The Effects of Carbon Mechanism on Supply Chain Costs and Inventories

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**Abstract.** The effects of global warming are very devastating. They are directing the earth’s ecosystems to destruction. Carbon emissions have become the most influential cause of global warming. Therefore, many countries in the world have seriously committed to reduce carbon emissions. This commitment is realized by different regulations from each country regarding carbon capacity limits. Transportation is one of the biggest contributors of carbon emissions in supply chain. The study of transportation and inventory problems has a significant impact to the total costs and the carbon emissions. To the best author’s knowledge, there is no research that proposes a model involving problem of multimodal transportation from the factory to the customer considering the carbon emissions. The model proposed in this study integrates the inventory problem and the combination of land transportation with long distance shipping routes by considering the effects of carbon emissions in supply chain activities. The transportation modes involved in this study are truck and train. The purpose of this model is to observe the impact of involving carbon emission indicator on the decision variables, such as the amount of inventory and the total cost.

1. Introduction

Carbon emission is defined as the total amount of carbon dioxide gas (CO2) produced. Then, the carbon emission is also categorized as a greenhouse gas (GHG). The ideal composition of CO2 in the clean air should be at the level of 300 ppm [1]. If the amount of carbon emissions in the atmosphere is excessive, it will increase the air pollution and cause a greenhouse gas effect [2]. The IPCC stated that there had been an increase of 70% in GHG emissions from 1970 to 2004, and most of the GHG elements is CO2. The increase of GHG is caused by three main sectors: energy, transportation, and industry [3].

Previous studies have shown that the correlation between costs and emissions is inversely proportional. For example, with value to the carbon cap, the more lenient the carbon limit is given, the lower the cost, but the higher the carbon emissions produced [4]. Therefore, optimization is needed between these two variables in terms of looking for a trade-off. The higher the emissions produced; the more costs are spent to reduce them in order to achieving the theoretical goal: zero emission. Several regulatory mechanisms have been issued related to carbon emissions policies: carbon cap (the regulation of carbon emission capacity permitted by a company) and carbon tax (this regulation is given by the state by giving tax sanctions on the amount of emissions produced company) [2] [5].

Reference [5], [6], [7] have conducted research in the area of inventory by considering carbon emissions. In addition, [8] [9] [10] [11] have conducted researches related to the selection of transportation modes that consider carbon emissions. If the inventory and the transportation mode selection decision are combined and make the carbon emissions as a key consideration, it is expected to minimize costs as well as carbon emissions in supply chain activities [12], [13], [14], [15], [16].

Some other studies have integrated the inventory and transportation decisions in one mode [12] [13] [14] [15] [16]. However, those researches only used truck with various variations such as Full Truck Load (FTL) and Less than Truck Load (LTL). From the previous studies about the integration of inventory management and the selection of long-distance multimodal transportation can be concluded that there is no comparison about the combination of the various modes of land transportation from the depot of origin (factory) to the destination depot (customer).

Therefore, this research is trying to bridge this issue. Besides, to date, no one has developed the optimization model which involves the integration of inventory and land transportation by considering the parameters of carbon to minimize the total cost of the supply chain. the modes of land transportation. Therefore, the purpose of this research is to optimize the total costs supply chain to transportation and inventory by considering the carbon cap limitation. Then, the research problem is how to make the model to optimize the supply chain costs and storage considering carbon emission mechanism. The optimization model is based on Mix Integer Linear Programming (MILP) approach.

1. Problem, Method and Model

The model development for land multimodal is carried out in a long delivery radius. The types of multimodal used are trucks and trains. The manufacturer (factory) is categorized as a supplier because it delivers solid raw materials such as cement, fertilizer, chemicals, and others. This research uses a single product. There are several factories (multi suppliers) sending their products to the station with various distances and locations. This condition will lead differences in the total shipping costs and emissions produced. The production capacity of each factory is different, causing the difference in the number of shipments. The capacity of trucks to ship from the factory to the start station is assumed to be the same because it uses the same truck. Transportation costs from the factory to the station differ depending on the location of the supplier.

In a planning horizon, the factory will send a number of products according to the number of customer requests to the station warehouse. The delivery uses truck mode. If there are remaining products that are not transported, they will be stored in the factory warehouse and become inventory in that period. The products will be sent to the station until the product quantity reaches the maximum capacity for long haul transportation (train) mode. At the initial station or the destination station, the solution obtained can store products (inventory) to get cost and emissions optimization.

The concept of mathematical modelling consists of inputs which have objective functions, decision variables, and constraint functions, which will produce an output. The decision variables in this modelling are the number of orders, the number of inventories, and the frequency of shipments. Outputs are generated to minimize total transportation costs, total inventory costs, total fixed order costs and total carbon emissions costs. In addition, it will minimize the amount of carbon emissions generated in all supply chain activities.

The following is a mathematical model of this research:

$\sum\_{t=1}^{T}\sum\_{s=1}^{n}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\_{i=1}^{n}c\_{swt}^{} q\_{swt}^{} +\sum\_{t=1}^{T}c\_{wvt}^{} q\_{wvt}^{}+ \sum\_{t=1}^{T}\sum\_{i=1}^{n}c\_{vit}^{} d\_{it}^{} +\sum\_{t=1}^{T}\sum\_{s=1}^{n}f\_{st}^{} y\_{swt}^{} +\sum\_{t=1}^{T}f\_{wt}^{} y\_{wvt}^{}+ \sum\_{t=1}^{T}\sum\_{i=1}^{n}f\_{vt}^{} y\_{vit}^{} $ = Z1 (1)

$I\_{st}^{}+ q\_{swt}^{}=I\_{s,t-1}^{}+Pr\_{st}^{}$ $, t>1^{},∀ s\in S^{}$ (2)

