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Freight consolidation and containerization strategy under business as usual scenario & carbon tax regulation

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ABSTRACT

With the increase of greenhouse gasses and climate change, international regulators faced a challenging task in determining carbon footprint regulations. With global greenhouse gas emissions from maritime logistics accounts for about 2.5%, this study would take to account for shipment containerization strategies under carbon tax regulation to explore the influence of carbon tax regulation on maritime logistics carbon emission reduction. The motivation of this study comes from a real case example of freight consolidation and containerization problem (FCCP) in Indonesia. This study tries to model an actual problem faced by a third-party logistics provider in consolidating goods into various sizes of containers while keeping the total transportation costs as low as possible. The most significant contributions of this study are to incorporate environmental factors into the FCCP model and to illustrate the impacts of various carbon footprints schemes on both cost and carbon emissions. Therefore, shipment containerization strategies under various carbon footprints schemes are formulated to minimize the transportation costs, as well as to lower the amount of carbon emission from maritime and land transport modes. The methodology used is a case-based approach; it depicts product delivery activities from one origin hub in Kaohsiung, Taiwan, to the biggest retailer stores in Jakarta, Indonesia. The aim is to incorporate environmental factors and illustrate how the proposed policy balances both cost and carbon emissions. Under the proposed policy, a new mixed-integer programming model is introduced considering the freight consolidation and containerization problem. Based on the different groups of numerical results, we found that the shipment containerization strategy under carbon tax regulation gives a better outcome in terms of total transportation cost and total carbon emissions compared with the business as usual policy.

1. Introduction

Most of the international trade rely on the maritime transport system, and according to the report of The International Maritime Organization, we knew that the maritime transport system carries over 90% of the world's trade volume. With the annual growth, volume, continue to increase in the past 20 years. Psaraftis and Kontovas (2009) found that container-ships were the largest maritime carbon emission emitters, which caused environmental problems such as climate change. Organizations such as the European Union, United Nations and many other countries like China, Korea are also taking actions to alleviate carbon emissions by legislation and carbon reduction mechanisms for environmental protection. Maritime transport sector need consider the adaptation to climate change and environmental sustainability (Wang et al., 2019; Monios and Wilmsmeier, 2020; Di Vaio et al., 2020). Psaraftis and Kontovas (2010) summarized the methods to reduce carbon emissions: (1) technical measures such as energy-saving engines and more efficient propulsion; (2) emissions trading schemes; (3) carbon levy schemes; (4) operational options schemes including speed optimization, optimized routing, etc. Balancing the economic and reducing the carbon emission simultaneously is a changing issue both for government and ship liners.

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Containerization provides many advantages for maritime transportation mode for reducing the transportation cost (Li et al., 2007), which is essential in modern logistics system due to its central role in hastening the delivery process and reducing logistics cost. As introduced by Qin et al. (2014), the complexity of maritime freight transport has led to the development of numerous logistics problems. One of them is freight consolidation and containerization problem (FCCP). FCCP models an actual problem faced by third-party logistics (3 PL) companies where they need to consolidate and ship the goods into various sizes of containers, then deliver them to different destination ports located abroad. Hence, a shipment of goods destined for a particular store can take some possible routes. Later on, an express delivery company will unload the shipments at the destination ports and distribute them to retailer stores by parcel delivery.

In the present time where environmental awareness becomes an outcry for the green movement, minimizing carbon emission is as essential as minimizing total cost. The original FCCP model may give the lowest transportation cost. However, its capability to ensure that it provides the lowest amount of emission is not guaranteed since no environmental factors are added to its formulation. Hence, this study proposes a shipment containerization strategy under carbon tax regulation, which helps the companies to decide the types of container and truck that should be chosen so that it could balance both cost and emission under the referred policy.

The motivation of this study comes from a real case example of freight consolidation and containerization problem (FCCP) in Indonesia. This study tries to model an actual problem faced by a third-party logistics provider in consolidating goods into various sizes of container while keeping the total transportation costs as low as possible. The most significant contributions of this study are to incorporate environmental factors into FCCP model and to illustrate the impacts of various carbon footprints schemes on both cost and carbon emissions. Therefore, shipment containerization strategies under various carbon footprints schemes are formulated to minimize the transportation costs, as well as lowering the amount of carbon emission from maritime and land transportation modes. The methodology used is a case-based approach; it depicts product delivery activities from one origin hub in Kaohsiung, Taiwan to the biggest retailer stores in Jakarta, Indonesia. Generally, the Freight Consolidation and Containerization Problem (FCCP) did not consider the emission factor to their objective function. The purpose is to minimize the total cost (container cost and parcel delivery cost). Therefore, we included the emission factor by incorporating some examples from international policies on restraining the increase of emission (through a carbon tax, carbon cap, and both).

The contributions of this study are listed as follows. Firstly, this study expands the previous research by Qin et al. (2014) where environmental factors are considered in the proposed models. Secondly, this study applies the proposed models in a real-world business case to show its effectiveness in lowering CO_2 emissions under the carbon tax scheme. Thirdly, this study compares the business as usual (BAU) scenario and carbon tax scenario. Under these scenarios, the trade-off value between cost and carbon emission can be determined by consolidating goods into appropriate containers and truck sizes. This study will help the administrator for design the carbon tax regulation. Lastly, this study discusses and analyses the sensitivity analysis of each parameter changes in each model scenario.

The rest of this study is organized as follows. Section 2 introduces the related works. The proposed mathematical models are formulated in section 3. Section 4 gave the experimental results, and finally, the conclusions and feature studies are described in the last section.

2. Literature review

In this section, we divided the related works into three parts including the green logistics related to maritime logistics, shipment containerization and carbon tax, which are introduced as follows.

2.1. Green logistics

Green logistics aims to minimize the damage to the environment, which is generated during the logistics operation process. In the following, the study related to reducing the carbon emissions, which are generated during the logistics operation process, is summarized. Leonardi and Browne (2010) proposed a method to calculate the carbon footprint of international supply chains, focusing on maritime freight transport. Peters et al. (2011) studied the future emissions from shipping and petroleum activities in the Arctic. Wygonik and Goodchild (2011) minimized the emissions of the pickup and delivery system with time windows constraint and evaluated the trade-off between cost, emissions, and time windows. The result of the study of Wygonik and Goodchild (2011) showed that there is no trade-off between CO_2 emissions and cost. Rizet et al. (2012) analysed the relationship between vehicle load, energy efficiency, and CO_2 emissions. Jiang et al. (2012) measured the CO_2 emissions and fuel inputs of the river-sea in ports of China with a case study of Shanghai Port, and they found that increasing the proportion of river-sea transportation to a reasonable level can obtain emission reduction and economic benefits. Küçükoğlu et al. (2013) proposed a fuel consumption optimization model of green capacitate vehicle routing problem. Pan et al. (2013) explored the greenhouse gas emissions impact of merging supply chains with real data from two main French retail chains, and they found that merging supply chains can reduce the carbon emissions. Molina et al. (2014) proposed a three-objective model including total internal costs, CO_2 emissions and another emission of air pollutant to formulate vehicle routing problems with a heterogeneous fleet. Aksoy et al. (2014) proposed a CO_2 emission calculation and fuel consumption model for supply chain management, which was an effective tool to calculate CO_2 emission and fuel consumption. Galos et al. (2015) analysed two heavy goods vehicle fleets operating in the United Kingdom and proposed a systematic approach to identifying trailers suited to lightweight, which will benefit the double-deck and walking-floor trailers. Lindstad et al. (2015) proposed a three-layered and damage-based approach for maritime shipping and emissions. Zhou and Lee (2017) studied a green vehicle routing problem to minimize greenhouse gas emissions by considering various realistic factors including three-dimensional customer locations, gravity, vehicle speed, etc. Recently, Fathollahi-Fard et al. (2019) studied a green home health care supply chain and proposed a novel simulated annealing method to solve it. Giallanza and Puma (2020) studied a fuzzy green vehicle routing problem exploring how to design a three echelons supply chain. Ganji et al. (2020) studied a green multi-objective problem considering scheduling of production and distribution to minimize various costs including fixed and variable fuel costs, the carbon emitted by the vehicles, total delivery tardiness, distribution cost, and customer dissatisfaction. Poonthalir et al. (2020) devised green routing solution for mobile advertisement vehicle to minimize route cost and carbon emission with considering speed constraint.

2.2. Shipment containerization

Shipment containerization is a modern, suitable, reliable and one of the efficient methods of transporting freight by placing it in large containers which ensures cargo safety, reduces transshipment time, and saves transport and storage expenses. In freight consolidation, low volume cargo is bundled into larger flows by moving to a consolidation center, and they are transported together by multimodal services. Dror and Hartman (2007) and Leung et al. (2009) have previously worked on freight consolidation, which plays an essential role in logistics management and can be divided into two categories based on the decisions made on a strategic level or operation level. In the study, the containerization related to maritime logistics is reviewed. Notteboom and Rodrigue (2009) investigated a series of issues, which can accelerate the adoption of containerization worldwide for logistics systems and global commodity chains in feature from maritime and inland freight distribution. SteadieSeifi et al. (2014) surveyed the multi-modal freight transportation planning in which the consolidation system was introduced. Qin et al. (2014) introduced the freight consolidation and containerization problem in the context of the transportation of textile products, which were loaded into containers that are then shipped to different possible hubs; from where they are sent to their final destinations. Melo and Ribeiro (2015) reformulated the freight consolidation and containerization model of the study of Qin et al. (2014) and their approach-aggregated items and later uses mixed-integer programming techniques to solve it. Nasiri et al. (2017) applied meta-heuristics, including red deer algorithm, genetic algorithm, hybrid genetic algorithm, simulated annealing, hybrid simulated annealing, and stochastic fractal search to solve the freight consolidation and containerization problem. Hanbazazah et al. (2019) proposed a mixed integer programming model for a transportation problem with freight consolidation by considering piece-wise costs and delivery time windows, which was solved by a three-phase exact solution method. Recently, Liu et al. (2020) defined a green degree of ships concept to evaluate the environmental impact of ships.

2.3. Carbon tax

Carbon taxes are a tax levied on the carbon content of fuels. This include motor gasoline, diesel, jet fuel, etc. in the form of carbon pricing, which can be considered as a pollution tax. Carbon taxes have been frequently advocated and implemented as a cost-effective instrument in responses to commitments under the United Nations Framework Convention on Climate Change. Ming et al. (2014) found that ocean freight was estimated to contribute 4–5% of global carbon emissions. Sikorska, P. E. (2015) investigated the necessity of legal regulation of global emissions from the aviation industry. Baranzini et al. (2000) studied carbon taxes by considering their competitiveness, distributional and environmental impacts. Kim et al. (2013) optimize the ship speed, fleet size, and chartered ship number with consisting of a carbon tax and an emission trading scheme. Tsai et al. (2013) studied the integration of activity-based costing volatility, considering the organic compounds emissions cost, which is taxed at different emission rates. Lee et al. (2013) quantitatively analysed the effects on the global economy of a maritime carbon tax on international container shipping. They found that China will suffer the greatest real GDP loss among all countries, and it will discourage distant container trade. Fahimnia et al. (2013) evaluated the impacts of carbon pricing on both a forward and a closed-loop supply chain in an Australian case study. They found that government may subsidize carbon costs incurred via reverse supply chain operations and corporations need to understand the level of 'scope' when determining carbon footprints. Fahimnia et al. (2015a) proposed a bi-objective mixed integer non-linear programming model for green supply chain planning to explore the impacts of a carbon tax policy scheme on the financial and emissions reduction performance of supply chains. Fahimnia et al. (2015b) investigated the trade-off between supply chain cost and environmental degradation, including carbon emissions, energy consumption and waste generation. Vera and Sauma (2015) analysed whether carbon tax can make a high potential for energy efficiency and compared the reducing-emissions effects of the carbon tax and energy efficiency. Cui and Notteboom (2017) studied vessels and port operations for emission control in port areas under the assumption that the government imposes a certain emission tax on it. Rotaris and Danielis (2019) investigated the willingness to pay for a carbon tax in Italy and given some suggestions on how to properly design a carbon tax.

3. Problem definitions and formulations

3.1. Problem definition

In this study, the delivery process done by 3 PL via maritime transportation is called long transportation mode while parcel delivery activity through land transportation is called short transportation mode. Original FCCP model does not separate these two terms clearly since they assume that once an item is assigned to a shipping route, its parcel delivery cost has been determined. We also follow the aggregation of items into shipments, as previously done by Melo and Ribeiro (2015). Therefore, instead of items, this study will use the term "shipment" as a single, indivisible unit formed by many items with similar characteristics and properties. This provision, however, only applies in long transportation mode.

For long transportation, it begins with sets of shipment with each of their weight w_s, and volume size ν_s. Later, these shipments will be loaded into various sizes of the container j with properties such as price p_j, tare weight w_j, cubic capacity V_j, payload capacity W_j, and emission factor e_j. Each shipment characteristics influence the selection of container j. There are two decision variables in long transportation mode. Firstly, x_{sj} denotes a binary decision variable, which will equal to 1 if a shipment s is loaded into container j. Otherwise, it equals to 0. Secondly, q_j denotes the quantity of container j. Altogether, these two decision variables influence the amount of fuel consumption, fuel costs and the amount of CO_2 emissions.

