Simulation-based Research on the Allocation of Low-carbon Container Terminal Handling Equipment

Ke LIU, Yun PENG*, Wen-yuan WANG, Xiang-da LI and Xiang-qun SONG
State Key Laboratory of Coastal and Offshore Engineering 1, Dalian University of Technology, Dalian, 116023, China
*Corresponding author

Keywords: Container terminal, Low carbon, Simulation, Handling technology.

Abstract. At present considerable attention is being given to climate change and global warming. In an increasing globalized world, international transportation produces considerable CO2, which is an essential cause for global warming. As important nodes in international logistics, seaports discharge massive CO2, especially for the handling equipment and vessels. In order to reduce the port carbon emissions influenced by handling facilities, a microscopic handling simulation model is built in this paper for a container terminal with four types of quay cranes and two types of vehicles by using Arena software. Firstly, by changing the type of quay crane and the number of vehicles, the carbon emissions from each facilities are analyzed. Secondly, the carbon emissions of system with five common combinations of quay crane and vehicles are contrasted, and two recommended combinations are provided.

Introduction

Growing emissions of greenhouse gases have been shown to be the cause of global climate change, and these greenhouse gases chiefly consist of carbon dioxide (CO2), methane (CH4), and nitrogen dioxide (N2O) in port operations [1]. Consequently, it is imperative for governments and industries to come forward with climate-friendly strategies. With the high speed of economic globalization, logistics is developing rapidly. Seaports, which are important hubs in the logistic chain of the transportation sectors, are important energy consumers and sources of CO2, where vessels and quay cranes (QCs) are the main components. Therefore, which types of QCs and vehicles should be selected as well as how many vehicles should be allocated need to be studied.

Recently, there has been growing concern about reducing carbon emissions in seaports. The method for assessing carbon emissions from seaports and the allocation strategies of handling equipment to reducing CO2 are two main direction. For assessing carbon emissions from ports in China, Jiang et al. [2] calculated consuming of fuel and CO2 using method in IPCC under three scenarios of intermodal transportation. Calculation formulas for the CO2 emissions in container terminals were proposed by Wang et al. [3], and QC was pointed out to discharge CO2 the most. Harry et al. [4] proposed a relatively simple assessment of carbon emissions. And Dong et al. [5] constructed model to measure carbon emissions from container terminals with different ways of inland transport and different handling technology. Rubber-tired gantry cranes have already been changed from diesel drive into electric drive in many Chinese ports, the environment benefits were evaluated by Yang et al. [6]. For increasing handling efficiency and reducing carbon emissions, simulation model was built by ESMER et al. [7] to analyze the number of handling equipment in Turkish container terminals. Guo et al. [8] built optimal allocation model in container terminal with constraint conditions of carbon emissions for unit handling cargo. Yang [9] analyzed the CO2 emissions of handling equipment from a carbon footprint perspective. A contrast of four types of handling equipment used in container yards was drawn by Yang et al. [10] based on carbon reducing performance. Peng et al. [11] proposed a method of allocating resources to yard cranes to minimize CO2 emissions.
Although considerable research has been devoted to measuring port CO2 emissions and comparison of handling equipment from carbon reducing perspective, rather less attention has been paid to the vessels CO2 emissions influenced by handling equipment. Therefore, in this paper, a microscopic handling simulation model was built for a container terminal based on the operating characteristics of different types of QC by using Arena software. By running this model with different allocation of QCs and vehicles, the carbon emissions of vessels, QCs and vehicles are analyzed. Then, the recommended number of vehicles for different QCs and combinations of QCs and vehicles can be provided for reducing carbon emissions of container terminals, which can provide references for the design of handling technology.

