A SIMULATION MODEL FOR ESTIMATING THE CARBON FOOTPRINT OF VEHICLES IN THE TERMINAL OPERATING PROCESSES

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ABSTRACT
Maritime container terminals face increasing transfer loads, causing severe air pollution. Controlling and reducing carbon greenhouse gas emissions has become a social responsibility of the logistics service providers, and it is encouraged by national policies. Nowadays, operational data for the handling equipment in the terminal are typically recorded in daily operation logs kept by the terminal's operating system. In this study, we aimed to construct a model and, using system tracking data, estimate CO_2 emissions from vehicles involved in various operating processes at a terminal yard. The proposed estimation method renders the daily log file visible, representing a potential method for further evaluating port operation efficiency during real-time control from a green terminal perspective.

Keywords: green terminal, carbon footprint estimation, terminal modeling

1. INTRODUCTION

With the rapid increase in the world trade, the volume of the international maritime trade has increased accordingly. Eighty percent of global merchandise trade by volume is carried by sea and handled by ports (UNCTAD 2013). However, increasing transfer loads are causing environmental issues, such as air pollution.

Greenhouse gas emissions, particularly carbon dioxide (CO_2) emissions, have a significant impact on global warming. Freight-related energy consumption and CO_2 emissions grow annually because of increasing transfer loads worldwide (U.S. IEA 2016). Controlling and reducing CO_2 emissions has become an important issue for the country as well as the logistics service providers as it attempts to fulfill its societal responsibility. Therefore, an effective assessment of the carbon footprint has become important and necessary.

A method of estimating the carbon footprint of a container terminal has been attempted by several researchers. Geerlings and Van Duin (2011) presented a bottom-up methodology for estimating CO_2 emissions from container port terminals based on fuel and energy consumption using macro data from the terminal. Yang and Lin (2013) employed a green terminal perspective to compare the performances of four types of cargo handling equipment used in the yard. Veidenheimer (2014) investigated CO_2 emissions of maritime container transport from Asia into the European hinterland through new built German port compared to the other European deepwater ports. The study also addressed measures for CO_2 reduction in maritime door-to-door container transport. Longo et al. (2015) developed a model for evaluating, in terms of throughputs, CO_2 and NO_x emissions beyond the traditional berth and yard operations using an LCA approach. Miodrag et al. (2016) developed a model for evaluating the relationship between crane power consumption and container handling distance. Carbon emissions from container handling equipment during ship loading (LD) and unloading (UL) is usually estimated using these studies. However, few studies discuss the emissions resulting from moving containers within the yard. And, in reality, congestion typically occurs at the yard gate or at entry intersections during rush hours.

Terminal operating systems often utilize information and communication technology such as the Internet, Electronic Data Interchange processing, wireless LANs, radio-frequency identification, etc., to manage container terminals and to control delivery, storage, container processing and handling operations at the container terminal, as well as to manage container documentation in real time (Yang and Takakuwa 2015). Daily operational data from handling equipment at the terminal are recorded by the terminal operating system. Trailer moving information can be extracted from movement information for yard cranes (YCs) and containers.

In this study, we aimed to construct a model for estimating the carbon footprint of container handling during yard operations based on daily operational records of the handling equipment. The method renders daily log files visible, and it represents a method that can further evaluate port operational efficiency in real time from the environment's perspective.

In this paper, section 2 gives the general descriptions of the container handling processes, as well as the terminal operating system. In the section 3, the modeling framework and the carbon footprint calculation method of the trailers is detailed. Section 4 presents the simulation model. Finally, summaries are presented in the Section 5.

2. GENERAL DESCRIPTIONS

2.1. Operational Processes in the Terminal

At a container terminal, operations can be classified as import or export processes, and these two categories employ opposite operation flows (Stahlbock and Voß 2008). The typical process flows of the cargo and information are shown in Figure 1.

Import cargo is usually stocked temporarily in a bonded warehouse near the terminal, and it is there that it is sorted and packed into containers. Export containers ready to be put onto a vessel are carried into the yard before the vessel's arrival. Therefore, export containers are generally gathered approximately one day before vessel arrival, and the logistics service providers can use container information to gather cargo for a given vessel prior to LD.

When the vessel arrives at the berth, import containers are first unloaded onto trailers. Upon an appearance damage-checking process, containers are transferred to the yard storage blocks. Once UL is completed, export containers are transferred from the yard to the quay before being loaded onto the vessel.