There are two activities in short transportation mode: (1) sending shipments from port to the distribution center (DC); (2) delivering all types of the item based on the demand number from DC to each retailer stores. From port to DC, two decision variables are taken into account: x_{st} denotes a binary decision variable, which will equal to 1 if the shipment s is loaded into the truck t, otherwise it equals to 0; Secondly, q_t denotes the quantity of truck t used to send the shipments to DC. Altogether, these two-decision variables influence the amount of fuel used, total costs of both trucks and fuels and the amount of CO_2 emissions. As for delivery activities from DC to each retailer stores, two decision variables are also considered: x_{itr} denotes a binary decision variable which will be equal to 1 if item type i is loaded into truck t then sent to retailer r, and 0 otherwise; and secondly, q_{tr} denotes the quantity of truck t used to send the goods to retailer r.

In short transportation mode, the truck is used as the main transportation mode. Each truck has several attributes, such as price p_t, tare weight w_t, cubic capacity V_t, payload weight W_t, fuel consumption factor o_t, and truck emission factor e_t. Same as long transportation mode, the selection of truck type t is heavily influenced by each item's characteristics and amount of demand each retailer orders. Seven classes of the truck are considered in this study, and later on, it should carry sets of the item i with each of their weight w_i and volume size ν_i characteristics. This study omits the formula for parcel delivery cost from the previous study (symbolized by r_{ij}) and changes it to become short transportation mode costs. In the end, this study adopts a slightly different hub and spoke network model. Fig. 1 shows an overall transportation network model. In this example, items are containerized at Kaohsiung Port and shipped to Tanjung Priok Port. The shipments are then trucked to the distribution center from where each item is transported to its destination (retailers).

3.2. Assumptions & notations of the model

Before introducing the detail of the mathematical model, the parameters, notations, and decision variables used in this study are listed as follow.

Set and indices	
i	Index of items
j	Index of containers
r	Index of retailers
t	Index of trucks
s	Index of shipment
I	Set of items. $\|I\|$ denotes the cardinality of I.
J	Set of containers. $\|J\|$ denotes the cardinality of J.
R	Set of retailers. $\|R\|$ denotes the cardinality of R.
S	Set of shipments. $\|S\|$ denotes the cardinality of S.
T	Set of trucks. $\|T\|$ denotes the cardinality of T.
Notations	
q_i	quantities of item type i shipped (unit)
B_j	payload weight of container type j (ton/unit)
M	mileage between origin hub to destination hub (km)
md	mileage between destination hub to the distribution center (km)
B_t	payload weight of truck t (ton/unit)
m_r	delivery mileage to each retailer r (km)
q_{ir}	quantities of item i which will be sent to retailer r (unit)
V_t	The capacity of the truck V_t
w_s	Weight of shipment
SP	speed of vessel (km/hour)
M	big number variable
b	average diesel fuel price per liter ($/liter)
e	energy conversion factor (MJ/ton.km)
f	fuel conversion factor (liter/MJ)
tc	carbon tax ($/ton.$CO_2$)
c_j	carbon emission factor of container type j (kg.CO_2/ton.km)
m_j	methane emission factor of container type j (kg.CH_4/ton.km)
n_j	nitrogen oxide emission factor of container type j (kg.N_2O/ton.km)
c_t	carbon emission factor of truck t (kg.CO_2/ton.km)
m_t	the methane emission factor of truck t (kg.CH_4/ton.km)
n_t	nitrogen oxide emission factor of truck t (kg.N_2O/ton.km)
LTC	Long Transportation Cost ($)
LTE	Long Transportation Emissions (ton.CO_2)
$STC1$	Short Transportation Cost 1 from port to DC ($)
$STE1$	Short Transportation Emissions 1 from port to DC (ton.CO_2)
$STC2$	Short Transportation Cost 2 from DC to retailer stores ($)
$STE2$	Short Transportation Emissions 2 from DC to retailer stores (ton.CO_2)
EC	Emissions cost
Decision variable	
q_j	A real number, which denotes the quantity of container j
x_{sj}	A binary number, which indicates a shipment s is loaded into container j or not
x_{st}	A binary number, which indicates a shipment s is loaded by truck t or not
q_t	A real number, which denotes the quantity of truck t
x_{itr}	A binary number, which denotes item type i is loaded into the truck t then sent to retailer r or not
q_{tr}	A real number, which denotes the quantity of truck t used to send the goods to the retailer r

The assumptions of the model are itemized as follows:

1. The carbon tax is already known.
2. Shipment is an indivisible unit in long transportation mode.
3. Trucks are not homogeneous with different capacity fuel consumption factors, emission factors, etc.
4. The delivery process is divided into two phases: the long transportation mode phase and the short transportation mode phase.
5. Maximum payload capacity is 95% of the original capacity value.

3.3. Model formulation of business as usual

The total cost of shipment containerization activities (Z) for business as usual scenario can be formulated as follows:

$$Minimize Z = LTC + STC\,1 + STC\,2 \tag{1}$$

$$LTC = \frac{e \times b \times m}{f}\left(\sum_{s=1}^{|S|}\sum_{j=1}^{|J|} w_s x_{sj} + \sum_{j=1}^{|J|} w_j q_j\right) \tag{2}$$

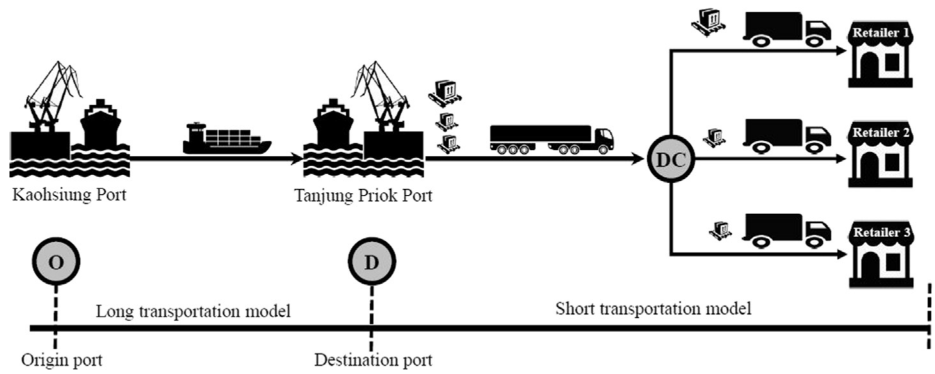

Fig. 1. Overall transportation networks model.

$$STC\ 1 = b \times md\left(\sum_{s=1}^{|S|}\sum_{t=1}^{|T|} w_s x_{st} o_t\right) \quad (3)$$

$$STC\ \ 2 = b\left(\sum_{i=1}^{|I|}\sum_{t=1}^{|T|}\sum_{r=1}^{|R|} w_i q_{ir} x_{itr} o_t m_r\right) \quad (4)$$

The objective function (1) minimizes the total cost of shipment containerization activities, which consists of three main parts: long transportation cost (LTC), short transportation cost from port to DC (STC 1) and short transportation cost from DC to retailer stores (STC 2). Here, the delivery process is separated into three parts: (i) long transportation, which involves the delivery of containers from origin hub to destination hub via ocean freight transportation; (ii) short transportation from unloading point (destination hub) to DC and (iii) short transportation from DC to each retailer store. Equation (2) is the long transportation cost, which covers the cost of moving both shipments and containers in maritime freight transportation. Equation (3) is the short transportation cost from port to DC, which includes the cost of moving the shipments only. Finally, equation (4) determines the short transportation cost from DC to retail stores, which covers the cost of moving items to the retailers. The objective function is then constrained as follows:

