The effects of carbon tax on inventory and land multimodal integration

T Ardliana\textsuperscript{1,2,*}, I N Pujawan\textsuperscript{2} and N Siswanto\textsuperscript{2}

\textsuperscript{1}Design and Manufacturing Engineering, Politeknik Perkapalan Negeri Surabaya, Surabaya, 60111, Indonesia
\textsuperscript{2}Department of Industrial and Systems Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia

*ardlianathina@gmail.com

Abstract. Climate change has contributed in extreme weather events recently due to the effect of global warming. One of the main factors is the carbon emissions that have exceeded the permitted limits. Many countries in the world have taken some significant actions by making some commitments to reduce the effect of it. One of the commitments is to give a penalty cost of each unit emissions produced by a country or a company. In this study, we developed an integration model between inventory and multimodal land transportation by focusing on the costs of emissions produced. To distribute products from several suppliers to several customers, we proposed train as long distance transportation mode and truck as short distance transportation mode. The purpose of this study is to find the best solution for total system costs which consists of operational and emissions costs. The numerical experiments show that the carbon tax rate affects the amount of carbon emissions and the total cost. The trade-off between emissions and the costs will produce an optimal solution. The method used in finding the optimal condition is Mixed Integer Linear Programming.

1. Introduction
The current climate change effects global warming caused by the increase of greenhouse gases (GHG) in the atmosphere. Natural damage and extreme disasters, such as long drought, hail, floods, earthquakes and tsunamis in various parts of the world, are the evidences of global warming effects. Based on the WRI Climate Action Initiative (CAIT) data, the top three greenhouse gas emitters: China, the European Union, and the United States have contributed more than half of total global emissions over ten years. Whereas, 100 countries at the bottom list only account for 3.5 percent of total global emissions [1]. To look for a way out, the Association of European Countries initiated to make policies to control the carbon emission which is supported and followed by other countries in the world [2]. Each member of the association has to commit to take action in reducing the carbon emissions.

Based on 2017 data from the US Energy Protection Agency, transportation sector is the biggest contributor (28.9 percent) of greenhouse gas emissions [3]. Trucks dominate the supply of GHG emissions compared to other transportation modes such as trains, planes and ships [4]. Therefore, a solution for creating an effective, competitive, and eco-friendly supply chain is to integrate transportation and inventory by considering carbon emissions [2].
Previous studies conducted by Konur & Schaefer [4] and Konur [5] focused only on comparing two types of trucks (LTL and TL) and solved the model using analytical approach and pareto front generation. Moreover, Hoen et al. developed a model by involving three carbon roles as carbon tax, cap-and-trade, and emission constraints for selecting transportation modes in stochastic demand [6]. From the model, Hoen et al. proved that a significant emission reduction can occur by changing alternative modes of transportation. Hoen et al. also concluded that carbon emissions factor affects the choice of transportation mode, even though the decisions were taken by the company still depended on the existing regulations [6]. This research attempts to follow the research stream but with additional assumption that the transportation is only counted between terminals. Whereas, in real condition, the transportation costs and carbon emissions from the origin depot to the destination depot require different calculations.

To the best authors’ knowledge, no one has developed a model that integrates inventory and transportation by considering the tax parameter of the carbon emissions [4-11]. Thereby, we intended to fill this gap by developing a Mixed Integer Linear Programming (MILP) model with the objective function to minimize the total costs related to inventory and transportation constraints by considering the carbon cap limitation. An integrated decision between inventory and transportation will become a significant contribution in addressing current issues. In the following sections we will present the description of the problem, the model, and the results from numerical examples.

2. Problem, method and model

This research used a single product for multimodal transportation. In the planning horizon, two suppliers (P) with an index of s send the product to the departure station (W) by short haul transportation (truck). The product is distributed from station W to station V (destination station) by long haul transportation (train). Then, the product is sent from station V to each customer (C) using truck.

A set of parameters and variables is used at each node. In each factory, there are parameters: Gs (warehouse capacity s), hst (holding cost s at period t), est (carbon emission value relating to inventory on s at period t), Prst (total production in factory s at period t), and a variable: Ist (inventory of each factory s).

