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Multi-objective decision support to enhance environmental sustainability in maritime shipping: A review and future directions

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ABSTRACT

This paper aims to examine the potential of multi-objective optimization (MOO) as a decision support to improving sustainability in maritime shipping. We focus on environmental sustainability and the trade-offs involved with economic and operational objectives. Through a systematic approach, we review the literature on environmental sustainability, decision support and multi-objective optimization in maritime shipping. We identify the gaps and directions for future research. It is expected that the next generation of decision support systems for maritime transport will exploit the theoretical development in MOO to facilitate informed decision making in maritime supply chains considering environmental sustainability and the competing objectives.

1. Introduction

Sea transport is a vital component of the world's economy, as the largest carrier of freight around the globe. Environmentally sustainable operations in maritime shipping have emerged as important topics for firms involved in maritime supply chains and policy makers (Cheng et al., 2013). In this line, the emission of greenhouse gases (GHG) from maritime transport has attracted increasing attention as a global issue over the past decade (Qi and Song, 2012). The International Maritime Organization estimated the level of GHG emitted by ships in 2007 at 1046 million tons of CO_2, about 3.3% of the global emissions (Buhaug et al., 2009), and in 2009 has set a target of a 15% reduction in maritime emissions by 2018 (Buhaug et al., 2009). Minimizing the carbon footprint and fuel consumption is a strategic direction for shipping companies. Research indicates that the financial and business performance of companies can be directly influenced by socially and environmentally responsible business practices (Sarkis, 2006). A reduced environmental impact and enhanced fuel efficiency will directly contribute to the environmental sustainability and economic prosperity of maritime supply chains, and furthermore will indirectly contribute to social sustainability as the third pillar, via improved quality of life: more economic operations can create more jobs in the shipping industry.

In the past few years, there has been a growing interest among researchers and practitioners to reduce the carbon footprint of maritime shipping by adopting sustainable operations management practices. These include operational decisions such as speed reduction, berth scheduling and route re-engineering to rationalize fuel consumptions and to reduce CO_2 emissions. The earlier work in this area has regarded minimizing GHG emissions as an implicit objective, surrogated by minimizing fuel consumption and cost, which could be combined with other items (such as penalty charges). We argue that such an

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assumption could negatively affect the post-optimization analysis by overlooking the true cost of GHG emissions and its impact on the environment. It would be illuminating for members of maritime supply chains to assess the trade-offs involved with their operational decisions, including energy consumption (and not just its cost) and GHG emissions, as explicit decision criteria. Such an approach will support informed decision making through the analysis of the impact of operational decisions (such as scheduling, routing and speed decisions) on the environment.

This paper aims to address this gap by providing a systematic overview of the extant literature on sustainability in maritime shipping as a challenge involving multiple objectives. We examine the potential of MOO to facilitate informed decision making by shipping companies. We have selected three distinctive areas for our literature search. First, we consider sustainability in maritime supply chains as a focused area of our exploration. Given that enhancing sustainability in maritime shipping involves trade-offs between environmental, economic and social dimensions, we are interested to examine the potential of MOO to analyze such trade-offs among competing objectives such as fuel emissions and service level. Therefore, we explore the extant body of literature on multi-objective optimization in maritime shipping as the second area of investigation. The outcome of the literature review in those areas is expected to contribute to theoretical implication of the study. The implementation of MOO based methodologies for practitioners requires the development of decision tools that can be used by members of maritime supply chains as they are usually not experts in mathematical modeling and analysis therefore require systematic support by information systems that are equipped with user friendly and easy-to-use user interfaces. Also, any trade-off relationships among multiple objectives in an optimization problem can best be analyzed and visualized through what-if analysis which is one of the core functionalities of a DSS. Hence we examine the literature on decision support systems for maritime shipping as the third area of examination to identify practical implication of the study. We explore these three areas (i.e. environmental sustainability, decision support systems (DSS)[1] and MOO in maritime supply chains) in a systematic way, outlined in Section 3, and place particular emphasis on the overlaps across the three areas.

Earlier survey papers have examined various focused areas in maritime operations. Christiansen et al. (2013) surveyed the recent developments in ship routing and scheduling as the fourth review by the authors in over three decades. Earlier reviews on this topic include Christiansen et al. (2004) and Ronen (1983, 1993). The literature on bunker optimization methods in maritime shipping has been reviewed by Wang et al. (2013a). Tran and Haasis (2013) review the literature on network optimization in container liner shipping in three categories: container routing, fleet management and network design. Our survey is distinctive from earlier work in terms of its aim, focus and scope. We are particularly interested in the role of MOO as a DSS to enhance the sustainability of maritime supply chains, an area which has not been explored previously. The main contributions of the paper can be summarized as follows:

- Our work has identified the gaps in the theoretical development of MOO as part of a decision support system to enhance environmental sustainability in maritime shipping.
- Through a systematic approach, our research identified the extant body of literature in three areas, namely environmental sustainability, DSS and MOO in maritime transportation.
- By analyzing the literature in the aforementioned areas and their overlap, we provide a detailed discussion of their aim and objectives, methodological approach, the type of data and key findings.
- We assess the trend of publications in the aforementioned areas to identify those areas that need future attention to facilitate informed decision making in maritime transportation, considering environmental sustainability as an explicit objective.

The remainder of the paper is organized as follows. Section 2 provides an overview of decision making in maritime shipping. The methodological approach undertaken is introduced in Section 3. The three research areas are reviewed in Sections 4–6. Finally, Section 7 concludes the paper by discussing the main finding including gaps, trends and future research directions.

2. Decision making and sustainable maritime transportation

Sustainable maritime transportation involves complex decisions and multiple actors. Moreover, it is influenced by economic, social and environmental responsibilities (IMO, 2013). The realization of a sustainable maritime transportation system faces multifaceted challenges regarding technical and organizational barriers, market and policy framework support, and socioeconomic acceptance (Tsamboulas and Moraiti, 2013). Informed decision making in such environment requires adequate support to underpin the so-called three pillars of sustainability for members of maritime supply chains. The majority of the existing decision tools for maritime transportation focus on cost and/or operational performance indicators. Examples of such systems are introduced by Fagerholt et al. (2009) and Lam (2010). Sustainability measures are now being considered in commercial decision support systems (DSS) for maritime transportation. Kontovas and Psaraftis (2011) surveyed the literature on speed decisions and its impact on the environment. They discussed lessons learned by slow steaming providing the link between economy and the environment for the sustainability of liner shipping. More recently, Psaraftis

[1] We use DSS as an acronym in both the singular and the plural case.