Subject to:

$$\sum_{j=1}^{|J|} r_j q_j \le CP_j; j \in \{1 \ldots |J|\} \quad (5)$$

where $r_1 = 1, r_2 = 2, r_3 = 2$

$$\sum_{j=1}^{|J|} x_{sj} = 1;\ \forall s \in \{1 \ldots 6\} \quad (6)$$

$$\sum_{t=1}^{|T|} x_{st} = 1;\ \forall s \in \{1 \ldots 6\} \quad (7)$$

$$\sum_{t=1}^{|T|} x_{itr} = 1;\ \forall i \in \{1 \ldots |I|\};\ \forall r \in \{1 \ldots |R|\} \quad (8)$$

$$\sum_{s=1}^{|S|} v_s x_{sj} \le V_j q_j;\ \forall j \in \{1 \ldots |J|\} \quad (9)$$

$$\sum_{s=1}^{|S|} v_s x_{st} \le V_t q_t;\ \forall t \in \{1 \ldots |T|\} \quad (10)$$

$$\sum_{i=1}^{|I|} v_i q_{ir} x_{itr} \le V_t q_{tr};\ \forall t \in \{1 \ldots |T|\},\ \forall r \in \{1 \ldots |R|\} \quad (11)$$

$$\sum_{s=1}^{|S|} w_s x_{sj} \le B_j q_j;\ \forall j \in \{1 \ldots |J|\} \quad (12)$$

$$\sum_{s=1}^{|S|} w_s x_{st} \le B_t q_t;\ \forall t \in \{1 \ldots |T|\} \quad (13)$$

$$\sum_{i=1}^{|I|} w_i q_{ir} x_{itr} \le B_t q_{tr};\ \forall t \in \{1 \ldots |T|\},\ \forall r \in \{1 \ldots |R|\} \quad (14)$$

Constraint (5) demands that the capacity of the New Panamax ship (where, $CP_j = 14000$ Twenty-foot Equivalent Unit/TEU) should not be violated. Since the capacity of the vessel is measured based on how many quantities of 20 ft container it could carry, hence constant ratios for 20 ft, 40 ft, and 40 ft HC (consecutively r_1, r_2, and r_3) are included. Constraint (6) and (7) enforce that each shipment s should be loaded into exactly one type of container j and exactly one type of truck t. Constraint (8) ensures that each item i can only be loaded into exactly one type of truck t and delivered to exactly one retailer r. Constraints (9), (10) and (11) demand that cubic capacity limitation for both container and truck are not exceeded. Constraints (12), (13) and (14) demand that payload weight limitations for both container and truck are not exceeded.

3.4. Model formulation of carbon tax scenario

In this section, the shipment containerization model under a carbon tax is developed to determine the impact of carbon emissions factor on shipment containerization activities. In this scenario, every amount of emitted carbon will be charged at the rate of \$10 per ton.CO_2 (based on assumption and average tax rates across countries).

Long Transportation Emissions, LTE (ton.CO_2)

$$LTE = LTCE + LTME + LTNE \quad (15)$$

where

$$LTCE = \delta_1 \times m\left(\sum_{s=1}^{|S|}\sum_{j=1}^{|J|} w_s x_{sj} c_j + \sum_{j=1}^{|J|} w_j q_j c_j\right) \quad (16)$$

$$LTME = \delta_2 \times m\left(\sum_{s=1}^{|S|}\sum_{j=1}^{|J|} w_s x_{sj} m_j + \sum_{j=1}^{|J|} w_j q_j m_j\right) \quad (17)$$

$$LTNE = \delta_3 \times m\left(\sum_{s=1}^{|S|}\sum_{j=1}^{|J|} w_s x_{sj} n_j + \sum_{j=1}^{|J|} w_j q_j n_j\right) \quad (18)$$

Short Transportation Emissions 1 from port to DC, $STE1$ (ton.CO_2)

$$STE\ 1 = STCE\ 1 + STME\ 1 + STNE\ 1 \quad (19)$$

where

$$STCE\ 1 = \delta_1 \times md\left(\sum_{s=1}^{|S|}\sum_{t=1}^{|T|} w_s x_{st} c_t\right) \quad (20)$$

$$STME\ 1 = \delta_2 \times md\left(\sum_{s=1}^{|S|}\sum_{t=1}^{|T|} w_s x_{st} m_t\right) \quad (21)$$

$$STNE\ 1 = \delta_3 \times md\left(\sum_{s=1}^{|S|}\sum_{t=1}^{|T|} w_s x_{st} n_t\right) \quad (22)$$

Short Transportation Emissions 2 from DC to retailer stores, $STE2$ (ton.CO_2)

$$STE\ 2 = STCE\ 2 + STME\ 2 + STNE\ 2 \quad (23)$$

where

$$STCE\ 2 = \delta_1\left(\sum_{i=1}^{|I|}\sum_{t=1}^{|T|}\sum_{r=1}^{|R|} w_i q_{ir} x_{itr} c_t m_r\right) \quad (24)$$

$$STME\ 2 = \delta_2\left(\sum_{i=1}^{|I|}\sum_{t=1}^{|T|}\sum_{r=1}^{|R|} w_i q_{ir} x_{itr} m_t m_r\right) \quad (25)$$

$$STNE\ 2 = \delta_3\left(\sum_{i=1}^{|I|}\sum_{t=1}^{|T|}\sum_{r=1}^{|R|} w_i q_{ir} x_{itr} n_t m_r\right) \quad (26)$$

$$q_j, q_t, q_{tr} \geq 0;\ \forall j \in \{1\ldots|J|\},\ \forall t \in \{1\ldots|T|\},\ \forall r \in \{1\ldots|R|\} \quad (27)$$

$$x_{sj}, x_{st}, x_{itr} \in \{0,1\};\ \forall i \in \{1\ldots|I|\},\ \forall j \in \{1\ldots|J|\},\ \forall t \in \{1\ldots|T|\},\ \forall\ r \in \{1\ldots|R|\},\ \forall s \in \{1\ldots|S|\} \quad (28)$$

$$\delta_1 = \frac{1}{1000}, \delta_2 = \frac{25}{1000}, \delta_3 = \frac{298}{1000} \quad (29)$$

Equations (15), (19) and (23) show the formula to calculate long transport emissions, short transport emissions from port to DC, and short transport emissions from DC to retailers, respectively. Equations (16), (20) and (24) determine the amount of carbon emissions for both transportation modes. Equations (17), (21) and (25) determine the amount of methane emissions. Equations (18), (22) and (26) calculate the amount of nitrogen oxide. Equation (27) restricts that quantity of container and truck should be non-negative. Lastly, Equation (28) restricts that $x_{s,j}$, $x_{s,t}$, and $x_{i,t,r}$ are binary variables.