At station W, there are variables and parameters: Iwt (inventory in warehouse W in period t), Gw (warehouse capacity W), ewt (carbon emission value per period related to inventory in W). Then, there variables and parameters at the destination station V are as the following: Ivt (inventory in warehouse V in period t), Gv (warehouse capacity of station V), evt (carbon emission value per period related to inventory in V). Whereas at each customer, there are parameters: Gi (warehouse capacity of each customer) and mit (demand of each customer i in the planning period t).

The transmission parameters of transportation emissions are denoted by e_{swt} (emission quantities from S to W), e_{wvt} (emission quantities from W to V), and e_{vit} (emission quantities from V to i). The other decision variables are namely as the number of product shipments notated with q_{swt} (number of products from supplier S to Station W), q_{vit} (the number of products shipped from V to customer i), q_{wvt} (number of products from W to V). Carbon emission parameters related to the consideration of this model are marked with "α" (carbon tax rate per unit of emission).

The objective function in this model is to minimize the total of inventory costs, transportation costs and carbon tax of emission cost.

\[
\begin{align*}
\sum_{s=1}^{S} h_{st} I_{st} + \sum_{t=1}^{T} h_{wt} I_{wt} + \sum_{t=1}^{T} h_{vt} I_{vt} + \sum_{t=1}^{T} \sum_{p=1}^{P} c_{swt} q_{swt} + \sum_{t=1}^{T} \sum_{p=1}^{P} c_{wvt} q_{wvt} + \sum_{t=1}^{T} \sum_{p=1}^{P} c_{vit} d_{it} + \alpha \left( \sum_{t=1}^{T} \sum_{p=1}^{P} e_{swt} q_{swt} + \sum_{t=1}^{T} \sum_{p=1}^{P} e_{wvt} q_{wvt} + \sum_{t=1}^{T} \sum_{p=1}^{P} e_{vit} d_{it} \right) = Z
\end{align*}
\]
Constraint:

- **Inventory Balance at Supplier**
  \[ I_{st} + q_{swt} = I_{s,t-1} + Pr_{st} \quad t > 1, \forall s \in S \]  
  \hspace{2cm} (2)

- **Inventory Balance at Station W**
  \[ \sum_{s=1}^{n} q_{swt} + I_{w,t-1} = q_{wvt} + I_{wt} \quad t > 1, \forall s \in S \]  
  \hspace{2cm} (3)

- **Inventory Balance at Station V**
  \[ q_{wvt} + I_{w,t-1} = \sum_{i=1}^{n} d_{it} + I_{vt} \quad \forall i \in K, \ t > 1 \]  
  \hspace{2cm} (4)

- **Warehouse Capacity**
  \[ I_{s,t-1} + Pr_{st} \leq G_s \quad \forall t > 1 \]  
  \hspace{2cm} (5)

  \[ \sum_{s=1}^{n} q_{swt} + I_{w,t-1} \leq G_w \quad \forall s \in S, \forall t > 1 \]  
  \hspace{2cm} (6)

  \[ q_{wvt} + I_{v,t-1} \leq G_v \quad \forall t > 1 \]  
  \hspace{2cm} (7)

- **Integrality and Non-Negativity**
  \[ q_{swt}, q_{wvt} \geq 0 \text{ (integer)} \]  
  \hspace{2cm} (8)

3. **Experiments, results and discussions**

In this study, 10 carbon tax parameters from 0.1 to 35 are experimented. The result of the study shows a trade-off between total emission and total cost happens at the value of tax parameter set to be 15. The greater the carbon tax parameter, the higher the total system cost. However, the greater the tax parameter, the smaller the carbon emissions. Although the effect on the amount of emissions is not significant, it generates a cyclical pattern that consistently has decreasing value. However, to strengthen the result of this study, further research development is still needed.

A numerical experiment is used to prove mathematical modeling. A set of generated data is employed in a numerical test. The experiment considers a scenario involving 2 factories and 3 customers in a four-period time span. Factory 1 and Factory 2 produce 1000 and 1200 tons for each period. The warehouse capacity of each factory is 2000 tons. Then, the warehouse capacity at the departure station W and at the arrival station V is 3000 tons. The truck is used to transport goods from the factory to W station and has a capacity of 30 tons and from station V to each customer has a capacity of 20 tons. The capacity of the train can carry a payload of 1000 tons in one trip. The total demand from the customers in period 1 to period 4 are 500 tons, 700 tons, 800 tons and 900 tons, respectively.

