity measure to minimize overall retrieval efforts. A well-known result from warehouse design is that high-demanded SKUs typically have lower per unit fulfillment costs (Gu et al., 2007). This is because the most popular SKUs are stored in the most convenient locations, while the least popular SKUs are stored in the least accessible and least convenient locations (Hackman et al., 1990). In very high density systems, this effect is even more pronounced because SKUs need to be moved out of the way to gain access to other SKUs (Awwad and Pazour, 2018; Gue, 2006). This results in low-demanded SKUs, which are placed in less convenient locations, requiring much more effort than high-demanded ones.

A responsive sea-based logistics system is one where the receiving vehicle experiences minimal waiting time to receive requested cargo. One way to improve responsiveness to the receiving vehicle, as well as utilization of the transfer process, is to utilize a proactive strategy, which applies resources in anticipation of unknown downstream requests. This is in contrast to a reactive strategy, which applies resources after the request materializes. The concept of “prestaging” cargo on the delivery ship’s flight deck before the arrival of the receiving vehicle is a proactive strategy in sea-based logistics. Prestaging involves identifying and retrieving cargo stored in the holds, transporting the cargo to the flight deck of the delivery ship, and temporarily securing and storing cargo on the flight deck in anticipation of requested demand from the receiving vehicle. Whereas, direct transfer is a reactive strategy that involves identifying, retrieving, and transporting cargo from the hold directly to the receiving vehicle, and requires the receiving vehicle to be present at the delivery ship. While prestaging improves the responsiveness to the receiving vehicle, it can increase the labor and storage efforts of the delivery ship. The additional labor efforts are due to additional transportation effort to the designated prestaging locations and double handling of cargo, which is time-consuming due to the need to stabilize cargo on the flight deck, and holding cargo on the flight deck exposes the prestaged cargo to higher risks of damage due to various weather conditions. Also, prestaging may require an additional strike-down process for the excess prestaged cargo.

In sea-based logistics, a requested SKU can be fulfilled through prestaging or direct transfer processes or a combination of both. The tradeoff between these two processes depends on the aggregation of (1) the unit retrieval cost of the SKU in the very high density holds, and (2) the unit double handling and additional transportation costs of prestaging the SKU. For some SKUs, direct transfer is less expensive than prestaging because the effort spent identifying and retrieving the units from holds is less than the additional material handling and stabilization efforts. Other SKUs, especially those stored in the back of holds, require time-consuming retrieval processes, identification and retrieval of units from the holds. Thus, for these SKUs, direct transfer is more costly than the double handling and additional effort of prestaging. Therefore the unit fulfillment costs varies from one SKU to another. We refer to this phenomenon as “varying unit fulfillment costs.” In this work, we define a unique cost function that distributes the varying unit fulfillment costs among a set of SKUs proportionally through a SKU’s popularity measure.

Given how best to “resupply combat troops from the sea” is an open challenge (Combined Joint Operations from the Sea Center of Excellence, 2012; Parsons, 2013), the goal of this research is to develop models to better understand how to implement prestaging operations for a Tailored Resupply Package scenario, as well as to better understand how the unique features of a sea-based logistics environment impacts fulfilment decisions. This work determines the optimal prestaging policy that minimizes the expected costs of internal cargo flow process for a set of SKUs with skewed, stochastic demand, and varying unit fulfillment costs. Our proposed model determines which SKUs and in what quantities to prestage using a two-stage newsvendor framework, which minimizes additional handling costs of internal cargo flow processes. If the demand that materializes is greater than the prestaging quantity, a reactive strategy is applied to the residual quantity. Based on discussions with the Navy and Marine Corps., a combination of planned and unplanned SKU requests is common in sea-based logistics applications. Planned requests are for SKUs like food, water, or ammo,