According to Brander (2012), it should be noted that by ratio, each methane (CH_4) emission has 25 times the global warming potential of carbon dioxide (CO_2); whereas nitrous oxide (N_2O) has 298 times the global warming potential of CO_2. Hence, it explains the use of constant value for methane (CH_4) and nitrous oxide (N_2O) emission calculations in Equations ((16), (17), (20), (21), (24) and (25). This scenario considers a carbon tax as a part of the cost functions related to the amount of carbon emission. The objective function of the proposed shipment containerization model under carbon tax scenario is presented as follows:

$$MinimizeZ = LTC + STC\ 1 + STC\ 2 + EC \quad (30)$$

where

$$EC = (LTE + STE\ 1 + STE\ 2) \times tc \quad (31)$$

The objective function (30) adds an additional cost variable, denoted as EC (emissions cost) where EC is defined in Equation (31) as the total amount of carbon tax (tc) to be paid for each ton of CO_2. The rest of the equations are the same as the business as usual scenario is given in Equations (2)–(29).

4. Experimental results and analysis

To verify the proposed mathematical models, we performed some numerical experiments. The following data has been used from the report of Hutahaean and Christina (2013):

- Items dimension, volume and weight
- Product Weight and Volume
- Shipments Volume and Weight
- Monthly Demand for Each Retailer
- Mileage from Distribution Center to Retailer Branches

4.1. Numerical analysis of BAU model

We used the data provided by the study of Coyle et al. (2010), Ashby (2013), Hutahaean and Christina (2013), National Research Council of The National Academies (2010) for the numerical analysis.

4.1.1. Measurement and specifications of each container type

Since this study considers the use of three types of container (20-feet standard, 40-feet standard and 40-feet high cube), hence the data related to the measurement and specifications of each container type are presented in Table 1 below.

In reality, 100% usage of both payload weight and cubic capacity is rarely the case due to packing issues and sizes of item. Therefore, it is assumed that the highest capacity fill shipment is 95% (for both payload and cubic capacity). See Table 2 below:

4.1.2. Container emission factor

Even in idle state (empty), containers are technically emitting greenhouse gases due to its tare weight being carried by vessels per nautical km. Hence, this study uses a formula proposed by Leonardi and Browne (2010) to calculate the general emission factor of 20 ft container vessels for three main GHGs: CO_2, CH_4, and N_2O. Based on some assumptions and previous data, the result is as follows:

1. CO_2 emission factor of 20 ft container = 0.02508 kg.CO_2/TEU.km

Table 1
Measurement and specifications.

	20-feet standard	40-feet standard	40-feet high cube
Tare weight (ton)	2.209	3.851	4.360
Max payload weight (ton)	28.1227	28.5763	28.5763
Cubic capacity (m^3)	33.1873	67.5923	76.0591

Source: Matson Navigation Company (as cited in Coyle et al., 2010)

Table 2
Measurement and specifications (95% utilization).

	20-feet standard	40-feet standard	40-feet high cube
Max payload weight (ton)	26.7166	27.1475	27.1475
Cubic capacity (m^3)	31.5279	64.2127	72.2561

Table 3
Comparing light duty vehicles with medium and heavy-duty vehicles (converted).

Greenhouse gases	Container emission factor		
	20 foot	40 foot	40-foot High Cube
CO_2	0.02508	0.05016	0.05518
CH_4	0.000001253	0.000002505	0.000002756
N_2O	0.000003767	0.000007534	0.000008288

2. CH_4 emission factor of 20 ft container = 0.000001253 kg.CH_4/TEU.km
3. N_2O emission factor of 20 ft container = 0.000003767 kg.N_2O/TEU.km

As different container types will emit a different amount of GHGs, Chong et al. (2014) proposed an emission ratio for each type (20-ft, 40-ft, and 40-ft HC) consecutively as 1: 2: 2.2 ratio. Therefore, the GHG emission factors per container type are presented in Tabel 3 as follows:

4.1.3. Shipments volume and weight

In long transportation mode, all items are categorized into six shipment groups which are based on similar attributes among them. The six shipment categories are: kitchen and dining, indoor and outdoor, stationery, clothes and textiles, edible/consumed goods and hygiene products. Each group category has its own weight and volume size as presented in Table 4 below.

4.1.4. Energy consumption and emissions factor

This section lists the energy consumption and carbon emissions factor for different types of freight transport mode. The data is presented in Table 5 as follows:

4.1.5. Truck classes and specifications

Measurement and specification regarding gross and empty weight, payload capacity, typical fuel consumed and cubic capacity for each truck class are presented in Table 6. The presented data has been converted into the appropriate unit that fits with the model.

The proposed mathematical models are solved by Lingo 9.0. The details of the experimental results and analysis are presented as follows:

4.1.6. Results and sensitivity analysis of BAU

The results obtained for business as usual scenario are listed as follows:

1. Quantities of container used = 6976.377 units of a 40-ft container

Table 4
Volume and weight for each shipment group.

Shipment category	Shipment volume (m^3)	Shipment weight (ton)
Kitchen and dining	46,929	1451
Indoor and outdoor	257,776	5561
Stationery	104,086	3713
Clothes and textiles	650	180
Edible/consumed goods	35,157	3423
Hygiene products	3374	796

Table 5
Energy and emissions factor for different freight transports.

Transport/vehicle mode	Energy	CO_2
	(MJ/metric ton-km)	(kg.CO_2/metric ton-km)
Ocean shipping – Diesel	0.16	0.015
Coastal shipping – Diesel	0.27	0.019
Barge – Diesel	0.36	0.028
Rail – Diesel	0.25	0.019
Articulated HGV		
(up to 55 metric tons) – Diesel	0.71	0.05
40 metric ton truck – Diesel	0.82	0.06
32 metric ton truck – Diesel	0.94	0.067
14 metric ton truck – Diesel	1.5	0.11

Source: Ashby (2013).

2. Quantities of truck used from port to DC = 14,062.19 units of class 7 trucks
3. Quantities of truck used from DC to retailers = 14,062.1142 units of class 7 trucks
4. Total cost = $ 560,387.73
   (a) Long transportation cost (LTC) = $ 509,874.80
   (b) Short transportation cost 1 (STC 1) = $ 22,144.44
   (c) Short transportation cost 2 (STC 2) = $ 28,368.49
5. Total emissions = 7960.579 ton.CO_2 per month
   (a) Long transportation emission (LTE) = 7789.023 ton.CO_2
   (b) Short transportation emission 1 (STE 1) = 75.2090 ton.CO_2
   (c) Short transportation emission 2 (STE 2) = 96.3477 ton.CO_2

The sensitivity analysis is performed by altering each parameter value by −20%, −10%, +10% and +20%. The objective of sensitivity analysis is to determine which parameters give significant impacts on both total cost and total emission. The degrees of significance are classified into four classes: significant (if the changes in cost and emission are around 11%–20% from its original value), moderately substantial (if the changes in cost and emission are around 1%–10% from its original value), slightly significant (if the changes in cost & emission are around 0.1%–0.99% from its original value) and insignificant (if the changes in cost and emission are lower than

Table 6
Comparing light duty vehicles with medium and heavy-duty vehicles (converted).

