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ESTIMATING OF CO_2 EMISSIONS IN A CONTAINER PORT BASED ON MODALITY MOVEMENT IN THE TERMINAL AREA

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ABSTRACT

The port sector has played an important role in global trade, with ports acting as a transportation chain-ring in environmental-social performance improvement. The usage of sea transportation means has spread across the world. Starting with the Kyoto Protocol for ships, the environmentally friendly trend has encompassed the port sector. However, it is difficult to find a model with the same characteristics as those of the ports as the models. The models can be used to compare operational performance regarding carbon dioxide (CO_2) emission production. This research aimed to estimate CO_2 emissions at container ports to portray how a port deals with its operational matters, using models suitable for ideal circumstances based on available equipment. This calculative system applies a bottom-up calculation of the work activities at a port, treating the amount of fuel consumption not as an input variable, but as the result of the calculation itself. The input variables include throughput, transshipment process, transportation modality, and terminal layout. The results show that several equipment operational activities can be optimized by comparing the calculation results for actual CO_2 emissions. It was found that each twenty-foot equivalent unit produced as much as 11.27 kg of CO_2 emissions at the Belawan International Container Terminal in Medan, Indonesia. This research has considerable potential use for ports, showing how to calculate CO_2 emissions at a port under ideal circumstances, that models in use can be adapted to any port characteristics, and that the data serving as the input variables are not difficult to obtain.

Keywords: Cargo handling equipment; CO_2 emission; Container terminal; Greenport

1. INTRODUCTION

Today's global trade makes the shipping sector one of those with vital roles in it. The need for shipping services keeps escalating, even in the gloominess of the global economy (Cullinane & Cullinane 2019). According to the Maritime Knowledge Centre (2011), over 90% of global trade involves sea transportation, and it is possible that the percentage will rise. With growing shipping activities involving cargo delivery, it is probable that port activities will also grow. (Zhang et al. 2017) reported that the increasing number of port activities resulted from expanding global trade is causing more emissions. The Kyoto Protocol, which has been conceptually adopted since the end of the twentieth century, has initialized the world's trend of concern for pollution by putting a limit on emissions (Bergqvist & Monios 2019). The world's maritime trend approaches an environmentally friendly system, driving the port sector towards increased effectivity and decreased emission generation from port production (Roh et al. 2016).

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Bergqvist and Monios (2019) reported that there are still a few ports continuing to calculate emissions from their production. (Davarzani et al. 2016) clustered research topics from international publications related to emissions, environmentally friendly ports, and efficiency. (Yang & Chang 2013) compared rubber-tired gantries to electric rubber-tired gantries from the perspective of energy saving and carbon dioxide (CO_2) reduction. Giuffre et al. (2011) counted vehicle emission factors on the basis of geometrical and traffic conditions, considering basic vehicle activities along with the time spent by vehicles (Giuffre et al. 2011). Several studies on reducing emissions have been carried out using biodiesel in diesel engines, with results showing promise regarding emissions control (Majid et al. 2016; Said et al. 2018). The initiative of energy saving in container terminals has been conducted through power consumption reductions in refrigerated containers; results have shown effective methods for reducing power consumption in this area (Budiyanto & Shinoda 2018; Budiyanto et al. 2018). Other studies on emissions reduction in container terminals have been conducted using building energy simulations to indicate some factors affecting increased energy consumption (e.g., solar radiation, container position, and weather condition) (Budiyanto et al. 2017, 2019a,b).

The large impact of port operational activities on the environment has drawn industrial and scholarly attention. (Berechman & Tseng 2012) studied Kaohsiung Port and found that the estimated combined cost of the environmental impact from ships and trucks in the port was over 100 million USD. With estimations based on energy consumption, Van Duin and Geerlings (2011) predicted that total CO_2 emissions resulted from port operation using a model and the result indicates there is the differentiation with the actual performance (provided by the port) about 15%. (Samiaji 2011) stated from his study at 2004-1010 that the concentration of CO_2 in Indonesia was escalating from 373 ppm to 383 ppm because of the conflagration of the biomass and the forest. By making use of emission burden inventories and records of sea transportation activities in ports, (Huboyo et al. 2018) found the distributions of emissions are dominated by the production activities of ports and the ship maneuvering and the results is port activities only contribute 1% of the activity of auxiliary engines when berthing time. (Lam & Notteboom 2014) reviewed the management of the renowned ports in Asia and Europe regarding pricing, monitoring, and measuring policies and the findings show that the ports are particularly mature in exercising environmental standard regulations which reveals that the enforcement approach is more prevalent. As hinterland transportation is a port mode, (Bergqvist et al. 2015) applied multi-actor multi-criteria analysis to evaluate the chance of improvising a system of hinterland transportation in a port in order to reduce the emissions of port activities. Research calculating the air pollution produced by vehicles in a city has been done (Ariztegui et al. 2004) profoundly for estimating emissions produced by some vehicles using instantaneous speed of the vehicle as the main variable in the study.

To improve port air quality, CO_2 emissions require reduction, making emissions factor descriptions necessary. This research will estimate CO_2 emissions at container ports to portray how ports deal with operational matters, using a model of an ideal condition, that there are no un-ideal activities, based on available equipment. Results would provide a description of port emissions, informing whether ports operate effectively, which could be used to evaluate operational conditions in suboptimal situations.

2. EMISSION ESTIMATION METHOD

Cargo handling equipment (CHE) was used for container transportation to and from a ship, train, or truck at the BICT. CHE was operated specifically in the container terminal operation area and began containers being transported from ships using a container crane. Containers were then taken by container trucks to the stacking field where yard cranes placed them in accordance to their correct locations. The CHE assisting in the process included container cranes, rubber-tired gantry/automatic stacking cranes, side handlers, top handlers, and terminal trucks.

Figure 1 Layout of the Belawan International Container Terminal

This research was conducted at the Belawan International Container Terminal (BICT). This terminal is located 3° 47’46” N and 98° 43’09” E of Medan, Indonesia, and its layout is displayed in Figure 1 inside the red line. Table 1 indicates the CHE located at BICT.

Table 1 Distribution of CHE at BICT

	Distribution of CHE	BICT
1	Container Crane	6
2	Rubber-Tired Gantry	12
3	Head Truck	24
4	Reach Stacker	2
5	Side Loader	1

The CO_2 emissions caused by transshipment in a container terminal can be mapped by using an emissions-per-terminal model (Van Duin & Geerlings 2011). Since CO_2 emissions are the direct consequence of energy used either fuel or electricity in the process of transshipment, it is important to describe the energy-consuming factors affecting transshipment (Mubarak & Zainal 2018). Such factors include the equipment used in each sub-process, the patterns of energy consumption for the various implements, the equipment distribution, and the average distance travelled by the mobile equipment in each sub-process.

The goal of this calculation is to determine the CO_2 emissions of a container terminal at the macro level. The precise data required for input are easily and freely obtained include:

1) Total throughput containers in one year—In this model of container terminal transshipment performance, all can be represented by the containers dealt with.
2) Transportation modality—Regarding the distribution of total throughput containers to various modalities, modality movement knowledge is essential. The process of dealing with containers and their route depends on the type of modality. In BICT, the used modality is land transportation with container trucks.
3) Transshipment Process—Transshipment processes vary depending on the types of modalities in the terminals, container moving process, and the types of equipment used.
4) Terminal Layout—The equipment energy consumption depends on the travelled distances to and from the sub-processes. The location of the container terminal also determines these

distances as every terminal has its own design. Energy consumption is calculated using the average travelled distance based on the type of equipment per modality and the travelled distances to and from terminal locations (e.g., the stacking area, jetty, gate) located using a satellite photo (Google-Earth ©) (Van Duin & Geerlings 2011). The calculations are applied using the Manhattan-distance metric system (Voet 2008).

This calculative system applies bottom-up calculation to the work activities performed at the port, using the amount of fuel consumption as a result of the calculation itself rather than an input variable. The container movement and ride activities are variable input in this type of calculation, where container movement is movement by means of a truck (an additional variable) over the distance calculated using the Manhattan-distance metric system, and ride is movement by means of a crane, stacking crane, rubber-tired gantry, or another implement.

The patterns of energy consumption for the various implements are shown in Table 2. Emissions were calculated from two different sources of energy: electricity and diesel fuel. The diesel emission factor was assumed at 2.65 kg/liter, based on the calorie (42.9 MJ/kg) and diesel emission factors (74.3 kg/GJ) combined with a density of 0.835 kg/dm^3 at the temperature of 15°C. Regarding electricity, CO_2 emissions were assumed to be 0.832 kg/kWh (The Ministry of Energy and Mineral Resources Republic of Indonesia. 2016).

Table 2 Energy consumption per type of equipment

Type of Equipment	Variable Consumption
Quay Crane	6.00 kWh/move; 2.77 l/move
Ship to shore	6.70 kWh/move
Automated Stacking Crane	5.00 kWh/move
Rubber-tired Gantry	1.32 l/move
Straddle Carrier	3.50 l/km; 0.80 l/move
Terminal Tractors	3.23 l/km
Automated Terminal Tractor	1.67 l/km
Reach Stacker/Top Lifter	5.00 l/km

Sources: (Van Duin & Geerlings, 2011; Vasanth et al. 2012; Wilmsmeier & Spengler, 2016)

The total CO_2 emissions at a container terminal can be calculated using the total emissions produced by the combination of various equipment and their contribution to the sub-processes of the movement to the other modalities.

$$W_x = \sum_{i=1}^{5} \sum_{J=1}^{1} \left((v_{i,j} \times f_D) + (P_{i,j} \times f_E) \right)$$

where

W_x: $Total\ weight\ of\ CO_2\ emission\ produced\ at\ terminal$
V_{ij}: $Yearly\ consumption\ of\ diesel\ in\ lit\ with\ equipment\ i\ to\ modality\ j$
f_D: $Emission\ factor\ in\ kg\ of\ CO_2\ emission\ per\ lit\ diesel\ (=\ 2.65)$
P_{ij}: $Yearly\ power\ consumption\ in\ kWh\ for\ equipment\ i\ to\ modality\ j$
f_E: $Emission\ factor\ in\ kg\ of\ CO_2\ emission\ per\ kWh\ (=\ 0.832\ )$

Combining the equation above with the following equations,

$$V_{ij} = n_{ij} * \left(C_{ij} + c_{ij} + X_{ij} \right) \forall^{i,j} \in T$$
$$P_{ij} = n_{ij} * \left(p_{ij} \right) \forall^{i,j} \in T$$

where

$n_{i,j}$: $Number\ of\ rides\ with\ equipment\ i\ to\ modality\ j$
$C_{i,j}$: $Fixed\ usage\ (for\ example\ lifting\ operations)\ per\ ride\ in\ liters$

$c_{i,j}$: $Variable\ usage\ per\ km\ in\ liters$
$\bar{X}_{ij}$: $Distance\ travelled\ for\ equipment\ i\ to\ modality\ j$
p_{ij}: $Fixed\ usage\ per\ ride\ in\ KWh$

3. RESULTS AND DISCUSSION

The number of container transfers through each device at each container terminal becomes an important variable in this calculation. Table 3 shows the inventory data held by each container terminal regarding the number of rides/moves carried out by each device. In the terminal truck, the data needed is how much movement in carrying the container, in ideal conditions this number will be the same as the number of boxes in a year at the container terminal. In container cranes, the number of movements in ideal conditions is the overall total box during the export or import process. Then for rubber-tired gantry, the number of movements is the total box that is added to the total shifting that occurs during the export or import process. The same thing happens with reach stackers.

Table 3 Number of Rides in BICT

Equipment	Number of Rides
Terminal Truck	416,048
Container Crane	416,048
Rubber Tired Gantry	416,048
Reach stacker/Side Loader	208,024

The distance traveled by the instrument to move containers is also an important variable in calculating port operational emissions. Equipment that pass the distance into the calculation are the truck terminal and reach stacker/side loader. To calculate the distance traveled by the truck terminal, the researchers calculated the distance traveled from the ship's loading and unloading point in the container crane to the stacking yard at the point where the container will be handed over to the rubber-tired gantry. For reach stacker/side loader the distance is calculated by measuring the point between the corners of the container stacking yard.

Table 4 Distance Traveled in BICT

Equipment	Distance Traveled (km)
Terminal Truck	0.347
Reach stacker/Side Loader	0.085

The calculation of each implement's energy consumption started with the division of implements on the basis of their energy source (Table 2). In BICT, as there are no devices that operate with electricity, the energy consumption in one operating year is 2.237.069 liters of diesel as shown in Table 5.

Table 5 Energy Consumption

Equipment	BICT	
Terminal Truck	447,022	Liter
Container Crane	1,152,453	Liter
Rubber Tired Gantry	549,183	Liter
Reach stacker/Side Loader	88,410	Liter
Total	2,237,069	Liter

Table 6 shows the estimation results of CO_2 emissions production for all equipment operating in the BICT by multiplying the total energy consumption in diesel with the emission factor of diesel (2.65 kg/liter). The equipment component producing the largest amount of CO_2 was the container crane, producing 3,054,000.34 kg of CO_2 during a year's operation and requiring 2.77

liters of fuel for each container movement. That was followed by rubber-tired gantries producing 1,455,335.90 kg of CO_2 by moving 416,048 boxes and using 1.32 liters of fuel per move. Terminal trucks travelled an average of 0.347 km for each box and required 3.23 liters of fuel per kilometer to produce 1,184,608.95 kg of CO_2. Total emissions equaled 5,928,232.23 kg of CO_2 produced directly by the BICT, as all the implements used in the BICT were diesel-powered.

Table 6 Estimation results of CO_2 emissions

Equipment	Weight of CO2 estimation (kg)
Terminal Truck	1,184,608.95
Container Crane	3,054,000.34
Rubber Tired Gantry	1,455,335.90
Reach stacker/Side Loader	234,287.03
Total	5,928,232.23

After totaling a year produced CO_2 in kilograms, the result was divided by the throughput at each terminal to determine the amount of CO_2 per twenty-foot equivalent unit (TEU). To obtain the amount of CO_2 produced per TEU at the BICT, the total emissions were divided into the throughput, giving 526,039 TEUs. Therefore, for every TEU, the BICT produced as much as 11.27 kg of CO_2. These estimated results are comparably good when shown against results provided by Duin at European Container Terminals Delta, where the range of emission values was 9.33–14.88 kg (Van Duin & Geerlings 2011; van Duin et al. 2019).

Table 7 Actual results of CO_2 emissions

Equipment	CO_2 Emissions in a year (Kg)
Container Crane	4,711,020
Rubber-tired Gantry Crane	2,393,000
Reach Stacker	183,790
Side Loader	59,120
Head Truck	1,034,370
Total	8,381,300

Table 7 shows the CO_2 emission produced by BICT in actual condition based on energy consumption data provided by BICT. This data means to make comparison with the results of estimation condition as shown in Table 6.

