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A carbon emission evaluation model for a container terminal

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ABSTRACT

South Korea has focused on strategic economic growth for the last several decades, resulting in booming international trade. To accommodate this trade, activity in container terminals has been steadily increasing, with corresponding environmental impacts. This study proposed a model using a system dynamics approach to evaluate the total amount of carbon emissions produced in a container terminal, while calculating the required reduction amount of carbon emissions in the container terminal at a given carbon emission reduction goal from the year 2017 to the year 2030. The results of this study indicated that the container terminal will produce annually on average 108.18 million kg of CO_2 equivalent emissions from the five types of processes – vessel maneuver, vessel at berth, container loading and unloading, container transportation, and container receiving and delivery – from the year 2017 to the year 2030. The total carbon emissions of the container terminal were comprised of 51.13% from the container vessel maneuver process, 0.57% from the vessel at berth process, 37.34% from the container loading and unloading process, 1.04% from the container transportation process, and 9.92% from the container receiving and delivery process. The results of this study indicated that the container terminal required the annual reduction of on average 0.53 million kg of CO_2 equivalent emissions from the year 2023 to the year 2030 in order to comply with the South Korean government's emission reduction targets.

1. Introduction

South Korea has had of the fastest growing economies in recent history, largely due to growth in manufacturing and the high-tech industry. It is also one of the largest producers of carbon emissions in the world. In recent years, the South Korean government has realized its obligation to do its part to offset global warming and has made an effort commitment to decrease carbon dioxide emission (CO_2) production in the nation's major industries (Sonnenschein and Mundaca, 2015). Specific targets have been set for each sector to reduce carbon dioxide emissions by the year 2030.

Of the major industries, the transportation sector accounts for 17.9% of the nation's total energy consumption and 12.6% of the total carbon dioxide emissions. The government has assigned this sector a carbon emission reduction target of up to 34.2 million ton by the year 2030 (ME, 2014). Containers, which can be used to transport goods via rail, ship, and truck, have become common globally. In South Korea, the container trade is one of the most important modes of transport and will continue to contribute a large amount of carbon emissions in the South Korean transportation sector.

Export and import containers are handled in a container terminal in two stages: a vessel operation and a receiving and delivery operation (Lee and Kim, 2010). The carbon emissions in the vessel operation are typically generated by a container ship and yard equipment, and in the receiving and delivery operation by a container trailer. In the vessel operation, the container loading and unloading activity associated with a container ship and yard equipment also produce the carbon emissions. In the receiving and delivery operation, the carbon emissions are generated from the container trailer, where containers are transported between the container terminal and the port hinterland facility, or vice versa.

Several research studies have been conducted to investigate air emissions generated from various activities in the seaport sector. Some studies investigated various vessel types to determine the impact of vessel movements and vessel operation modes on air emissions in ports (Goldsworthy and Goldsworthy, 2015), while others looked at vessels at berth to estimate the production of air emission in their operation while in ports (Hulskotte and Denier van der Gon, 2010). Several studies assessed various emissions of

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vessels – nitrogen oxides, sulfur dioxide, carbon monoxide, carbon dioxide, volatile organic compounds, and particulate matter – in the cases of Greece (Tzannatos, 2010), Italy (Lucialli et al., 2007), Norway (López-Aparicio et al., 2017), Portugal (Nunes et al., 2017), and Turkey (Deniz and Kilic, 2010). Since the existing studies of vessels focused solely on air emissions generated from the vessel maneuvering in port areas and on the vessel at berth, it has not been possible to comprehensively estimate the total air emissions generated in port areas.

The port operation generates a large amount of emissions in the loading, unloading, and transporting of containers in the yard. Some studies analyzed the air emissions generated from the truck (Berechman and Tseng, 2012), yard tractor (Yu et al., 2017), gantry crane (Liu et al., 2011) and quay cranes (Liu and Ge, 2017) in a port operation in terms of nitrogen oxides, sulfur dioxide, carbon monoxide, carbon dioxide, volatile organic compounds, and particulate matter. A study by Gibbs and colleagues (2014) found that the transportation activity from a hinterland to a port also contributed a large amount of environmental impact, as did the port operation in the yard. A shortcoming of these studies is that they provided only the total amount of air emissions related to the port operation, but not the vessel operation.

In the South Korean context, some research studies investigated various air emissions – greenhouse gas, nitrogen oxides, sulfur dioxide, carbon dioxide, volatile organic compound, and particulate matter – of port vessel operations (Chang et al., 2013) and of different vessel types (Song and Shon, 2014). These studies did not consider port operations, so the results do not provide the total amounts of air emissions generated in the port. One study investigated greenhouse gas emissions of both vessel operation and port operation from the year 2000 to the year 2007 (Shin and Cheong, 2011) but did not consider the greenhouse gas emitted from the vessel at berth, which is an important activity of vessel operation.