Truck Class	Empty Weight Range (kg)	Volume Capacity (m^3)	Typical Payload Capacity Max (kg)	Typical Fuel Consumed (liter/ton.km)	Emission Factor (kg.CO_2/ton.km)
1t	2041.164	5.4274	680.388	0.138306	0.36513
2a	2721.552	5.4274	1133.98	0.090558	0.23907
2b	2857.6296	8.937013	1678.29	0.090558	0.23907
3	3968.93	19.11387	2381.358	0.078327	0.20678
4	3968.93	31.85645	3288.542	0.055981	0.14779
5	4898.7936	31.85645	3946.25	0.060215	0.15897
6	6577.084	31.85645	5216.308	0.047984	0.12668

Source: National Research Council of The National Academies (2010)

0.1% or if there are no changes for both cost and emission at all). Hence, the total transportation cost and carbon emissions for every altered parameter value are presented in Table 7.

Table 7 shows the optimal total cost significantly increases as m and b increase and slightly increases as o_t and md increase. The rest of the other parameters (c_j, m_j, n_j, c_t, m_t & n_t) do not give any significant changes to the total cost. As for the total emissions, it slightly increases as n_j, c_t & md increases and significantly increases as c_j & m increase. The rest of the other parameter changes do not give any effects to total carbon emissions (o_t, n_t, m_j, m_t & b). It shows that total cost is significantly sensitive to parameters m & b; and slightly sensitive to o_t & md. Hence, it can be stated that total cost is sensitive to the changes in mostly all parameters except the changes in parameters c_j, m_j, n_j, c_t, m_t & n_t.

Also, for the total carbon emissions, it is slightly sensitive to parameters n_j, c_t and md; and highly sensitive to the changes in parameters c_j and m. The rest of the other parameter changes do not give any significant effect to total carbon emissions (o_t, n_t, m_j, m_t and b).

4.2. Numerical analysis for carbon tax scenario

For this scenario, the same data collection will be used from the previous ones. Additional data includes the carbon credit price (cp) for \$10 per ton.CO_2, carbon tax rate (tc) for \$10 per ton.CO_2, carbon cap (cc) = 7165 ton.CO_2 (10% lower than BAU scenario) and a penalty cost (pn) for \$113 per ton CO_2. As mentioned before, the refund price for excess permit is the same as the carbon tax (tc) = \$10 per ton.CO_2.

4.2.1. Results and sensitivity analysis of carbon tax scenario

The obtained results for shipment containerization strategy under the carbon tax scenario are presented as follows (tax = \$ 10):

1. Total cost = \$ 638,902.50
   (a) Long transportation cost (LTC) = \$ 514,676.4
   (b) Short transportation cost 1 (STC 1) = \$ 22,144.44
   (c) Short transportation cost 2 (STC 2) = \$ 28,368.49
   (d) Emission cost (EC) = \$ 73,713.16
2. Total emissions = 7371.316 ton.CO_2 per month
   (a) Long transportation emission (LTE) = 7199.759 ton.CO_2
   (b) Short transportation emission 1 (STE 1) = 75.2090 ton.CO_2
   (c) Short transportation emission 2 (STE 2) = 96.3477 ton.CO_2
3. Quantities of container used
   (a) 20-foot container = 1242.741 units
   (b) 40-foot container = 6366.202 units
4 Quantities of truck used from port to DC = 14,062.11 units of class 7 truck
5 Quantities of truck used from DC to retailers = 14,062.19 units of class 7 truck

Similarly, for this scenario also, the sensitivity analysis has been performed for various values of the carbon tax (see Table 8).

Table 8, shows that the total cost significantly increases as m and b increase; moderately increases as c_j increases, and slightly increases as o_t, and md increases. The rest of the parameters (m_j, n_j, c_t, m_t, and n_t) do not give any effects to the total cost. As for the total emissions, it slightly increases as parameters n_j, c_t, and md increase; moderately increases as c_j increases, and significantly increases as parameter m increases. The rest of the parameters (o_t, m_t, m_j, n_t, and b) do not give any effects to the total carbon emissions.

It shows that total cost is significantly sensitive to the changes in parameters m and b; moderately sensitive to the parameter c_j; and slightly sensitive to o_t & md. Hence, it can be stated that total cost is sensitive to the changes in mostly all parameters except the changes in parameters m_j, n_j, c_t, m_t, & n_t.

As for the total emissions (tax = \$10/ton.CO_2), it is slightly sensitive to the changes in n_j, c_t, and md; moderately sensitive to c_j; and highly sensitive to m. Parameters o_t, m_t, m_j, n_t, and b do not give any significant effect to total emissions.

Table 9 shows that the total cost significantly increases as m and b increase; moderately increases as c_j increases, and slightly

Table 7
Sensitivity analysis of total cost and emissions for BAU scenario.

Parameters	−20% changed		−10% changed		+10% changed		+20% changed	
	Total costs (\$)	Total emissions (ton.CO_2)	Total costs (\$)	Total emission (ton.CO_2)	Total costs (\$)	Total emission (ton.CO_2)	Total costs (\$)	Total emission (ton.CO_2)
c_j	560,387.7	6467.17	560,387.7	7209.45	560,387.7	8708.84	560,387.7	9451.11
m_j	560,387.7	7958.72	560,387.7	7959.65	560,387.7	7961.51	560,387.7	7962.44
n_j	560,387.7	7893.91	560,387.7	7927.27	560,387.7	7993.89	560,387.7	8027.25
o_t	550,285.1	7960.58	555,336.4	7960.58	565,439.0	7960.58	570,490.3	7960.58
c_t	560,387.7	7927.78	560,387.7	7944.18	560,387.7	7976.98	560,387.7	7993.38
m_t	560,387.7	7960.54	560,387.7	7960.56	560,387.7	7960.60	560,387.7	7960.62
n_t	560,387.7	7959.11	560,387.7	7959.85	560,387.7	7961.31	560,387.7	7962.05
m	458,412.8	6402.77	509,400.2	7181.68	611,375.2	8739.48	662,362.7	9518.38
md	555,958.8	7945.54	558,173.3	7953.06	562,602.2	7968.10	564,816.6	7975.62
b	451,043.8	7960.58	505,715.8	7960.58	615,059.7	7960.58	669,731.7	7960.58

Table 8
Sensitivity analysis of total cost and emissions (tax = $ 10).

