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REVIEW ARTICLE

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Operation management of green ports and shipping networks: overview and research opportunities

Abstract Global ports and maritime shipping networks are important carriers for global supply chain networks, but they are also the main sources of energy consumption and pollution. To limit ship emissions in ports and offshore areas, the International Maritime Organization, as well as some countries, has issued a series of policies. This study highlights the importance and necessity of investigating emergent research problems in the operation management of green ports and maritime shipping networks. Considerable literature related to this topic is reviewed and discussed. Moreover, a comprehensive research framework on green port and shipping operation management is proposed for future research opportunities. The framework mainly comprises four research areas related to emission control and grading policies. This review may provide new ideas to the academia and industry practitioners for improving the performance and efficiency of the operation management of green ports and maritime shipping networks.

Keywords maritime shipping, port operations, green port, green shipping, emission control areas

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1 Introduction

Over 90% of the world's trade is carried by the shipping network as reported by the United Nations Conference on Trade and Development (UNCTAD, 2011), which is a main impetus of global economic growth and supply chain network development (Fransoo and Lee, 2013; Lee and Song, 2017). However, the frequent shipping activity produces numerous emissions of pollutant and greenhouse gases and is thus a main source of pollution and energy consumption. The development of management science theory and engineering practice has led to the in-depth research on the operation management of green ports and shipping networks to improve productivity and service levels, which then contribute to the development in scientific operation of ports and shipping networks. However, from the perspective of emission control in green port operations, relevant research has not yet been conducted systematically in the academia or by the industry. This situation indicates that no comprehensive theory and method of operation management exists for operation efficiency, energy saving, and emission control optimization.

From the perspective of port operators, the following aspects are lacking: a comprehensive evaluation system for the emission footprint analysis of handling activities; effective models of emission load mechanism in container ports; and optimization models for coordinating operation efficiency, energy saving, and emission control. As a result, no scientific mechanism is available for controlling emission in ports given the incomplete information. The logistic activity of ports is related to many logistic activities in sea ports, hinterlands, inland river ports, and road/railway/waterway multimode transportation networks. Thus, a reasonable design of the collection and distribution system is crucial in solving the pollutant-control problem of ports. Moreover, a comprehensive theory needs to be developed immediately to improve the operation management of green ports, optimization in energy-saving measures, and management of port operations. With the aim of grading the emission level of port operations, an intelligent transportation mode for port activities needs to be proposed to optimize the layout of logistic operation system in ports, which is also the foundation of scientific development in green ports.

From the perspective of shipping companies, two operation strategies satisfy the standards of Emission Control Area (ECA). The first strategy is to use the heavy- and low-sulfur fuel (or marine gas oil, MGO) in sailing. Low-sulfur fuel is preferred when sailing in ECAs despite its high cost. The second strategy is to equip the desulfurization facility (i.e., the scrubber), which indicates that only heavy-sulfur fuel is applied during shipping. If the first strategy is chosen, then shipping companies need to use the high-priced low-sulfur fuel or MGO in ECAs, and they will try to minimize the consumption of low-sulfur fuel. If the second strategy is chosen, then shipping companies need to upgrade the equipment of fleets and operate them in accordance with fleet construction to save on operation costs. In satisfying ECA standards, shipping companies need to choose different strategies depending on their shipping activities, such as the optimization of vessel speed and the operation method of scheduling fleets. Therefore, the main obstacle of shipping companies with regard to operation management is the quantitative optimization of shipping networks, namely, the lack of an operation strategy through the application of a mathematical method and an optimization algorithm. Operation costs need to be controlled under the policies of green ports and ECA to ensure the competitiveness of shipping companies.