$\sum\_{s=1}^{n}q\_{swt}^{}+I\_{w,t-1}^{}=q\_{wvt}^{}+I\_{wt}^{}$, $ t>1 ,∀ s\in S^{}^{}$ (3)

$q\_{wvt}^{}+I\_{w,t-1}^{}=\sum\_{i=1}^{n}d\_{it}^{}+ I\_{vt}^{}$ , $∀ i\in K, ^{} t>1^{}$ (4)

$I\_{s,t-1}^{}+ Pr\_{st}^{}\leq G\_{s}^{}$ $∀ t>1, ^{}$ (5)

$\sum\_{s=1}^{n}q\_{swt}+I\_{w,t-1} \leq G\_{w}^{}$ $∀ s\in S^{} ∀ t>1, ^{} $ (6)

$q\_{wvt}+ I\_{v,t-1}\leq G\_{v}^{}$ $∀ t>1, ^{}$ (7)

$\sum\_{t=1}^{T}\sum\_{s=1}^{n}e\_{st}^{} I\_{st}^{} +\sum\_{t=1}^{T}e\_{wt}^{} I\_{wt}^{}+ \sum\_{t=1}^{T}e\_{vt}^{} I\_{vt}^{}+ \sum\_{t=1}^{T}\sum\_{i=1}^{n}e\_{swt}^{} q\_{swt}^{} +\sum\_{t=1}^{T}e\_{wvt}^{} q\_{wvt}^{}+ \sum\_{t=1}^{T}\sum\_{i=1}^{n}e\_{vit}^{} d\_{it}^{} +\sum\_{t=1}^{T}\sum\_{s=1}^{n}e\_{st}^{} y\_{swt}^{} +\sum\_{t=1}^{T}e\_{wt}^{} y\_{wvt}^{}+ \sum\_{t=1}^{T}\sum\_{i=1}^{n}e\_{vt}^{} y\_{vit}^{} \leq CCap^{}$,$ ∀ t\in T, ^{}∀ i\in K^{}$ (8)

The equation (1) is the objective function for carbon cap mechanism. The goals are to minimize cost for the transportation, inventory and fixed order. The goals are to minimize cost for the transportation, inventory, fixed order and carbon emission tax. Equation (2), (3) and (4) are the inventory balance at supplier, initial station and final station. Equation (5), (6), (7) are warehouse capacities at supplier, initial station and final station. Equation (8) is carbon cap constrain.

1. Experiments, Results and Discussions

In this study, seven experiments were carried out using the carbon capacity parameter. These parameters are 1140, 1150, 1160, 1170, 1180, 1190 and 1200. The purpose of this experiment is to determine the magnitude of the impact of changing carbon capacity on total supply chain costs and the amount of supply chain emissions. Supply chain costs include setup costs, inventory costs, and transportation costs. Total supply chain emissions include emissions at factories, emissions from trucks and trains, emissions from inventory at stations and factories.

 **Figure 1.** The Effect of Carbon on Supply Chain Emission and Cost

Figure 1 shows the changes in the seven carbon parameters on emissions and the resulting supply chain costs are inversely related. The effect of increasing carbon capacity is the increasing of emissions. The increase in total emissions from parameter 1 to the next parameter is about 1,007 percent. There is an increase in total emission from parameter 2 to parameter 3 by 1,009 percent.

Conversely, Figure 1 shows that when carbon is loosened, the effect of increasing carbon capacity makes total costs decrease. The percentage of reduction between parameter 1 and parameter 2, parameter 2 to parameter 3, and so forth is equal to 0.997 percent. This cost reduction is stable following the same interval of increasing carbon capacity.

In the experiment (Figure 1), the results showed that the higher carbon capacity parameters, the lower the supply chain costs. Conversely, when this parameter increases, the amount of supply chain emissions will also increase, approaching the carbon capacity limit set. The carbon allowance assigned to supply chain activities in a company has a significant impact on the cost efficiency of its supply chain. But on the other hand, the number of emissions has also increased. Although the percentage increase in emissions is not too sharp when compared to the reduction in costs. The trade off between supply chain costs and the resulting emissions creates optimal conditions in order to provide benefits for these two factors.

The result in Figure 1 is consistent with some previous studies [3], [4], [5] which showed a tradeoff between costs and emissions. However, the percentage increase and decrease is different. This depends on the magnitude of the increase in carbon capacity, the costs of each supply chain activity and also on the multimodal.

**Figure 2.** The Effect of Carbon on Inventories

In another experiment (Figure 2), the effect of limiting the allowable carbon capacity had a significant impact on the amount of inventory at the factory and at the station. In graph 2 it can be seen that when carbon capacity is relaxed, the total inventory at the plant significantly decreases. In contrast to the total inventory at the two stations, the higher the carbon capacity, the higher the inventory at the station.

The results of this second experiment is a novelty. There is no previous study conducted this experiment. Therefore, it cannot be compared. In addition, the second experiment still requires further development regarding the factors that cause it.

This research shows that modeling provides optimal solutions to the system. Long-distance transportation costs by train are more expensive, when compared to inventory costs at the factory. As a result, the product will be stored at the arrival station, in order to optimize the railroad car.

1. Conclusions

This research show that the involvement of carbon capacity (carbon cap) mechanism as the constraints to observe the effect on total system costs, emission produced and inventories. Sensitivity analysis is conducted by changing the parameters of carbon capacity. To see the behaviour of the model on the carbon capacity, numerical studies for seven parameter scenarios have been researched. From the experiments, we can describe that a trade-off occurs between the supply chain emissions and the supply chain costs. High costs will cause small emissions. The other result shows that the changes in carbon cap also affects the inventory levels both at the factory and at the station. The higher carbon, The higher inventory on station and the lower inventory at factories.

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