Parameters	−20% changed		−10% changed		+10% changed		+20% changed	
	Total costs ($)	Total emissions (ton.CO_2)	Total costs ($)	Total emissions (ton.CO_2)	Total costs ($)	Total emissions (ton.CO_2)	Total costs ($)	Total emissions (ton.CO_2)
c_j	624,672.7	6379.184	631,972.0	6678.271	645,819.0	8062.964	652,680.1	8749.081
m_j	638,885.3	7369.597	638,893.9	7370.458	638,911.1	7372.176	638,919.7	7373.035
n_j	638,286.3	7309.694	638,594.5	7340.520	639,210.4	7402.112	639,518.7	7432.937
o_t	628,799.9	7371.316	633,851.2	7371.316	643,953.8	7371.316	649,005.1	7371.316
c_t	638,574.5	7338.513	638,738.5	7354.914	639,066.5	7387.717	639,230.5	7404.118
m_t	638,902.1	7371.275	638,902.3	7371.295	638,902.7	7371.336	638,902.9	7371.357
n_t	638,887.8	7369.847	638,895.1	7370.581	638,909.8	7372.050	638,917.2	7372.784
M	521,567.7	5931.364	580,235.1	6651.340	697,569.9	8091.292	756,237.3	8811.267
Md	634,323.2	7356.274	636,612.8	7363.79	641,192.1	7378.837	643,481.8	7386.357
B	528,621.6	7371.316	583,762.1	7371.316	694,042.9	7371.316	748,835.4	7851.441

Table 9
Sensitivity analysis of total cost and emissions (tax = $ 30).

Parameters	−20% changed		−10% changed		+10% changed		+20% changed	
	Total costs ($)	Total emissions (ton.CO_2)	Total costs ($)	Total emissions (ton.CO_2)	Total costs ($)	Total emissions (ton.CO_2)	Total costs ($)	Total emissions (ton.CO_2)
c_j	737,455.50	4682.20	752,537.90	4903.38	782,491.10	5901.82	797,438.40	6400.06
m_j	767,395.00	5398.61	767,413.80	5399.24	767,451.20	5400.48	767,469.90	5401.11
n_j	766,090.50	5355.13	766,761.00	5377.48	768,103.90	5422.24	768,774.40	5444.59
o_t	757,329.90	5399.86	762,381.20	5399.86	772,483.70	5399.86	777,535.00	5399.86
c_t	766,448.40	5367.06	766,940.40	5383.46	767,924.50	5416.26	768,416.50	5432.66
m_t	767,431.20	5399.82	767,431.80	5399.84	767,433.10	5399.88	767,433.70	5399.90
n_t	767,388.40	5398.39	767,410.40	5399.13	767,454.50	5400.59	767,476.50	5401.33
m	625,077.90	4354.20	696,255.20	4877.03	838,609.70	5922.69	909,787.00	6445.52
md	762,552.30	5384.82	764,992.40	5392.34	769,872.50	5407.38	772,312.60	5414.90
b	649,298.50	5399.86	708,365.50	5399.86	826,499.40	5399.86	885,566.40	5399.86

increases as o_t, and md increase. Other parameters (m_j, n_j, c_t, m_t, and n_t) do not give any effects to the total cost. As for total emissions, it slightly increases as n_j, c_t, and md increase; moderately increases as c_j increases, and significantly increases as m increases. Other parameters (o_t, m_t, m_j, n_t, and b) do not give any effects to total emissions.

The optimal total cost under parameter changes (for tax = $30/ton.$CO_2$) is depicted in Table 9. It shows that total cost is significantly sensitive to the changes in parameters m and b; moderately sensitive to the parameter c_j; and slightly sensitive to parameters o_t, and md. Hence, it can be stated that total transportation cost is sensitive to the changes in mostly all parameters except the changes in m_j, n_j, c_t, m_t and n_t.

As for the total emissions (tax = $30/ton.$CO_2$), it is slightly sensitive to the changes in parameters n_j, c_t and md; moderately sensitive to c_j; and sensitive to the parameter m. Hence, it can be stated that the total carbon emissions are sensitive to the changes in mostly all parameters except the changes in parameters o_t, m_t, m_j, n_t and b.

Table 10 shows that the total cost has significantly increased as m increases, moderately increased as c_j and b increase, and slightly increased as c_t, o_t, and md increase. The rest of the other parameter changes (m_j, n_j, m_t, and n_t) do not give any effects to the total cost. As for the total emissions, it has slightly increased as n_j, c_t, and md increase and significantly increased as c_j and m increase. The other parameter changes (m_j, o_t, m_t, n_t and b) do not give any effects to the total emissions.

The optimal total cost under parameter changes (for tax = $50/ton.$CO_2$) is depicted in Table 10. It shows that total cost is significantly sensitive to the changes in m; moderately sensitive to c_j, and b; and slightly sensitive to c_t, o_t, and md. Hence, it can be stated that total cost is sensitive to the changes in mostly all parameters except the changes in m_j, n_j, m_t, & n_t. Table 10 shows the recapitulation of significant changes for every parameter in three carbon tax rates (in the context of total cost). It can be stated that total cost is not affected by m_j, n_j, m_t, & n_t for every different tax rate. However, on the other hand, it is susceptible to m.

As for the total carbon emissions (tax = $50/ton.$CO_2$), it is slightly sensitive to the changes in parameters n_j, c_t, and md; and highly sensitive to the changes in parameters m & c_j (can be seen in Table 11 above). Therefore, it can be stated that the total carbon emissions is sensitive to the changes in mostly all parameters except the changes in parameters m_j, o_t, m_t, n_t & b.

Table 12 shows the recapitulation on the significant changes for every parameter in the three different carbon tax rates (in the context of total carbon emissions). It can be stated that the total carbon emission is not affected by some parameters, such as parameters o_t, m_t, m_j, n_t, & b for every different tax rates. However, the total carbon emission is very sensitive to m.

4.3. Comparison of BAU and carbon tax scenario

The following calculations are presented to determine the optimal scenario in terms of effectively and efficiently between the businesses as usual (BAU) and the proposed carbon tax policy.

Based on the emission differences between the two scenarios (see Table 13), it can be inferred that under carbon tax scenario, the total amount of carbon emissions can be minimized to its lowest amount at 5399.86 ton of CO_2 compared to business as usual scenario (7960.58 ton of CO_2). The results from the carbon tax scenario also indicated that the optimal carbon tax price to minimize the emissions is at $30. Beyond this tax rate, it will not lower total emission any-more (but it will continue to increase the total cost).

From the cost perspective (see Table 14), it can be inferred that

Table 10
Sensitivity analysis of total cost and emissions (tax = $ 50).