Table 8 Comparison of Estimated and Actual Emissions

Condition	Total Emission (kg)	Emission per TEU (kg/TEU)
Estimation	5.928.232,23	11,27
Actual	8.381.300,00	15,93

As shown in Table 13, it can be seen that there are significant differences in each terminal. For BICT, there is a difference of 2.453.067,77 kg of CO2 which is contributed by the high energy consumption in container cranes and rubber-tired gantries. Actual emissions produced by container cranes are 54% greater than estimated, and rubber-tired gantries produce 64% greater actual emissions than estimated. This difference can occur due to the shifting done by both container cranes and rubber-tired gantries, or as a result of the movement of equipment that have to move places too often. Unfortunately, BICT does not carry out an inventory of the movements of each device, so it is difficult to find the exact cause of energy consumption that is very far from the estimated conditions that are attempted to be a benchmark ideal condition. In actual conditions, BICT operates for each TEU producing CO2 of 15,93 kg, there is a difference of 4,66 kg.

4. CONCLUSION

This research estimated port emissions, using ideal circumstances as its models, and determined that the emissions in the BICT were 11.27 kg of CO_2 per TEU. The estimation of CO_2 emission production with the models under ideal circumstances is a description for ports, which informs them whether operations are close to ideal. The results of this research can easily be compared to results calculating of actual CO_2 emission production, making it possible to compare CO_2 emission production from certain implements. This information indicates the range of operational matters that should be performed by an implement to minimize CO_2 emission production, causing port operational costs to shrink.

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6. REFERENCES

Ariztegui, J., Casanova, J., Valdes, M., 2004. A Structured Methodology to Calculate Traffic Emissions Inventories for City Centres. *Science of. Total Environment,*. Volume 334–335, pp. 101–109

Berechman, J., Tseng, P.H., 2012. Estimating the Environmental Costs of Port Related Emissions: The Case of Kaohsiung. *Transportation. Research Part D: Transport Environment*, Volume 17(1), pp. 35–38

Bergqvist, R., Macharis, C., Meers, D., Woxenius, J., 2015. Making Hinterland Transport More Sustainable a Multi Actor Multi Criteria Analysis. *Research in Transportation Business and Management*, Volume 14, pp. 80–89

Bergqvist, R., Monios, J., 2019. *Green Ports in Theory and Practice*. Elsevier Inc.

Budiyanto, M.A., Nasruddin, Zhafari, F., 2019a. Simulation Study using Building-Design Energy Analysis to Estimate Energy Consumption of Refrigerated Container. *Energy Procedia*, Volume 156, pp. 207–211

Budiyanto, M.A., Shinoda, T., 2018. The Effect of Solar Radiation on the Energy Consumption of Refrigerated Container. *Case Studies in Thermal Engineering*, Volume 12, pp. 687–695

Budiyanto, M.A., Shinoda, T., Nasruddin, 2017. Study on the CFD Simulation of Refrigerated Container. *In:* IOP Conference Series: Materials Science and Engineering, Volume 257(Conference 1)

Budiyanto, M.A., Shinoda, T., Sunaryo, Nugroho, F.A., Wibowo, B., 2018. Estimated of Energy Saving from the Application of Roof Shade on the Refrigerated Container Storage Yard. *J. Adv. Res. Fluid Mech. Therm. Sci.* Volume 46(1)

Budiyanto, M.A., Sunaryo, Fernanda, H., Shinoda, T., 2019b. Effect of Azimuth Angle on the Energy Consumption of Refrigerated Container. *Energy Procedia*. Volume 156, pp. 201–206

Cullinane, K., Cullinane, S., 2019. Policy on Reducing Shipping Emissions : Implications for " Green Ports". *Green Ports: Inland and Seaside Sustainable Transportation Strategies* 2019, pp. 35–62

Davarzani, H., Fahimnia, B., Bell, M., Sarkis, J., 2016. Greening ports and Maritime Logistics:

A Review. *Transportation Research Part D: Transport and Environment,* Volume 48, pp. 473–487

Giuffre, O., Grana, A., Giuffre, T., Marino, M., 2011. Emission Factors Related to Vehicle Modal Activity. *International Journal of Sustainable Development and Planning,* Volume 6(4), pp. 447–458