Little research has been conducted to assess the carbon emissions of a container terminal in terms of container handling processes in the South Korean context (Liao et al., 2010). A review of the relevant existing literature indicated that most studies failed to include the entire processes in ports related to a container vessel – a vessel operation, a receiving and delivery operation to a container trailer, and a handling and storage operation with yard equipment – in the estimation of carbon production in port. Few studies used a system dynamics approach to consider the carbon emission reduction target issues in the container terminal.

To address the research gap in studies of carbon emission production in a container terminal, this study developed a system dynamics model to comprehensively analyze carbon emission equivalent (CO_2-e) amounts generated from all of the activities of container transportation in the container terminal, from container trailer to container ship. Based on the analyzed annual carbon emission amounts, this study determined the required amount of carbon emission reduction for container terminals, while satisfying the specific carbon emission reduction target assigned by the South Korean government.

Based on the results of this study, government officials will be able to set environmental policies for green container terminals, while satisfying the assigned specific carbon reduction target by the year 2030. The proposed methodology can also be applied to evaluate the carbon emissions generated from all types of ports and further estimate the required reduction amount of carbon emissions in the overall South Korean sea transportation sector.

2. Methodology

This study analyzed the carbon emissions produced during the entire gamut of container handling processes at a container terminal in South Korea. It also developed a carbon emission evaluation model to measure the required amount of carbon emission reduction using a system dynamics approach. This study considered the carbon pollutants generated during two operations of a container terminal – a vessel operation of a container ship and a receiving and delivery operation of a container trailer.

This study first estimated the amount of carbon emissions generated from each stage by multiplying the amount of energy required in a stage of the container handling process within the port boundary by the carbon emission density value of consumed energy in that stage. In the next step, drawing on the author's previous studies on the carbon emission reduction targets of a residential building sector (Sim and Sim, 2016) and a land transportation sector (Sim, 2017), this study calculated the required reduction amount of carbon emissions at an assigned specific reduction target from the year 2017 to the year 2030, the latter being the target year set by the South Korean government for carbon emission reduction. Finally, this study conducted a sensitivity analysis to estimate the effect of uncertain container volume on the total carbon emission amount and the required carbon emission reduction amount in the container terminal.

2.1. Busan container port

This study considered the South Korean Port of Busan, the fifth busiest container port in the world (Kim et al., 2009), to exemplify the application of the carbon emission estimation method in the case of a container terminal. The Port of Busan, located at the southeastern area of the Korean Peninsula, is a gateway connecting South Korea with the Pacific Ocean and the Asian continent (see Fig. 1). According to the Busan Port Authority, the Port processes approximately 40% of the nation's total overseas cargo and 80% of the nation's total container cargo (Geerings and Duin, 2011). The Port of Busan is composed of four container terminals – Gamman, Shinsundae, Shingamman, and Gamcheon.

2.2. Carbon emission assessment

This study considered the carbon production emitted within the container port boundary. The total carbon emissions at the container terminal, CD_{CNTR}, were calculated by the summation of carbon emissions from the processes of vessel maneuver, $CD_{CNTR,M}$, vessel at berth, $CD_{CNTR,B}$, container loading and unloading, $CD_{CNTR,L}$, container transportation, $CD_{CNTR,T}$, and container receiving and delivery, $CD_{CNTR,R}$, as shown in Eq. (1).

$$CD_{CNTR} = CD_{CNTR,M} + CD_{CNTR,B} + CD_{CNTR,L} + CD_{CNTR,T} + CD_{CNTR,R} \tag{1}$$

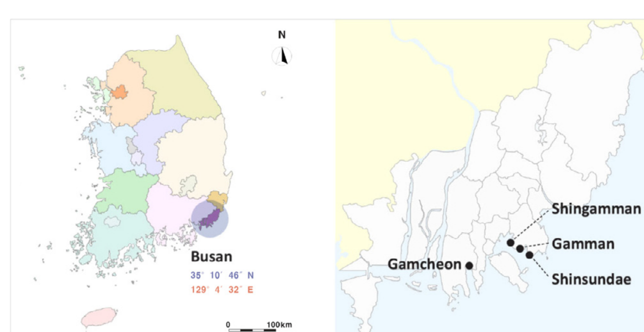

Fig. 1. The location of the Port of Busan in South Korea.