From the perspective of government regulation departments, little research regarding the formulation of emission control and subsidy policies is available, especially on quantitative methods and models. Further investigation on the supervision and regulation of shipping industry pollutant discharge is needed. Policymakers can analyze the positive and negative impacts of the shipping industry on emissions with the aid of emission grading policies based on the dynamic analysis of certain emission control policies. Here, the emission grading policies involve dividing the emissions of port operation activities (or shipping activities) into several grades (levels); then, different policies of penalty or incentive are designed for dissimilar grades. The global shipping industry is experiencing "post-financial crisis." Numerous small- and medium-sized companies have chosen to become less competitive, which indicates the timeliness of proposing an emission control policy. Models are needed to aid government regulation departments and shipping companies in wisely choosing emission control policies and other subsidy policies for effectively controlling port operation emissions.

The above-mentioned discussions reveal that port cities, port operators, shipping companies, and governments need to realize the goal of emission reduction for improving the service level of shipping companies and port operators and controlling overall cost. This study reviews the literature regarding the operation management of green ports and shipping networks and discusses how to construct a management optimization theory system on green ports and shipping networks.

2 Background

The shipping industry in China has increased rapidly over the past decades. Seven of the top ten biggest ports in the world are located in China. UNCTAD (2015) reported that the global container throughputs handled in China accounted for 26.5% in 2014. However, the energy consumption of Chinese ports increased by 112% in 2014 compared with that in 2005, with an average annual growth rate of 8.7%. CO_2 emission increased by 55% in 2014 compared with that in 2005, which is evidently considerably higher than the average level. These phenomena directly affect economic efficiency and the environment. Moreover, the implementation of "The Belt and Road" will further improve the maritime transportation networks and import and export trade in China, which can further aggravate air pollution and deteriorate the environment. The ports in China are distributed intensively in the areas of Bohai Rim (BR), Yangtze River Delta (YRD), and Pearl River Delta (PRD), which also have the highest population densities. Therefore, air emissions from shipping in these areas may cause severe environmental and health problems. According to the 13th Five-Year Plan, pollutants from port activities need to be regulated in the three areas. By 2020, the overall annual emissions of SO_x, NO_x, and particulate matters (PM) should decrease by 65%, 20%, and 30%, respectively, compared with those in 2015. The Domestic Emission Control Area (DECA), including BR, YRD and PRD, has been further extended along the shoreline of China in 2018, and the major rule is that seagoing vessels within the new DECA should use marine fuel with the sulfur content of no more than 0.5% since January 1, 2019.

An important issue at present is achieving the goal of energy saving and emission reduction in ports while improving the service level of these ports. The International Maritime Organization (IMO) reported that CO_2 emissions from ships account for nearly 2.6% of the world's annual emissions, whereas SO_x and NO_x emissions from ships account for 13% and 15% of the annual emissions from human activities, respectively. Moreover, 70% of ship emissions are emitted in offshore areas shorter than 400 km from land. For example, in Shanghai, emissions from shipping activities account for approximately 12% of the city's emissions. Shipping activities have been the third largest source of air pollution, following those of motor vehicle activities and industrial enterprises. The Intergovernmental Panel on Climate

Change reported that the growth of carbon emissions in the shipping industry is the fastest among global carbon emissions. The amount in 1995 was two times that in 1990, and carbon emissions from the shipping industry will increase 10 times by 2050 compared to that in 1995. IMO has warned that unregulated carbon emissions from the shipping industry will increase to 12%–18% of the global carbon emissions by 2050 (Buhaug et al., 2009). To control the destructive influence of shipping activities on the climate and the environment, IMO proposes ECA policies that require ships to strictly obey emission control rules in certain jurisdiction areas (IMO, 2008). IMO and some governments, including that of China, have issued a series of policies to control emissions in ports and offshore areas. Fuel costs account for more than 70% of overall operating costs, which indicates that these emission control measures will impose considerable burden on the costs of shipping companies. For example, COSCO Shipping Group spent 180 million CNY to implement low-sulfur fuel or ECA in 2015. Therefore, an in-depth research on optimizing resource management and scheduling plans for ports and shipping networks under emission control policies is important to control operating costs while developing green ports. Although emissions from shipping activities have a significant impact on the global environment, regulating emissions during shipping is difficult for multisource owners (Heitmann and Khalilian, 2011). As a result, the optimization research on emission grading and control policies and other subsidy policies should be initiated.