Parameters	−20% changed		−10% changed		+10% changed		+20% changed	
	Total costs ($)	Total emissions (ton.CO_2)	Total costs ($)	Total emissions (ton.CO_2)	Total costs ($)	Total emissions (ton.CO_2)	Total costs ($)	Total emissions (ton.CO_2)
c_j	825,617.70	4403.62	850,605.50	4903.38	900,527.50	5901.82	925,439.60	6400.06
m_j	875,367.20	5398.61	875,398.50	5399.24	875,460.80	5400.48	875,492.10	5401.11
n_j	873,193.00	5355.13	874,310.50	5377.48	876,548.80	5422.24	877,666.30	5444.59
o_t	865,327.00	5399.86	870,378.30	5399.86	880,480.90	5399.86	885,532.20	5399.86
c_t	873,789.50	5367.06	874,609.60	5383.46	876,249.70	5416.26	877,069.80	5432.66
m_t	875,427.60	5399.82	875,428.60	5399.84	875,430.70	5399.88	875,431.70	5399.90
n_t	875,356.20	5398.39	875,392.90	5399.13	875,466.40	5400.59	875,503.10	5401.33
m	712,161.90	4354.20	793,795.70	4877.03	957,063.50	5922.69	1,038,697.00	6445.52
md	870,248.70	5384.82	872,839.10	5392.34	878,020.10	5407.38	880,610.60	5414.90
B	757,295.70	5399.86	816,362.60	5399.86	934,496.60	5399.86	993,563.60	5399.86

Table 11
Significance degree of each parameter in various tax rates (cost).

Tax rates	Significance degree	Parameters
Carbon tax = $ 10	Significant	m, b
	Moderately significant	c_j
	Slightly significant	o_t, md
	Insignificant	m_j, n_j, c_t, n_t, m_t
Carbon tax = $ 30	Significant	m, b
	Moderately significant	c_j
	Slightly significant	o_t, md
	Insignificant	m_j, n_j, c_t, n_t, m_t
Carbon tax = $ 50	Significant	m
	Moderately significant	b, c_j
	Slightly significant	c_t, o_t, md
	Insignificant	m_j, n_j, n_t, m_t

Table 12
Significance degree of each parameter in various tax rates (emissions).

Tax rates	Significance degree	Parameters
Carbon tax = $ 10	Significant	M
	Moderately significant	c_j
	Slightly significant	n_j, c_t, md
	Insignificant	o_t, m_t, m_j, n_t, b
Carbon tax = $ 30	Significant	M
	Moderately significant	c_j
	Slightly significant	n_j, c_t, md
	Insignificant	o_t, m_t, m_j, n_t, b
Carbon tax = $ 50	Significant	m, c_j
	Slightly significant	n_j
		c_t, md
	Insignificant	o_t, m_t, m_j, n_t, b

the BAU scenario will give higher total transportation costs since its carbon emission is higher than the ones from carbon tax scenario. Hence, the higher tax rate in the BAU scenario will also cause higher total transportation costs (parallel to each other). Since the shipment containerization strategy under carbon tax scenario has already considered tax rate value, hence the amount of emission is lower than the BAU scenario, thus also lowering the total transportation cost.

4.4. Managerial implications and benefit of the proposed model

We have shown that the formulated shipment containerization models will benefit most companies especially the 3 PL providers in forecasting their expenses for transportation and delivery. The models can provide managerial insights in foreseeing what decisions to take if the local government or international law implements one of the three-carbon regulations. This will enable the enterprise to make a contingency plan based on the carbon regulations in order to obtain the optimum outcomes. Results of our analysis shows that a higher carbon tax will result in higher total cost but will cause lower carbon emissions. Under carbon tax scenario, it provides a balanced trade-off between (lowest) cost and (lowest) emissions. This study will help to foresee what decisions companies should take if one of those three carbon regulations is implemented by local government or internationally. Therefore, they can make a contingency plan based on the carbon regulations in order to obtain the most optimum outcomes.

Another benefit of the models is the result of the detailed consideration not only the type of items, containers, and trucks; but also, its quantities, payload capacities, fuel consumption, and other factors that are usually ignored by most studies. By incorporating these factors, it could capture the real-life condition into the model. Hence, the results would be more accurate and precise.

The last benefit is the adaptability and ease of application attributes of the models for both companies and the local governments who have the authority to set the emission regulations. Using these models, local governments could determine a standard/average tax rate; they can predict the expected outcomes of the regulation set. Corporations or industries could also use this model to foresee and calculate their optimal expense.

5. Conclusions and future studies

According to the report of Olmer et al. (2017), we knew that the ship emissions are expected to increase in both absolute terms and shipping's share of global CO_2 and GHG emissions. Cames et al.

Table 13
Emission differences under various carbon tax rates.

Carbon tax rates	Emission from each tax rate	BAU emission	Emission differences
10	7371.32	7960.58	589.26
20	6628.06	7960.58	1332.52
30	5399.86	7960.58	2560.72
40	5399.86	7960.58	2560.72
50	5399.86	7960.58	2560.72

Table 14
Cost differences under various carbon tax rates.

Carbon tax rates	Cost from each tax rate	BAU cost + carbon tax
10	638,902.50	560,387.73 + (10 × 7960.58) = 639,993.53
20	710,716.10	560,387.73 + (20 × 7960.58) = 719,599.33
30	767,432.40	560,387.73 + (30 × 7960.58) = 799,205.13
40	821,431.00	560,387.73 + (40 × 7960.58) = 878,810.93
50	875,429.60	560,387.73 + (50 × 7960.58) = 958,416.73

(2015) forecasted that the international shipping sector could account for 17% of global CO_2 emissions in 2050. At this moment, it is urgent to set out strategies to reduced carbon emissions from the shipping industry. In this study, to reduce the carbon emissions, the carbon tax regulation is studied by extending the freight/shipment consolidation, and containerization problem with minimizing the carbon emission and total transportation cost simultaneously. We assumed that the carbon tax is already given. To explore the influence of the carbon tax regulation, business as usual scenario is adopted as a benchmark policy. We then compare the performance and effectiveness of both scenarios in terms of cost and as well as carbon emission. Parameters provided by the previous study is adopted. Sensitivity analysis of total cost and emissions was conducted with a different group of parameters of the carbon tax. From the numerical results, we found that the shipment containerization strategy under carbon tax regulation gives a better outcome in terms of total transportation cost and total carbon emissions compared with the business as usual policy.

Further studies can be considered in the following parts: (i) consider stochastic problems where some of the defined parameters can either be variables or stochastic; (ii) consider the relationship between parameters (using design of experiments) by changing two parameter values instead of one in the same time; (iii) modify the model under BAU scenario, in order to solve shipment containerization problems with multiple shipping routes instead of only one route; (iv) optimize the parameter of carbon tax; (v) inspired by the studied of Zhou and Kim (2019), when design carbon tax the administrator can give some discount when the carbon emission is lower than a predefined threshold and give penalty when the carbon emission is greater than the predefined threshold.

CRediT authorship contribution statement

Sunil Tiwari: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Numerical analysis, Validation, Visualization, Funding acquisition. **Hui Ming Wee:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Supervision, Data curation. **Yanjie Zhou:** Writing - review & editing, Validation. **Leonardo Tjoeng:** Writing - original draft, Data curation, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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