Quayside Handling Equipment in Container Terminal

Quay Crane

Four types of QCs are widely used in container terminals: traditional QC, tandem-lift QC, double-trolley QC, and tandem double-trolley QC. Traditional QC lifts one 40ft container or two 20ft containers for an operation cycle with one spreader. Tandem-lift QC can lift two 40ft containers or four 20ft containers by using two spreaders. Widely used in container terminal in recent years, tandem-lift QC improves the handling efficiency greatly. Double-trolley QC, using a transfer platform, divides one operation cycle for traditional QC into two cycles for two trolleys (quayside trolley transforms containers from vessels to transfer platform, and landside trolley transforms it to vehicle). Tandem double-trolley QC employs one more spreaders for quayside trolley than double-trolley QCs.

Vehicle

Three are two common vehicles employed in container terminal: container truck (CT) and automatically guided vehicle (AGV). The former is driven by diesel and the latter is driven by electric.

Calculation of Carbon Emissions for Quayside Handling System

Calculation Formulas

**Vessel.** Auxiliary engine produces CO2 by consuming diesel when berthing for handling, which can be denoted as:

\[ W_{\text{berth}} = C \cdot \omega \cdot \left( \sum_{j=1}^{n} P_j \cdot V_j \right) \cdot t_{\text{berth}}. \]

where \( W_{\text{berth}} \) is carbon emissions of vessel handling at berth (kg); \( C \) is the carbon emission coefficient of diesel (kg/L); \( \omega \) is the diesel consumption rate; \( P_j \) and \( V_j \) is the power (kW) and diesel consumption for the unit power (L/kWh) of auxiliary engine; \( t_{\text{berth}} \) is handling time of vessel.

**QC.** Carbon emissions of QC driven by electric can be denoted as:

\[ W_{\text{qc}} = EF \cdot \left( P^u \cdot t^u + P^t \cdot t^t + P^d \cdot t^d \right). \]

where \( W_{\text{qc}} \) is carbon emissions of QC (kg); \( EF \) is the carbon emission coefficient of electric (kg/kWh); \( P^u \) is the power of lifting motor (kW); \( P^t \) is the power of trolley motor; \( P^d \) is the power of cart motor; \( t^u \) is the working time of lifting motor; \( t^t \) is the working time of trolley motor (h); \( t^d \) is the working time of cart motor.
Vehicle. Carbon emissions of CT driven by diesel and AGV driven by electric can be denoted as:

\[ W^{CT} = \sum_{i=1}^{n} C \cdot \rho_{i}^{CT,s} \cdot v_{i}^{CT,s} \cdot t_{i}^{CT,s} \cdot s. \]  

(3)

\[ W^{AGV} = \sum_{i=1}^{n} EF \cdot P_{i}^{AGV,s} \cdot t_{i}^{AGV,s}. \]  

(4)

where \( W^{CT} \) and \( W^{AGV} \) is carbon emissions of CT and AGV (kg); \( \rho_{i}^{CT,s} \) is the diesel consumption efficiency of CT in the status of \( s \) (L/km); \( s = 0 \) if CT is empty, or \( s = 1 \) if CT is loaded; \( v_{i}^{CT,s} \) and \( t_{i}^{CT,s} \) is the velocity (km/h) and working time (h) of CT in the status of \( s \); \( P_{i}^{AGV,s} \) and \( t_{i}^{AGV,s} \) is the power (W) and working time (h) of AGV.

Parameters in calculation formulas above like \( t_{d}, t_{l}, t_{u} \) and the working time of vehicles are hard to determine the value. Moreover, the berthing time of vessel is influenced by the allocation of QCs and vehicles. Consequently, based on the operating characteristics of different types of QCs, a microscopic handling simulation model with different QC-vehicle combinations was built for a container terminal.

Simulation Model

Model assumption. The assumption of the model is: Load containers after unloading work; CO2 emissions from auxiliary operating facilities are not concerned.

