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Views & Comments

Data-Driven Modeling of Maritime Transportation: Key Issues, Challenges, and Solutions

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1. Uncertainty in maritime transportation

Maritime transportation plays a central role in global logistics systems. Over 80% of international trade is carried out via the maritime transportation network [1], which has received widespread attention from academia and industry. In the shipping network, ports are the vertices where large numbers of activities occur, including cargo loading, unloading, and transshipment. Ships sailing between different ports travel along routes that form the links of the network. Shipping operation studies usually cover ship routing, schedule design, fleet deployment, and network design.

Port operation is a typical research area in the maritime industry. Most related research works focus on a deterministic operational environment. However, port operations in reality involve many uncertain factors, such as uncertain ship arrival times, uncertain tugging process times, uncertain loading and unloading times, uncertain berth availability, uncertain quay crane availability, and uncertain yard space availability [2–5].

Shipping operations also include numerous uncertainties. For example, sea conditions (i.e., currents and tides) and weather conditions cannot be predicted [6], and different sea and weather conditions have different impacts on sailing speed and thus on sailing time. Moreover, transport demand between origin and destination ports—especially spot market demand—is usually uncertain [7,8], and the actual transport volume may be restricted by the availability of ship capacity [9]. In addition, marine fuel price is volatile, and price fluctuations will lead to different sailing speed decisions and fuel consumption [10,11].

All these uncertainties in port and shipping operations affect maritime transportation planning. Making port or shipping operation decisions without considering such uncertainties is rarely applicable in practice. Therefore, it is extremely important to pay attention to uncertain factors in order to improve the efficiency of port activities and shipping companies.

2. Challenges in maritime transportation modeling under uncertainty

As discussed above, it is both important and necessary to consider uncertain factors when addressing research problems on maritime transportation. In this section, we analyze the challenges of introducing such uncertainties into maritime transportation models. The uncertainties within port and shipping activities lead to difficulty in developing maritime transportation models. One possible reason is that it can be difficult to collect historical data related to port and shipping activities. Another reasonable explanation is that port and shipping operations cannot be predicted accurately in advance, while decisions on subsequent visited ports and sailing voyages will be affected by previous decisions; therefore, it is difficult to make optimal decisions for an entire voyage, considering the uncertainties of future maritime transportation activities.

The joint influence of various uncertain factors further increases the modeling difficulty. Take an Asian Pacific liner service route in COSCO Shipping Lines as an example (Fig. 1) [12]. A liner ship departs from the first port of call (Xiamen) according to the schedule designed by the shipping company; then, the sailing time to the second port of call (Shekou) is uncertain, mainly due to the uncertain conditions of sea, weather, and machines. As a result, the arrival time at the port of Shekou is uncertain, which is combined with an uncertain port time due to uncertain loading and unloading container volumes, as well as available port facilities. Therefore, the departure time from the port of Shekou also cannot be predicted. The liner ship then visits the ports of Hong Kong, Sydney, Melbourne, and Brisbane and returns to the port of Xiamen, with the designed schedule of each port being affected by the uncertainties of previous voyages and current port activities. The combination of all the uncertain factors on a service route complicates the construction of an optimization model for the route, and the model is even more complicated when extended to the whole shipping network.

Solving a maritime transportation model under a multitude of uncertain factors is extremely difficult, due to its complexity. Therefore, when developing maritime transportation models, how to present a solution method that can simultaneously guarantee the accuracy of the solutions while requiring an acceptable computation time is a key concern. A focus on developing solution methods will further increase the difficulty of model construction.

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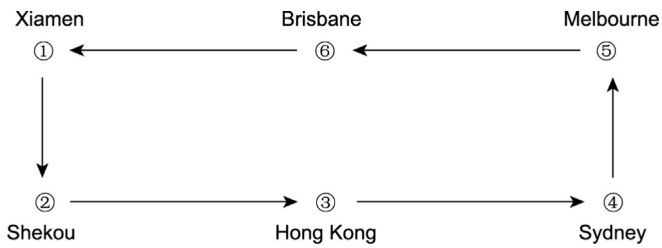

Fig. 1. An Asian Pacific liner service route.

3. Data-driven modeling in maritime transportation optimization

The challenges of the construction of maritime transportation models that stem from uncertainties indicate a demand for data gathering. Hence, several measures have been applied to collect and handle maritime industry data in order to develop data-driven models. A common measure is to generate port and shipping operation scenarios based on historical data. Maritime transportation data can be obtained from various databases, such as Shipping Intelligence Network, The Shipping Database, and VesselsValue. For research problems with limited cases, uncertainties can be investigated by generating a few scenarios; for research problems with numerous cases, the Monte-Carlo sampling method is often used to produce a considerable number of scenarios in order to simulate the real operation environment. Compared with deterministic models, maritime transportation models based on simulation scenarios can generate solutions with lower expected costs or higher expected profits.

Another effective measure is to provide real-time data—typically, automatic identification system (AIS) data. The AIS is an automatic tracking system that uses transceivers on ships. All passenger ships and international voyaging ships with 300 or more gross tonnage are required to install the AIS. Ships equipped with AIS transceivers can deliver voyage information to base stations and allow maritime authorities to monitor ship movements. The AIS can provide considerable amounts of real-time information, including the ship name, ship draft, location, course, speed, and other details. A large number of reports can be produced by analyzing AIS data. According to updated real-time and forecast data based on AIS data and reports, port and shipping activities (e.g., ship schedule, sailing path and speed, and port service time window) can be redesigned for cost savings or profit maximization. AIS data has also been used in recent greenhouse gas (GHG) studies by the International Maritime Organization (IMO) to estimate GHG emissions from the world commercial fleet.

The introduction of the emerging technology of blockchain into the maritime industry is also effective in optimizing port and shipping operations. Blockchain can facilitate information sharing and communication within the maritime transportation network and mitigate the management complexity caused by uncertainties. Information in a blockchain scheme can be divided into interdependent blocks, such as shipping companies, consignors, and port operators. By introducing a blockchain, the data from different blocks of maritime industry—such as the AIS data from ship voyages, the container transportation demand information from consignors, and reports on container handling progress from port operators—can be integrated. The blocks in the blockchain can exchange information and take advantage of the shared data to improve operation management. Some practical applications of blockchain are as follows: Blockchain in Transport Alliance was built as a trade data-sharing platform enterprise alliance in 2017, and Maersk and IBM established a shipping transaction platform (TradeLens) using blockchain in 2018.

The three measures discussed above—that is, generating port and shipping operation scenarios based on historical data, providing real-time information such as AIS data, and introducing blockchain into the maritime industry—can overcome the challenges in data collection and the joint effect of various uncertain factors. Based on the obtained historical or real-time data, data-driven models can be proposed for maritime transportation problems with uncertain factors. It should be noted that, when building data-driven models, methods for solving models—such as neural network and other machine learning models and sample average approximation methods—should be developed simultaneously in order to validate that the proposed models can be solved effectively and efficiently. To further alleviate the effect of uncertainties in port and shipping activities, the development of maritime transportation models from a data-driven perspective by integrating maritime transportation data and blockchain is essential. However, the application of blockchain in maritime transportation still presents significant obstacles, which predominantly include incomplete information records in the maritime industry, the incompatibility of different systems, and blockchain's immature technology and application. Therefore, the blockchain system in the maritime industry must be improved, on the basis of which port and shipping models can be developed to further optimize maritime transportation decisions.

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