3 Related work

The academia has paid considerable attention toward green ports and shipping logistics. Davarzani et al. (2016) proposed a systematic literature review of recent articles regarding green ports and maritime logistics. In the current study, the review focuses on three areas: (i) operation management and optimization of green ports, (ii) optimizing the operation management in green shipping networks, and (iii) emission control measures and related policies in green shipping. The relation among these works is also reflected by three categories: port, shipping, and policy on port and shipping. The main methodologies for those studies mainly focus on operation research and management sciences.

3.1 Operation management and optimization of green ports

The operation system of container ports is a complicated stochastic dynamic system of activities, including container and vessel handling, truck transportation, and equipment operation (Zhen, 2017). Although the decision problems and related models on optimization are varied and complicated, the aim of these problems is specific and the boundaries are relatively clear. Therefore, operation management of ports has attracted scholars from different fields, such as operation research, system engineering, computer science, and applied mathematics (Wang et al., 2017). This paper reviews the related articles on green ports from the perspective of quayside and yard side operations.

The core problem in quayside operations is the berth allocation problem (BAP), which involves the assignment of location and staying time for visiting ships. BAP is important because it represents the foundation of various scheduling problems in ports. Considerable literature has focused on two types of BAP, namely, discrete BAP (Imai et al., 2001; Cordeau et al., 2005; Giallombardo et al., 2010) and continuous BAP (Lim 1998; Wang and Lim 2007). Combining BAP with "green" studies is a major topic in academic and practice. Du et al. (2011) investigated a BAP considering fuel consumption and developed a general power function between fuel consumption rate and speed rate to determine the precise emission of ships. Their experiments proved the efficiency of this model in controlling emission levels. To solve the general fuel consumption rate functions efficiently, Wang et al. (2013) put forward static and dynamic quadratic outer approximation approaches. Du et al. (2015) also focused on BAPs in tidal ports from the perspective of emissions from vessel activities. On the basis of daytime preference that involves energy saving, Hu (2015) proposed a bi-objective model on BAPs to minimize the workloads at nights and the delayed workloads at the terminal operations. Venturini et al. (2017) addressed BAPs in green ports and considered the speed and emission control factors. Hou (2017) explored a dynamic BAP based on the application of shore power. The target of this research is to minimize the total fuel cost, penalty cost, and emissions. Quay crane scheduling and allocation problems are also important in quayside operations. Talavera et al. (2016) reported that the emissions from quay cranes affect bay allocation and quay crane workload distribution and should therefore be addressed to minimize the emissions in terminals. With regard to tides at ports and fuel consumption of vessels, Yu et al. (2017b) addressed a quay crane scheduling problem by presenting a mixed-integer nonlinear programing model. Liu and Ge (2018) developed a convex mathematical model of a quay crane assignment problem for minimizing CO_2 emissions when unloading containers from quay cranes to automatic guided vehicles (AGVs) on the basis of queuing theory. Some recent work integrates the problem on quay crane and BAP. Hu et al. (2014) proposed a multi-objective mathematical model for the integrated problem of berth and quay crane allocation by considering fuel consumption and emissions. He (2016) investigated a berth allocation and quay crane assignment problem for trading off energy and time saving to minimize the total energy consumption and departure delay of all ships. In consideration of a unitary carbon emission taxation rate and a piecewise carbon emission taxation rate, Wang et al. (2018) developed two models on the joint problem of berth allocation and quay crane assignment, which were then eased by some equivalent and relaxed models.