Huboyo, H.S., Andarani, P., Hadiwidodo, M., 2018. *Inventarisasi dan Sebaran Emisi Aktivitas Pelabuhan dengan Aermod View* (Inventory and Distribution of Port Activity Emissions with Aermod View). *Jurnal Presipitasi Media Komunikasi dan Pengembangan Teknik Lingkungan,* Volume 15(1), pp. 31–35

Lam, J.S.L., Notteboom, T., 2014. The Greening of Ports: A Comparison of Port Management Tools Used by Leading Ports in Asia and Europe. *Transport Reviews,* Volume 34(2), pp. 169–189

Majid, Z.A., Mohsin, R., Nasri, N.S., 2016. Effect of Bioethanol on Engine Performance and Exhaust Emissions of a Diesel Fuel Engine. *International Journal of Technology.* Volume 7(6), pp. 972–980

Mubarak, A., Zainal, F., 2018. Development of a Framework for the Calculation of CO_2 Emissions in Transport and Logistics in Southeast Asia. *International Journal of Technology.*, Volume 9(4), 99. 787–796

Roh, S., Thai, V.V., Wong, Y.D., 2016. Towards Sustainable ASEAN Port Development: Challenges and Opportunities for Vietnamese Ports. *The Asian Journal of Shipping. Logistics,* Volume 32(2), pp. 107–118

Said, N.H., Ani, F.N., Said, M.F.M., 2018. Emission and Performance Characteristics of Waste Cooking Oil Biodiesel Blends in a Single Direct Injection Diesel Engine. *International Journal of Technology,* Volume 9(2), pp. 238–245

Samiaji, T., 2011. *Gas* CO_2 *Di Wilayah Indonesia* (CO_2 Gas in Indonesian Territory). *Berita Dirgantara LAPAN,* Volume 12(2), pp. 68–75

The Ministry of Energy and Mineral Resources Republic of Indonesia. 2016. Study of Use of Local Emission Factors (Level 2) in the Energy Sector GHG Inventory. Center for Data and Information Technology, Ministry of Energy and Mineral Resources. Jakarta

van Duin, J.H.R., Geerlings, H., Tavasszy, L.A., Bank, D.L., 2019. Factors Causing Peak Energy Consumption Of Reefers At Container Terminals. *Journal of Shipping and Trade*. Volume 4(1)

Van Duin, J.H.R., Geerlings, H., 2011. Estimating CO^2 Footprints of Container Terminal Port-Operations. *International Journal of Sustainable Development and Planning,* Volume 6(4), pp. 459–473

Vasanth, M., Chowhan, S., Hiremath, A.M., Asolekar, S.R., 2012. Carbon Footprinting of Container Terminal Ports in Mumbai. *In:* International Conference on Impact of climate change on Food, Energy and Environment

Voet, M van der. 2008. *CO^2-Emissions by Container Transshipment Processes in the Rotterdam Port. A Method for CO^2-Emissions from Transshipment Processes in the port of Rotterdam in Identifying and Impact of Proposed Policies and Knowledge to make (in Dutch).* Master's thesis, Delft University of Technology

Wilmsmeier, G., Spengler, T., 2016. Energy Consumption and Energy Efficiency Indicators in Container Terminals-a National Inventory. *In:* Conference: IAME 2016, At Hamburg

Yang, Y.C., Chang, W.M., 2013. Impacts of Electric Rubber-Tired Gantries on Green Port Performance. *Research in Transportation Business & Management,* Volume 8, pp. 67–76

Zhang, Y., Peng, Y.Q., Wang, W., Gu, J., Wu, X.J., Feng, X.J., 2017. Air Emission Inventory of Container Ports' Cargo Handling Equipment with Activity-Based "Bottom-Up" Method. *Advances in Mechanical Engineering,* Volume 9(7), pp. 1–9