Models establishment. In order to analyze with comparison in this paper, four simulation models with four types of QC are constructed respectively via software Arena 14.0. Take the model with tandem double-trolley QC as an example. According to the logic model as outlined in Figure 1, the model consists of four subsystems as follows:

a) Container entities create subsystem: entities are created by Create module in short time. Then assign these entities attribute of slot in the ship and attribute of imported or exported. In the following subsystems the imported containers are taken as an example.

b) Quayside trolley subsystem: entities seize the resource of quayside trolley when quayside trolley is unoccupied and the number of containers in transfer platform is less than the capacity. The minimum lifting height is decided on the basis of slot. Acceleration time and deceleration time are taken into account for the working time of trolleys, then the resource of quayside trolley is released. After that, it can move to the next loop.

c) Landside trolley subsystem: the route of landside trolley is constant. The resource of landside trolley is seized when there are more than one containers in transfer platform, and it is released when no less than two vehicles are ready for handing over containers.

d) Vehicle subsystem: the working time of vehicles follow triangular distribution. A process module is used to simulate the vehicle. The resource capacity is the number of vehicles.
Analysis of Carbon Emissions from Quayside Handling System

The load capacity of container vessels is 8000TEU, and the parameters of QC is estimated to satisfy the need of operational requirements of vessels. Run the simulation model for 1000h. Then the carbon emissions per container from each equipment with different allocation of QC and vehicles can be obtained.

For different types of QC, change the number of vehicles, the carbon emissions per container from system are counted. Moreover, the carbon emissions per container from each equipment can be evaluated when the number of vehicles is adequate. The results are shown in Figure 2:

a) The CO2 from system is mostly produced by vessel as shown in Fig. 2b, using shore power can be effective for reducing carbon emissions for seaports [12]. We can see from the curves of Fig. 2a, when the number of vehicles is relatively few, the carbon emissions from system decrease as the number of vehicles increases. This is because increasing vehicles decreases handling time for vessel. However, when the number of vehicles increases to some extent, the carbon emissions change little with the increase of the number of vehicles. Take the system with double-trolley QC as an example, when the number of vehicles is more than six, the carbon emissions changes a little.

b) The carbon emissions from tandem-lift QC is less than tandem double-trolley QC, but the system with the two QC produces almost equal carbon dioxide as shown in Fig. 2b. This is because tandem double-trolley QC have higher handling efficiency than tandem-lift QC.

c) The carbon emissions from traditional QC and tandem-lift QC are almost the same, which are less than other QCs as shown in Fig. 2b. It can be observed that the carbon emissions from QC are mainly influenced by the number of trolleys, which are relatively unrelated to the number of spreaders.
There are five common combinations of QCs and vehicles: traditional QC and CT, tandem-lift QC and CT, traditional QC and AGV, double-trolley QC and AGV, and tandem double-trolley QC with AGV. The first two combinations are widely used in non-automated container terminals and the latter three are applied in automated container terminals. The carbon emissions for all the combinations are evaluated as shown in Figure 3: tandem-lift QC with CT and tandem double-trolley QC with AGV produce the least CO₂. The carbon emissions for traditional QC with CT is a little more than traditional QC with AGV. However, the cost for changing CT from diesel drive to electric is relatively low and the decrease for carbon emissions is the same with changing CT to AGV. Besides, the nitrogen oxides, sulfur oxides, particulate matter and noise will be reduced.
Conclusions

A microscopic simulation model was developed for a container terminal with four types of QCs and two types of vehicles, the carbon emissions in different QCs and different number of vehicles and different combinations of QC and vehicle are analyzed. The following issues were addressed: firstly, in the perspective of seaports, the CO2 from system is mostly produced by vessel, improving service level such as increasing the number of vehicles or using shore power can be effective for reducing carbon emissions. Secondly, in the point of handling technology, tandem-lift QC with CT is recommended to be employed in non-automated container terminal, tandem double-trolley QC with AGV is recommended to be employed in automated container terminal. Finally, in the perspective of QC, the carbon emissions from QC is mainly influenced by the number of trolleys and relatively unrelated to the number of spreaders.

Acknowledgements

This work was supported by National Natural Science Foundation of China (No. 51709037 and No. 51779037).

References