In yard side operations, the topic on yard crane in combination with the concept of green ports is a typical research area at present. Rizaldi et al. (2015) presented three methods, namely, a market-based method, a zonal 1-1 method, and a zonal 1-2 method, to coordinate a special type of yard cranes, that is, rubber-tyred gantry cranes. These authors evaluated the efficiency of these coordination methods by estimating the utilization of the cranes, the fuel consumption values of the cranes, and the waiting time of trucks. He et al. (2015a) studied a yard crane scheduling problem that considers energy consumption, which is different from the traditional approaches. A mixed integer programming model with soft time windows was built to minimize the total energy consumption of yard cranes and the total delay of tasks. A simulation was designed to assess the solutions, and an optimization algorithm of integrated genetic algorithm (GA) and particle warm optimization (PSO) was developed to search the solution space. He et al. (2015b) addressed a joint scheduling problem of three types of handling equipment at container terminals, namely, quay cranes, internal trucks, and yard cranes, to minimize the total energy consumption of tasks and the total departure delay of ships. Moreover, the same integrated algorithm of GA and PSO was used. Peng et al. (2016) focused on electric rubber tire container gantry cranes and addressed a yard crane allocation problem with limited resources in consideration of carbon emissions. A general model on the energy replacement problem (from diesel to electricity) was developed by combining an allocation resource model and a simulation model. From the low carbon perspective, Sha et al. (2017) formulated a model related to energy consumption of yard cranes to optimize yard crane scheduling at container terminals. Optimization of truck scheduling in yards is important in this field and is widely studied (Bish et al., 2005; Lee et al., 2010). Yu et al. (2017a) proposed an optimization model and algorithm for the truck scheduling problem in yards in relation to CO_2 emissions. Kavakeb et al. (2015) introduced a green technology of emission reduction for equipment in yards and analyzed the influence of the application on European ports. To reduce truck emissions in yards, an AGV is often applied. Thereafter, a greedy algorithm proposed by Chen et al. (1998) can be used to solve the problem.

3.2 Optimizing the operation management in green shipping networks

In recent years, scholars from all over the world have conducted in-depth research on the management optimization of general shipping networks, and most have been reviewed by Meng et al. (2014). Agarwal and Ergun (2008) presented problems related to the optimization of liner service networks, including route design, ship capacity allocation, and cargo flow distribution. They addressed the problem by a mixed integer programming model based on the column generation-based heuristic algorithm and Benders decomposition-based heuristic algorithm. Jin et al. (2014) applied a tabu search algorithm to solve the mathematical model for the utilization of idle capacity in shipping networks in relation to vessel speed and amount of ships. The experimental results showed that the rate of idle ships and operating costs can be decreased by applying low-speed shipping. Scholars have also considered several emergent factors, such as cargo transshipments (Wang and Meng, 2012a), diversity of demand and competition among shipping alliances (Zhao, 2015), buyer preferences (Chen et al., 2017), distribution of benefits within shipping alliances (Agarwal and Ergun, 2010; Zheng et al., 2015), and speed optimization of vessels (Wang and Meng, 2012b; Psaraftis and Kontovas, 2014; Xia et al., 2015).

Research on the management of green shipping networks mainly focuses on the speed optimization of vessels. On the one hand, the speed optimization of vessels reduces fuel cost. Alvarez (2009) and Brouer et al. (2014) considered the optimal uniform speed setting on a single-route design of the liner network. Norstad et al. (2011) addressed the optimization problem of vessel speed in a single route by assuming that port anchorage is constrained by the time window. They then developed a set of divide-and-concur algorithm based on recursive ideas to solve the problem. Xia et al. (2015) offered a novel perspective for shipping companies to optimize vessel speed by relating cargo weight with fuel consumption. On the other hand, the speed optimization of vessels involves carbon oxide emissions, and some research results were reviewed by Psaraftis and Kontovas (2013). Lindstad et al. (2011) analyzed the impact of low-speed shipping on controlling the emissions of greenhouse gases. Yu and Wang (2015) optimized ship speed under different carbon emission control policies by trading off carbon emission reduction caused by speed reduction and change in carbon emissions caused by the amount of ships. They then established a speed optimization model based on different emission control policies. Zhu et al. (2016) established a fleet allocation optimization model that considers the carbon emission trading mechanism for liner shipping companies and verified the findings by random experiments.

IMO has gradually established several ECAs. Given the ECA policy, ships need to use low-sulfur fuel in ECAs, but the burden is on shipping companies. Doudnikoff and Lacoste (2014) argued that low-speed shipping can be applied to avoid extra fuel cost in ECAs. Chen et al. (2018) focused on the influence of ECA on the choice of shipping route, which suggests that many ships can reroute to save on fuel cost. In certain conditions, this phenomenon will indirectly affect the surrounding area of ECA. Therefore, the implementation of the ECA policy needs to be supported by many other aspects. Under the ECA policy, the related government department needs to control the emissions, whereas shipping companies need to control operating costs; the joint role renders the optimization problem of shipping network management under emission control policies a central topic for research. However, articles on ECA are generally lacking. Lv and Mao (2017) addressed the joint optimization problem of selecting ship types and corresponding amount and speed under the ECA policy. Fagerholt et al. (2015) developed a mixed integer programming model to solve the joint optimization problem of ship and route selection near the ECA based on the linear approximation of the fuel consumption function. The numerical experiments showed that ships will likely take the long route outside ECA to reduce navigation distance and then minimize fuel consumption within ECAs. In addition, the ship will sail slower within ECAs and faster outside ECAs to keep the total sailing time constant for reducing fuel consumption within ECAs. Fagerholt and Psaraftis (2015) proposed a mathematical formulation for both speed optimization problems (i.e., within and outside ECAs) under the emission control policy for ECA by introducing the concept of ECA refraction problem, in which optimal speeds and crossover points through the ECA boundary can be determined. Gu and Wallace (2017) investigated the influence of scrubbers on ECA as a novel perspective. They found that the sailing pattern of ships is an important factor and the effect of scrubbers is closely related to port call density.

3.3 Emission control measures and related policies in green shipping

In view of the increasingly prominent role of the maritime transport industry in international trade, pollutant emissions caused by the increasing number of shipping vessels in recent years have been the focus of the international community, maritime authorities, industry associations, and the academia. In 2011–2014, IMO added technical and operational measures for shipping emissions to Annex VI of the Maritime Agreement Regarding Oil Pollution (MARPOL) in the form of amendments. Thus far, three aspects have been considered in the IMO framework to solve the problem of pollutant emissions in the shipping industry: technical, operational, and market-based measures (MBMs).

Pollutants such as CO_2, SO_x, and NO_x are emitted during shipping. To improve fuel efficiency and reduce fuel consumption, an advanced technology needs to be applied to the shipping equipment. Among the technical measures, IMO introduced the new energy efficiency design index (EEDI), which aims to provide a fair basis to compare ships of different types and sizes and encourage the development of efficient shipping. The index refers to environmental cost (contaminant emissions) generated by social benefits (freight volume) created per unit of shipping (Li et al., 2015). Ančićn and Šestan (2015) observed that emission reduction factors can determine the actual EEDI of ships in the dry bulk market. They provided a specific emission reduction strategy on the basis of this observation. Cheng and Li (2012) proposed a new concept based on the EEDI; used the Fairplay database to calculate for the tanker, bulk carrier, and container ship; and compared the results via the EEDI benchmark method. However, this approach ignores the impact of ship speed. Nonetheless, the accuracy of the EEDI benchmark method was verified on the basis of analytical results.

The technical measures for pollutant emission reduction mainly focus on newly built ships. In the IMO framework, such measures are mandatory to some extent, but they do not restrict most of the existing operating ships. Therefore, IMO proposed the ship energy efficiency management plan (SEEMP), which is mainly focused on existing operating ships. In other words, operational measures for the shipping industry to reduce emissions have been considered, but the implementation is not mandatory. During operation, the energy efficiency management plan of a ship is reflected by the energy efficiency operational indicator (EEOI), which is directly related to fuel consumption.

Acomi et al. (2014) developed a method to calculate EEOI. They analyzed the influence of different types of fuels in relation to EEOI value in full load and no-load conditions through system analysis. Lu et al. (2015) established a semi-positive operation performance prediction model to support operators in selecting optimal navigation speed depending on ship characteristics. They applied the model to analyze fuel consumption in different conditions. Sun et al. (2013) empirically analyzed the operational efficiency of inland vessels. They found that navigation environments can remarkably affect the operational efficiency of inland vessels by calculating energy efficiency index of ships in calm water and real navigation conditions.

