Three-Level Supply Chain considering Direct and Indirect Transportation Cost and Carbon Emissions

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Abstract. Managing sustainable supply chains has become a challenge for most industries primarily because environmental, social, and economic aspects must be taken into account, and the difficulty in satisfying customer demands for sustainability and environmental protection has been increasing globally, making sustainability the focus of numerous studies on green supply chains. Previous studies are usually only applicable to a specific product supply chain. Therefore, this paper review model that focuses on a general three-level supply chain considering direct and indirect transport and industrial carbon emissions and costs. Specifically, the model involves joint economic lot sizing considering a single set-up-multiple-delivery (SSMD) policy.

Keywords: carbon tax, single set-up-multiple-delivery, supply chain, sustainability

1. Introduction

Current research trends deal with optimizing sustainable supply chains (Tancrez et al., 2011), which include minimizing the total costs for supply chains, and addressing environmental factors such as minimizing total carbon emission as a form of competitive advantage to other industries (Sana, 2010). This optimization is a challenge due to the consideration of the three dimensions: environmental, social, and economic aspects of the supply chain (Zadjafar and Gholamian, 2018). In addition, Zadjafar and Gholamian (2018) stated that customer awareness regarding sustainability and environmental conservation has been rising globally, making it the focus of most studies, and especially in global supply chains. Improved sustainability optimizes environmental factors, products, and cost. In line with this, carbon emissions are classified to better affix the costs incurred in an industry. These carbon emission costs are considered as indirect and direct emission costs. Indirect carbon emission costs are the consumptions of electricity, heating, cooling, steam, and the like for industrial use. Direct carbon emission costs cover the production of materials. In addition, transportation costs are divided into indirect and direct carbon emission costs as well. Indirect transportation emission costs result from business-related travel, pick-up and distribution (considering the weight of the material), and other outsourced activities (Wangsa, 2017). Direct transportation emission costs cover company-owned vehicles, equipment, fuel combustions, etc. According to Miyamoto and Takeuchi (2019), to reduce
carbon emissions, implementation of the 1995 Kyoto Protocol is required. The parties involved in sustainable supply chains should also consider additional factors such as a carbon tax and carbon capping in annual costs (Daryanto et al., 2019). A carbon tax is a cost implementation to a certain amount of carbon emission produced corresponding to an amount of currency which varies by each country (Ding et al., 2019). On the other hand, a carbon cap is define as having a minimum amount of allowable carbon emission through a production process, for which any emission in excess would incur a corresponding monetary cost (Yi et al., 2019).

Numerous studies regarding sustainable supply chains have been done, including studies that dealt with a three-echelon supply chain considering deteriorating items (Daryanto et al., 2019). In addition, imperfect quality product-inventory modelling (Sana, 2010), sustainable inventory modelling for pulp and paper mills (Zadjafar and Gholamian, 2018), location-inventory (Tancrez et al., 2011), permissible delay in payment of a three-echelon supply chain (Sarkar, et al., 2018), and a two-echelon supply chain with permissible delay in payment for multi-constraint products (Priyan and Uthayakumar, 2014). Permissible delay in payment describes a scenario wherein the supplier can give ample time for the manufacturer to pay for ordered products, and similarly for the retailer with the manufacturer. The results of these studies showed great promise in producing sustainable supply chains for environmental emission factors and total supply chain costings. This study focused on the paper of Sarkar et al. (2018) wherein permissible payment delay in credit was considered in a three-echelon supply chain. It also considered a single supplier, single manufacturer, with multiple retailers following a single-set-up multiple delivery (SSMD) policy for the inventory system of a total supply chain. In the paper of Sarkar et al. (2018), the model considered transportation and variable transportation costs together. Moreover, the carbon emission cost was set to be constant with respect to the transportation cost of a player of the supply chain. In a real-world scenario, the carbon emission results from different factors (i.e. industrial and transportation) that comply with the Kyoto Protocol. The main goal of the Kyoto Protocol is reducing air pollution from industrial waste including through production, transportation, or inventory, with the goal to reduce at least 5% percent of the annual CO2 emissions in the European Union and 37 other countries (Miyamoto and Takeuchi, 2019). Miyamoto and Takeuchi (2019) summarized studies on shifting to alternative sources of renewable energy and its effect on Kyoto Protocol implementation. The result of their study showed that reductions of carbon emissions would be beneficial to countries applying the protocol. However, shifting resources may not be applicable to every sector of a supply chain due to costing constraints. Moreover, Maamoun (2019) showed how the Kyoto Protocol reveals hidden carbon emission reduction and optimization of costs to be utilized by different industries. Because of that, studies are being conducted to minimize the production of greenhouse gas (GHG) emissions by parties of a supply chain (Daryanto et al., 2019; Hovalaque and Bironneau, 2014; Jauhari, et al., 2014; Sarkar et al., 2015; Sarkar, et al., 2018; Wangsa, 2017).

This study discusses Sarkar et al. (2018) and the direct and indirect industrial and transportation carbon emissions. The paper therefore proposes a model that focuses on a three-level supply chain considering direct and indirect transport and industrial carbon emissions. