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Joint berth allocation and quay crane assignment under different carbon taxation policies

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ABSTRACT

The environmental pollution issue of port has been highly concerned about by government and green port has been a focus to sustain the development of maritime transportation. At present, the port operator mainly takes measures of designing reasonable berth allocation for vessels and improving loading/unloading efficiency of quay cranes to reduce the carbon emission of port. The International Maritime Organization (IMO) has proposed to impose carbon emission tax on ports in the long-term, which would definitely enhance the willingness of ports to reduce the carbon emission. Therefore, this paper makes effort to explore the study of integrated berth allocation and quay crane assignment problem with considering two policies of different carbon emission taxation rates on port: one is unitary taxation rate and the other is piecewise taxation rate. Two corresponding mathematical optimization models are proposed for the two policies respectively and a number of equivalent or relaxed models are developed to ease the models. Finally, a set of test instances are randomly generated to access the applicability of the proposed models and an actual case is implemented to evaluate the effect of imposing carbon emission taxation on carbon emission reduction. It is found that the carbon emission taxation policy has significant effect on berth-QC plans and the carbon emission can be significantly reduced.
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1. Introduction

The climate change problem has been almost universally understood and acknowledged since it was proposed on the United Nations Science Conference held at Stockholm in 1972. The 2015 United Nations Climate Change Conference was held in Paris and released the Paris Agreement, which calls for zero net anthropogenic greenhouse gas emissions to be emitted during the second half of the 21st century. Therefore, it compels all industries to take energy-saving and emission-reduction measures to reduce greenhouse gas emissions. International Energy Agency (IEA) reports that the transportation industry contributes the second most to the global carbon emission with the proportion of 27%, in which land transportation occupies 20% while maritime transportation accounts for 3% (IEA, 2016). The statistical data shows that the carbon emission of maritime transportation is much less than that of land and air transportation, though most global trade transportation is undertaken by maritime. For this reason, the carbon emission of maritime transportation did not attract high attention

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paid by governments in the past decades. But this does not indicate that the emission reduction of maritime transportation can be exempted or postponed. It is predicted that there will be 1.4 billion tons of carbon dioxide produced by maritime transportation in 2020 which accounts for 6% of the total global carbon emissions; if no measures are taken, it will be up to 18% in 2050 (IMO, 2015). Therefore, the carbon emission growth rate of maritime transportation cannot be neglected.

Port is a key node in the global maritime transportation network. Under the requirement of energy saving and emission reduction, green port has recently been a focus to sustain the development of maritime transportation, such as the “Clean Air Action Plan” proposed by Port of Long Beach and Port of Los Angeles (Jelenić, 2016), the “Clean Air Action Program” developed by Port of Rotterdam (Mshe, 2012), the “Clean Air Strategy” for Port of New York & New Jersey (Port of NY & NJ, 2009), etc. According to the statistical data of Corbett et al. (2009), the vessels moored at ports and cargo handling equipment of ports are the two major sources of carbon emission with a proportion of 74% of total carbon emission at port area. Particularly, container vessels produce 1.3 times as many carbon emissions as bulk vessels, 2.2 times the carbon emissions crude oil tankers produce, and 2.5 times the carbon emissions general cargo ships generate. To reduce the carbon emissions at port areas, port operators have proposed various strategies, such as suggesting a vessel to adjust the speed when it moves into ports, improving the efficiency of cargo handling equipment to reduce the working hours of the equipment, using low-sulfur diesel fuels, etc.

Besides the strategies mentioned above, the Maritime Environmental Protection Committee (MEPC) under IMO proposed to impose carbon emission tax on ports in the long-term (IMO, 2005), which is the focus of this work. Carbon tax is a form of pollution tax based on the economic principle of negative externalities, which are costs generated by the production of goods and services. It levies a fee on the production, distribution or use of fossil fuels based on how much carbon their combustion emits. If implemented, it will increase the operating cost of a port and entice the port operator to reduce the carbon emission by its own willingness. It is noted that the carbon emission at port to be taxed refers to that produced by cargo handling equipment. Note that some cargo handling equipment may use electric power, such as quay cranes (QCs). However, the consumption of electricity would also indirectly produce carbon emissions. Geerlings and Duin (2011) estimated the carbon emissions due to the operations of electric QCs for the Port of Rotterdam.

The QC hours required to complete the workload determines the amount of carbon emissions of QCs. It's noted that the required QC-hours depend on the quantity of workload of moored vessels and the productivity of QCs. The productivity of QCs is determined by the hoisting speed to lift containers and the trolley speed to transversely move container between vessel and shore platform, which are affected by interference among QCs and deviation of vessel's real berthing position away its desired berthing position (Schonfeld and Sharafeldien, 1985; Meisel and Bierwirth, 2009). Poor berthing and QC allocation would slow down the hoisting speed and trolley speed, resulting the decrease of the productivity of QCs, and resulting more QC-hours and more carbon emissions. Therefore, in response to the carbon emission taxation strategy, the port operator should jointly optimize the berthing allocation and QC assignment to improve the efficiency of cargo handling equipment and reduce the carbon emission of these equipment. It may create biased decisions if the port operator solves an individual berth allocation or quay crane assignment problem but not them both.

However, to the best of our knowledge, there are no existing studies investigating the problem of joint berth allocation and quay crane assignment under carbon emission taxation. This paper is aimed at filling the gap by making joint decisions on berth allocations and quay crane assignment accounting for carbon taxation policies. More specifically, this paper intends to study the problem of integrating berth allocation and quay crane assignment under a variety of carbon emission taxation policies, such as the policies using unitary and piecewise taxation rates.

This work makes the following substantial contributions on port terminal operations under carbon emission taxation:

1) To the best of our knowledge, this paper is the first to consider the carbon emission taxation in the problem of joint berth allocation and quay crane assignment.
2) The proposed problem is formulated as two mixed-integer programming (MIP) models (Model I and Model II) under two carbon emission taxation policies, unitary taxation rate and piecewise taxation rate.
3) To reduce the hardness of Model II, we develop a variety of mathematical programs that are either equivalent to Model II or the relaxations of Model II. Furthermore, we theoretically establish the equivalence between Model II and various related models.
4) We present a branch and bound (B&B) solution method to solve Model II and theoretically establish the convergence of the B&B algorithm.
5) We investigate the effect of carbon emission taxation on berth-QC plans.

The remainder of this paper is organized as follows: Section 2 reviews the existing literature. Section 3 states the BQCAP with consideration of carbon emission taxation. Section 4 formulates the BQCAP as two MIP models and develops a series of relaxed and equivalent models to reduce the hardness of the models. Section 5 develops the solution approaches to solve the proposed models. An actual case is implemented to verify the effect of carbon emission taxation policy on carbon emission reduction and set of instances are carried on to evaluate the effectiveness of the proposed solution algorithm in Section 6. Finally, Section 7 concludes the work and recommends future studies.

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