The MBMs in the emission reduction of shipping focus on economic and market incentives to encourage companies to adopt the most economical approach for reducing emissions and minimizing costs while meeting emission reduction targets. Thus, MBMs are the main measures to control carbon oxide emissions in the international maritime industry. The emission reduction principle needs to reconcile the two principles of international law (i.e., "common but differentiated responsibilities" and "no more preferential treatment"), but a plan acceptable to developed and developing countries has yet to be proposed. Heitmann and Khalilian (2011) discussed the influence of various proposals from the UN Framework Convention on Climate Change (UNFCCC) and found that no existing proposal can effectively and fairly solve the emission problems. Lee et al. (2013) analyzed the economic impact of carbon tax on international container transportation. The results showed that the introduction of seaborne carbon tax in international container transportation will not lead to significant global economic changes in low-carbon tax condition; on the contrary, the loss of gross domestic product (GDP) in China is the greatest, and this introduction will affect long-distance container routes in high-carbon tax conditions. Wang et al. (2015b) discussed two sets of measures in the emission trading system (ETS), namely, open ETS and shipping industry ETS. An in-depth research was conducted to analyze the influence of the two ETS measures in controlling emissions. Shi (2016) discussed the current seven emission reduction measures of greenhouse gas fund, port state taxation, energy efficiency incentive, ship energy efficiency and credit transactions, international shipping global CO_2 ETS, trade development penalties, and tax refund mechanism as an international shipping marketization tool. A comparison of the scope of the seven measures showed that greenhouse gas reduction is acceptable to many countries, and such reduction has thus been recommended for implementation in 2016. Meanwhile, domestic scholars have focused on the policy interpretation of MBMs, which generally suggest the neglect of quantitative research. Zhang et al. (2008) analyzed the design elements, possible main problems, and development trends of the international shipping carbon emission trading mechanism. On the basis of the results, they proposed for China to urgently focus on the establishment of a comprehensive database on ship information for determining the influence of emission trading mechanism on China's shipping industry and the investigation of the political and economic impact of international shipping emission trading mechanisms. Li (2012) analyzed the recent emission reduction situation in China and found that problems are associated with weak foundation, inadequate management mechanism, and insufficient technology accumulation; subsequently, the potential market for low carbon development was proposed.

In addition to the aforementioned strategies for shipping companies to reduce emissions, many countries have also set up ECAs around their ports to limit emissions in controlled areas. Panagakos et al. (2014) focused on the strategy of opening a sulfur ECA in the Mediterranean. They compared the cost and level of emissions from road and waterway transportation by applying the logit model, and they found that this strategy will force 5.2% of transportation transfer into road transportation. Fagerholt et al. (2015) developed a route-speed model to minimize operating costs and meet ECA requirements. They found that shipping companies will choose to avoid ECAs and accelerate outside ECAs to cover lost time cost. By contrast, Adland et al. (2017) applied the automatic identification system to obtain data from more than 7000 ships that sail through ECAs in the Northern Sea. They found that the ECA policy does not affect the speed of visiting ships.

Many scholars have examined the existing emission control policies issued by IMO or government maritime departments for shipping companies. Zhao et al. (2015) proposed an optimization model for container terminals that considers transportation, port calls, discharge costs, and limiting capacity of ports. Jia et al. (2015) established a system involving 17 indicators for the development of green shipping and identified the significance of each indicator. Wang et al. (2016) proposed a model based on price compensation and found that this strategy will benefit ports and shipping companies and simultaneously reduce emission.