The storage cost for each factory, station W and station V are $0.5, $0.3, and $0.2. The transportation cost from Factory 1 and Factory 2 to the original station is $2 and $3. The shipping cost from the original station to the destination station is $4 per trip rate. The distribution costs from station V to each customer are $1, $2, and $1.5.

The experiments are performed to analyze the effect of carbon tax parameters on the amount of carbon emissions produced and on the total system cost. Ten carbon tax parameters scenarios are generated as seen in Figure 1. In the carbon tax scenario 0.1 to 1, the amount of emissions produced remains constant. Similarly, in the carbon tax parameters 10-20 and 25-35, the amount of emissions produced does not change. However, in carbon tax parameter scenarios 1-10 and 20-25, the amount of emissions quantities are decreasing. The greater the carbon tax parameters, the lower the number of emissions. However, at certain tax parameter intervals, the amount of emissions is stable. As seen in Figure 1, the line graph of 10 carbon tax parameter scenarios makes a cyclical pattern which has consistently decreasing values.
This result is different from the impact of carbon tax on total system costs (Figure 1). In the carbon tax interval parameter 0.1 - 1, the increase that occurs is not too significant. This is estimated because the interval difference is not significant. However, in the scenario of tax parameters 1 to 35, the total cost rises quickly (as evidenced by a straight line upward). This condition indicates that the greater the carbon tax parameters given, the greater the total system costs generated.

In this experimental study, the effect of carbon tax on total emissions and total costs shows that the trade-off occurs at the value of the parameter tax 15. This result is the optimal value applied to reduce the amount of emissions as well as the system costs. Although, the effect on reducing emissions is not very significant.

4. Conclusions

In this study, 10 carbon tax parameters from 0.1 to 35 are experimented. The result of the study shows a trade-off between total emission and total cost happens at the value of tax parameter 15. The greater the carbon tax parameter, the higher the total system cost. However, the greater the tax parameter, the smaller the carbon emissions. Although the effect on the amount of emissions is not significant, it generates a cyclical pattern that consistently decreasing. However, to strengthen the result of this study, further research development is still needed.

References

[1] World Resource Institut 2017 Data Visualization of GHG Emissions [Online] Retrieved from: http://www.wri.org/blog/2017/04/interactive-chart-explains-worlds-top-10-emitters-and-how-theyve-changed.

[2] Ardliana T, Pujawan I N and Siswanto N 2018 Inventory-Transportation Model Considering Carbon Cap International Conference on Industrial Engineering and Operations Management 1319-1325

[3] Environmental Protection Agency 2017 Sources of Greenouse Gas Emission [Online] Retrieved from: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

[4] Konur D and Schaefer B 2014 Integrated Inventory Control and Transportation Decisions under Carbon Emissions Regulations: LTL vs. TL Carriers Transportation Research Part E: Logistics and Transportation Review 68 14–38

[5] Konur D 2014 Carbon Constrained Integrated Inventory Control and Truckload Transportation with Heterogonous Freight Trucks Int. J. Prod. Econ. 153 268-279.

[6] Hoen K M R, Tan T, Fransoo J C and Van Houtum G J 2014 Effect of carbon emission regulations
on transport mode selection under stochastic demand Flexible Services and Manufacturing Journal 26(1-2) 170-195

[7] Benjaafar S, Li Y and Daskin M 2010 Carbon Footprint and the Management of Supply Chains: Insights from Simple Models IEEE Trans. Autom. Sci. Eng 10(1) 99–116

[8] Palak G, Eksioglu S D and Geunes J 2014 Analyzing the Impacts of Carbon Regulatory Mechanisms on Supplier and Mode Selection Decisions: an Application to to a Biofuel Supply Chain Int. J. Prod. Econ. 154 198–216

[9] Schaefer B and Konur D 2015 Economic and Environmental Considerations in a Continuous Review Inventory Control System with Integrated Transportation Decisions Transportation Research Part E 80 142-165

[10] Pan S, Ballot E and Fontane F 2013 The Reduction of Greenhouse Gas Emissions from Freight Transport by Pooling Supply Chains International Journal of Production Economics 143(1) 86–94

[11] Chen X and Wang X 2016 Effects of Carbon Emission Reduction Policies on Transportation Mode Selections with Stochastic Demand Transportation Research Part E: Logistics and Transportation Review 90 196–205