The terminal yard is usually divided into an area for export containers (LD area) and an area for import containers (UL area) for efficiently handling cargo. Operations in the LD area include receiving (R), the process whereby an export container is received by the terminal, and LD, the process whereby the container is loaded onto the vessel. Conversely, operations in the UL area include UL, the process whereby container is unloaded from the vessel, and Delivery (D), the process whereby an import container is delivered to the cargo owner. Each of these operations require the use of trucks with trailers, either from outside the yard or owned by the yard. Additionally, shift (S) operations occur in these two areas, and they can be divided into those that occur without a trailer (SS), which is usually referred as re-handling, and those that occur with a trailer (ST), which is usually referred as moving a container under the shift plan. The operation processes at the terminal are supported by the terminal operating system.

2.2. Terminal Operating System

A terminal operating system is a software application that supports a container terminal's planning, scheduling and equipment-control activities (Boer and Saanen, 2008). When a vessel arrives at the berth, containers are unloaded by a gantry crane (GC) onto trailers that are trucked to the yard's storage blocks. Once a container is loaded onto a trailer, information indicating completion of UL is transferred to the system. Shortly thereafter, handling instructions for container storage spots are sent to the YCs. Concurrently, system tracking records time to completion. Other operations inside the yard (S, D, R and LD), and basic information about the container and vessel are also recorded in the system. The information flows as depicted in Figure 1.

Data records can be used to analyze and improve the system, and they are divided into vessel information, yard operation data, and container inventory data. Additionally, in this study, yard operation data is used primarily for extracting moving information for the trailers.

3. MODELING FRAMEWORK

3.1. Model Logic Flow

To extract information about the trailers, the process flows of the YCs and containers must be clarified and analyzed. The flow chart is shown in Figure 2.

The logic flow of the model consists of logic control and calculations.

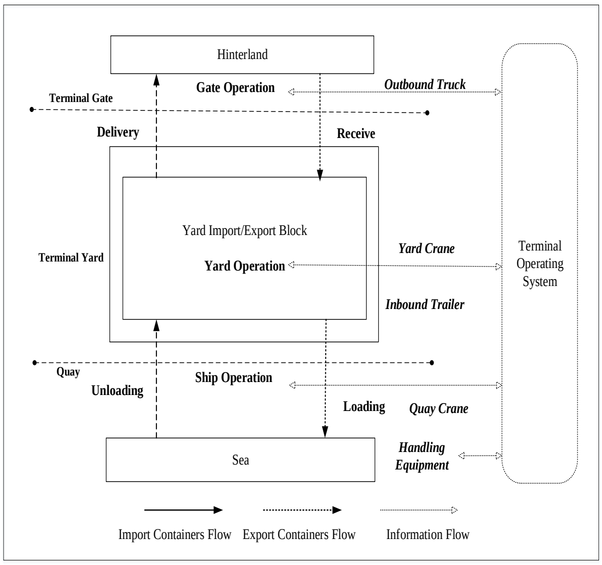

Figure 1: Typical Cargos Flow and the Information Flow in a Terminal

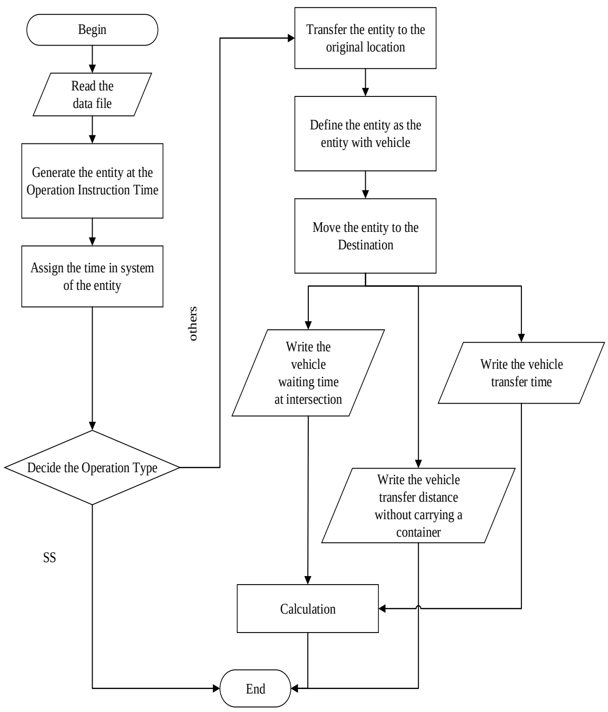

Figure 2: The Flow Chart of the Model

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Container handling processes typically use a trailer. The relationships between the origins and destinations are shown in Table 1.

Table 1: Positional Relations of the Operations

Operation Type	Original Position	Destination
UL	GC	Yard Block
LD	Yard Block	GC
R	Gate	Yard Block
D	Yard Block	Gate
ST	Yard Block	Yard Block

Furthermore, trailers are either inbound (LD, UL or S operations) or outbound (R or D operations). During LD and UL, a group of trailers is usually assigned to a given GC so that these operations can be processed quickly. Therefore, these trailers are defined travel one-way distance again without carrying a container.