To further reduce at-berth emissions, especially NO_x and PM, governments currently promote the use of shore-side power (SP). This implementation enables ships at berth to use electricity from national grids to power onboard electrical systems, such as lighting, ventilation, communication, and cargo pumps, while auxiliary engines are turned off. Shore power can considerably reduce air pollutant emissions, which can cause health problems, climate change, and environmental damage. Using shore power can reduce emissions of CO_2 by up to 85% (Hall, 2010), SO_2 by 88%, NO_x by 94%, and PM by 95% (Wang et al., 2015a). Furthermore, an international standard on SP is being developed to ensure worldwide compatibility between ports and vessels. Most shore power-related studies focus on cost-benefit analysis, that is, whether a port should install SP infrastructures (a health benefit from reducing emissions versus the installation cost of SP infrastructure), by assuming a fixed percentage of SP utilization. Ballini and Bozzo (2015) assumed that 60% of all cruise vessels visiting Copenhagen use shore power. Their calculated results show that the total capital cost of establishing SP infrastructures in Copenhagen will be compensated by health benefits in 12–13 years. Zis et al. (2016) analyzed the payback period for ships retrofitted with SP equipment and found that payback time depends on the price of fuel and electricity and the time spent at berth. The promotion of SP requires ports and shipping lines to invest in infrastructure/facilities considering each other's decision. However, limited studies have accounted for this network effect. Wang et al. (2015a) assumed that 40% of ships visiting the port of Shenzhen come from ports in Europe and North America and are already equipped with SP equipment. They also evaluated potential emission reduction if the port installs an SP infrastructure. Vaishnav et al. (2016) used historical vessel call data and identified combinations of vessels and berths at US ports that can be switched to shore power to yield the largest gains for society. They assumed that port operators and ship owners act in a socially optimal manner. The above-mentioned studies incorporate one-stage interaction between ports and shipping lines. However, in practice, ports and shipping lines interact repeatedly in a "chicken and egg" manner (Winkel et al., 2016). In other words, when a large number of ports build shore power infrastructure, ships with SP equipment will have a large number of opportunities to use SP, thereby reducing the cost for shipping companies; as a result, a large number of ships will be retrofitted, and additional large numbers of ports will install SP infrastructure (Wang et al., 2015a).

4 Discussions on literature

This study has reviewed 80 related papers to provide a comprehensive overview of the operation management of green ports and maritime shipping networks. The target of the study is to summarize existing literature and identify some future research directions. Three related research areas are analyzed in Section 3. In the first research area, we pay attention to the green ports regarding quayside and yard side operations. Several studies have investigated operation management of ports, but the research combining with the concept of "green" is insufficient. For example, storage location allocation is a central problem in yard side operations and widely studied (Murty et al., 2005; Kozan and Preston, 2006), whereas the research integrating this central issue and energy saving or emission reduction is lacking. In the second research area, the joint problem of speed optimization and fuel cost or carbon oxide emissions and some studies on ECAs is reviewed and reported. Some extant papers reveal that, if the measure of fuel switching is chosen for obeying ECA regulations, then two schemes can be implemented to minimize fuel cost: one is to avoid ECAs, and the other is to sail slower within ECAs and faster outside ECAs. In the last research area, we analyze emission control measures from the perspectives of technical measure (i.e., the introduction of EEDI), operational measure (the proposal of SEEMP), and MBM that focuses on economic and market incentives for reducing cost and emission. Many existing works for carbon emission reduction in shipping are discussed in our paper, and it is likely to reduce carbon dioxide emissions with current technologies as reported by Bouman et al. (2017). We also investigate papers on emission control policies, especially those on the cost-benefit analysis of SP infrastructures.

In summary, four conclusions can be drawn from the review of the aforementioned articles.

(i) Although many articles regarding the operation management of ports are available, the traditional decision model needs to be improved and adjusted to adapt to the concept of green ports. Scholars need to consider the concept from a different perspective, such as the analysis of emission mechanism in port operation and the optimization of operation in ports considering emission control. Researchers need to expand research from a different perspective, redefine the existing scheduling problem of resource in ports, attempt to propose the evaluation and regulation method to control emission, and investigate the joint optimization problem from an extensive view to solve the problems port operators are experiencing in the development of green ports.

