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Sustainable decision model for liner shipping industry

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ABSTRACT

Maritime transport facilitates international trade activities and contributes to world's economic growth and prosperity. Still maritime transport faces several operations challenges such as non-storability of shipping space, matching supply with dynamic shipping demand, and non-availability of fair allocation mechanism in the age of information exchange systems due to ban of anticompetitive liner conference amongst others. This paper develops a sustainable decision model for allocating ship capacity to satisfy shipping demand and to generate a route plan. The model is referred as sustainable because it determines flexible freight rates and coordinates market players with social interest. The paper uses multi-agent system modeling and an iterative combinatorial auction mechanism with Vickrey–Clarke–Groves payments to deploy ships at economically efficient prices in the age of information exchange systems. To tackle the computational complexity of multi-agent system model with auction mechanism, this paper proposes an enumerative search algorithm. Our proposed model and method can aid liner shipping industry managers to better realize their desired economical and social sustainable decisions targets by sharing information, costs, and benefits.

1. Introduction

In view of the growing trend of globalizing production and marketing activities, countries become more open in their borders and markets for foreign investments and trade. The growth of these international business activities increased the intensity and speed of physical cargo flows across national borders [6]. Maritime transportation role is predominant among various transport modes in support of international trade development and growth. Interestingly, containerization improves the operations efficiency of maritime transport by packing the variety of resources in standard size containers. It also simplifies the handling and transport of goods securely in container terminals and in ships. This containerization development has led the evolution of cargo ships into large containerships to benefit from the scale economy in ship operations. Generally, containerships are liner ships operated according to a schedule of loading and discharge ports to satisfy the shipping demand for container transport. Hence, carriers use to fill their supply of ship along trade routes at freight rate that is determined in liner conference which serves as a critical place for liner shipping companies to make transaction and earn profit [14].

However, liner conference is anticompetitive and banned due to its monopolistic characteristics in Europe, US, and Asian countries. Also, fluctuations in freight rate due to variations in fuel cost as well as demand of frequent shipping services by shippers pressurizes liner shipping companies to reduce their operations costs. It leads liner shipping companies to look for alternative forms of cooperation in tackling these challenges. Increasingly, shipping companies form alliances to exchange the resources and merge with logistics service providers to reduce operations cost and expand its service coverage in geographical locations [13]. It is a popular practices of liner shipping companies to establishment inter-firm agreement to share their slot capacity with partners with the aim to have fully loaded container ships and to reduce financial risk due to excessive unused capacity [21]. But the determination of exchange price to share the resources and provide quality service to members in cooperation remains as a critical challenge to practitioners [26].

In addition to price determination, cooperation and quality service, liner shipping industry face several other operations challenges. These challenges include non-availability of cooperative mechanism in-light of ban of liner conference, non-storability of shipping space, shipping supply instability, change in international

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trade patterns, difficulty in determining cost-based freight rates, inelastic shipping demand for maritime transport, and emergence of new technologies for shipping management [15]. Recent studies resonated that a well-organized administration, sound financial system, and competitive policies considering the effect of information exchange on coalition models could promote sustainability [17]. Knowledge sharing within strategic alliance network of shipping services is also critical for enhancing shipping firm performance in the liner shipping industry [27].

In physical transaction exchanges, cooperation is built based on trust and mutual understanding of traders who can have good understanding of information, resources, benefits, and costs. However, cooperation in physical market supports market consolidation and avoids participation of small market players. Thus, this indicates the need of a market-based model to regulate physical and virtual transaction exchanges, and assist shippers and shipping companies to work in uncertain and dynamic liner shipping service market.

To address the above challenges, this paper develops a mathematical model to match the supply and demand of ship capacity for ship deployment and route planning in liner shipping industry. To include economic sustainability such as pricing and allocation as well as social sustainability to regulate cooperation and competition, this paper suggest multi-agent models. According to Henesey et al. [8], agents possess properties such as autonomous (ability to execute tasks with little or no intervention from other entities), adaptive (ability to learn and adapt to future behavior based on past experiences), goal-orientated (ability to react and act proactively to environment), mobile (ability to change the locality within a physical or virtual environment), reactive (ability to respond to changes in the environment), situatedness (ability to sense the environment and act), and social (ability to communicate and interact with other agents in a cooperative and competitive manner).