3.2. Emission Factor

Energy-based and activity-based method are two basic approaches using in carbon auditing. Energy-based method directly apply standardized energy or fuel conversion factors. Activity-based method is based on transport activity data expressed typically in ton kilometers (tkm). For calculation of activity data the weight of carried goods (ton), and distance travelled (km) is needed (Veidenheimer 2014). For this model, both energy based and activity based methods are used for calculation.

We adopted the Japanese standard CO_2 emission factors specified by the Port Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan in 2009.

Trailers used for transporting marine containers are driven primarily by diesel engines filled with diesel fuel. Therefore, the emission factor for diesel fuel, 2.62 t-CO_2/kl, is adopted. Fuel consumption of an idling engine (e.g., when in congestion) is 1.25 l/h.

CO_2 emission volume while idling = 1.25 l/h × 1/1000 × 2.62 t-CO_2/kl × idle time (h). (1)

CO_2 emission factor (while moving) = 0.0421 (l/tkm) × 1/1000 × 2.62 (t-CO_2/kl) = 110 (g-CO_2/tkm). (2)

CO_2 emission volume while moving = cargo weight (t) × transfer distance (km) × CO_2 emission factor (g-CO_2/tkm). (3)

= 110 (g-CO_2/tkm) × cargo weight (t) × transfer distance (km) (4)

Additionally, these emission factors and the parameters can be adjusted to correspond to the actual situation.

4. SIMULATION MODEL

4.1. Modeling Software

For this simulation, Simio modeling software (Kelton, Smith, and Sturrock 2013) is used for coding. Simio is a simulation-modeling framework based on graphical object-oriented programming. The model is realized using multiple modeling paradigms, including event, process, object, system-dynamics and agent modeling views (Thiesing and Pegden, 2014). 3D animation provided an efficient mechanism for model verification.

4.2. Data and Model

The external data files, such as excel or csv files can be imported into Simio. A data example of the model is shown in Figure 3.

The YC operation data is used as input data. In the demo, a four-hour data set is used for testing.

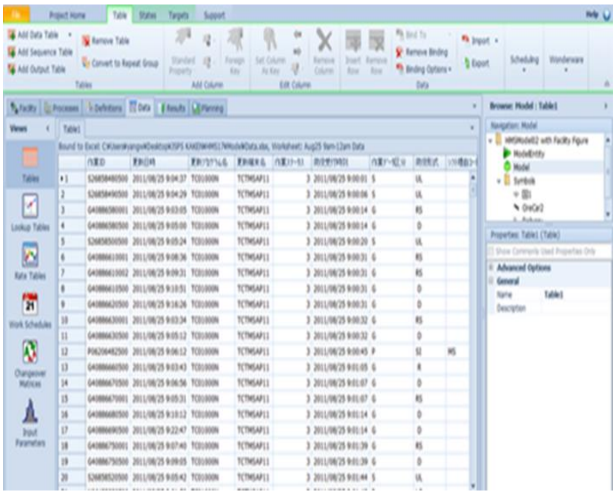

Figure 3: A Data Example of the Model

A very large amount of information is recorded in the system. The items listed below are the primary ones used in the study.

(1) Operation No.;
(2) Container attributes:
Container No.,
Container Size (20 ft or 40 ft)
Container Weight;
(3) Vessel information:
GC No.,
UL Time (in the UL process) from the ship;
(4) Yard crane information:
YC No.,
Operation Area;
(5) Operation information:
Operation Type,
Operation Instruction Time,
Operation Completion Time,
Original Location,
Destination.

The logic flow to build the model is shown in Figure 2. Firstly, the entity (an operation) is generated at the operation instruction time. Secondly, decide if the operation need a trailer by operation type. Then, transfer the entities which are need a trailer from the original location to the destination. The trailer transfer time and the waiting time at intersection are written for further calculation. The travel distance of the trailer without carrying loads is also recorded in the model.
The equation (1) and (4) are used for calculation. Statistics can be collected in real time while the model is running. CO_2 emissions can be obtained from the model interface. The model can be further used for evaluating port operational efficiency from the environmental viewpoint.

5. SUMMARY

In this study, a model for estimating the carbon footprint of trucks operating in the yard was developed. Daily YC operational data recorded in the terminal operating system can be utilized effectively in the model. The modeling framework and the carbon footprint calculation method of the trailers was detailed. Both energy based and activity based methods were used for calculation. The proposed method represents a potential method for evaluating port operations in real time from the green terminal perspective.

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