(ii) Optimization in liner operation regarding emission control is a new research topic. For example, the speed and route of ships need to be reconstructed due to the set of sulfur ECA, or several elements such as the cost of heavy- and low-sulfur fuel, fuel consumption, the location, size, and shape of the control area need to be considered to save the fuel consumption cost. Specific models and algorithms need to be proposed to meet the need of green ports and contribute to economic and environmental development.

(iii) In consideration of emission control policies, the fuel cost, the fleet deployment, and the schedule design will be affected by the installation of the scrubber and shore power equipment. Under the emission control policy, port operators need to decide whether they need to adopt the new technology for emission control, equip ships with the scrubber, and upgrade the ships for shore power transformation. Little research is available with regard to the adoption of new technology on shipping emission reduction, especially in quantitative decision theory and methods.

(iv) Few systematic analyses are available for emission control policies. For example, the enforcement of EEDI will continuously affect the operating mechanism. Similarly, the implementation of EEOI and MBMs will promote the relationship between policies. In addition, several articles regarding green shipping based on the quantitative decision method treat emission control policies as given conditions. In other words, they analyze the operating strategy under certain policies and fail to conduct in-depth research for current emission control policies and verify the rationality of emission grading policies. Emission control policies need to be further explored.

5 Potential topics for future studies

On the basis of the aforementioned conclusions, problems in the field of green ports and greening shipping network are proposed in this study. These potential topics mainly focus on the short- and long-term strategic levels of operation management problem from the perspective of sustainability and on the basis of the operation research, which involve four research areas: (i) dynamic evaluation of port operations based on emission grading policies; (ii) optimization of port operations under emission control policies; (iii) optimization of potentially adopted green port and shipping technologies under emission grading policies and emission control policies; and (iv) analysis and optimization of emission control, emission grading, and other subsidy policies. The potential topics are proposed from several different dimensions: decision subject, decision-making level, and decision object. The framework of potential topics is shown in Table 1.

Future work can also focus on automated equipment at

Table 1 Framework of potential topics

Decision subject		Decision-making level	Decision object	Research topics
Enterprise	Ports	Short-term tactical level	Points in shipping network	Dynamic evaluation of port operations based on emission grading policies
	Shipping companies	Short-term tactical level	Lines in shipping network	Optimization of port operations under emission control policies
	Port and shipping companies	Long-term strategic level	Shipping network	Optimization of potentially adopted green port and shipping technologies under emission grading policies and emission control policies
Government	Maritime management department and environmental protection department	Macro-policy level	Shipping network	Analysis and optimization of emission control, emission grading, and other subsidy policies

ports, such as automated mooring systems, automated guided vehicles, and automated stacking cranes. Some scholars (Pjevčević et al., 2011; Kavakeb et al., 2015) have explored this area to optimize operation performance, but studies on automated equipment are still lacking. Exploring the problem on improving efficiency of automated equipment with some uncertain factors is interesting as uncertainty is a critical concern in the operation management of ports. In addition, research associated with new green shipping technologies, such as battery, bioenergy, and nuclear energy, is needed to save energy and reduce emissions.

6 Summary

In this study, the research results on ports and shipping network and emission control are discussed together with the construction of an optimization theory system for green ports and shipping network management. Then, the potential topics for the optimization management of green ports and shipping networks are proposed. This research accords with the concept of sustainability because it involves meeting targets on emission reduction in shipping activities, improving the service level of shipping companies, and controlling operating cost. The construction of the optimization theory system of green port and shipping network management not only benefits the development of management science, system science, and decision optimization theory but also forwards the conceptualization of related models for shipping companies to balance cost saving and emission control. New tools for decision making on the development of green ports can be developed, decision-making processes for government regulation departments can be enhanced, and scientific evidence for the adoption of new technologies regarding emission reduction in shipping companies can be supported. Moreover, shipping activities can be optimized while meeting the emission control requirement. The potential topics proposed in this study are vital in decreasing the emission of pollutants from shipping activities, promoting a low-carbon economy, protecting safety of lives, and improving the sustainability of a global economic society.

Conflict of interest statement We declare that we have no conflict of interest.

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