Hence, we design a multi-agent system (MAS) model that is suitable for both primary and secondary transaction for liner shipping services. In primary transaction exchange, both shipping companies and shippers act as agents to interact through information exchange system (IES) to determine freight rate and slot allocation. In the case of secondary transaction exchanges, only the shipping company act as agents to determine exchange price and allocation.

MAS include several computer agents similar to people in physical exchange interaction using several messages with one another. The MAS needs protocol and smart mechanism to connect agents. Auctions are successful protocols and mechanisms to interlink agents including sustainability factors to win allocation. Thus an efficient auction mechanism defined with a set of feasible strategies, allocation and payment criteria to promote competition is used in our study. Vickrey Clarke Groves (VCG) payment is observed to satisfy the criteria such as incentive compatibility (each agent gets incentive to reveal the information truthfully), individual rationality (agents expected payoff is always greater due to its participation in auction), and budget-balance (the total payments made by agents must be equal to zero, or non-negative). Even though VCG mechanism has several desirable properties, it is very hard to solve the model developed using this protocol within reasonable computational time. One way suggested by Kalagnanam and Parkes [9] to derive solution for VCG auction mechanism is through the use of iterative approaches. Using the suggestion, this paper proposes a complete enumerative search algorithm to implement the iterative auction with VCG mechanism for our MAS based sustainable model. We use reported real case data from the literature to validate our MAS based sustainable model for liner shipping industry.

The next section presents a literature review followed by a description and definition of problem in the liner shipping industry. The mathematical and MAS based sustainable model for solving the slot allocation, ship deployment, and route planning problems are then explained and illustrated. Subsequently, the results obtained from the methodologies are discussed, and the conclusion and future research directions are presented in the final section.

2. Literature review

Maritime transport contributes to international trade and economic growth and spread prosperity throughout the world [23]. There are studies proposing decision models to optimize fuel management, route planning, and ship deployment to maximize shipping companies' profit. For instance, Yao et al. [32] developed an empirical fleet management model to determine the optimal bunker fuel management strategy. To determine the share of empty equipment repositioning cost between carrier and forwarders, Xu et al. [31] built a mathematical model to address the issue. Van Riessen et al. [30] proposed a service network design for an intermodal container network to improve shipping operations, while Martinez-Lopez et al. [16] defined mathematically cost and time models for the evaluation of intermodal chains by using short sea shipping. There are attempts to develop heuristic methods to obtain optimal deployment of the ships and minimize operational costs for Single Liner Shipping Service Design Problem [22,7]. To maximize freight contribution through slot allocation and pricing, Ting and Tzeng [28] developed a liner shipping revenue management system. To obtain maximum profit through slot allocation and slot sharing among alliance members, Lu et al. [11,12] proposed a mathematical model. To analyze the impact of entering new markets, vessel acquisitions, and fleet mergers, variations in demand for transportation and bunker price fluctuations, a mathematical model was formulated by Alvarez [1] for joint routing and deployment of a fleet of container vessels.

These extant models and methods aided shipping company managers to maximize the profit through fleet deployment or route plan or minimize the operational cost. However, there is a lack of studies addressing economical efficient allocation such as welfare of the customers, mechanism for price determination, and the governance for cooperation and competition. This reveals a gap in the literature and seriously mandates a model that could address both economical and social dimensions of shipping industry. Thus, it is necessary to develop a sustainable decisions model that facilitates the shipping industry to share costs, benefits, resources, and information between the market traders.

To design sustainable agent models, few studies provided enough evidences in support of MAS applicability. Suggestions for usage of agent models in international trade, container distribution and inland distribution by Sinha-Ray et al. [24], and the application of MAS approaches in container terminal planning and management problems by Henesey et al. [8] favored strongly the suitability of MAS for formulating sustainable decision model. The review of agent based models as optimization technique for complex and distributed systems by Barbati et al. [2] presented the infancy in MAS application. The review also emphasized a focus on the negotiation mechanism, information handling and validation system, and computational methods on coalition formation in MAS for its successful implementation.

The overview of various auction mechanisms design by Kalagnanam and Parkes [9] clearly explained the computational challenges as well as strategic and implementation complexities. It provides insights on how to choose an auction mechanism that suits to the market requirements. Parkes [20] avoided the need of truth revelation in bidding by designing iBundle Extend and Adjust, an ascending price combinatorial auction. Kevin [10] proposed different heuristics to solve Winner Determination Problem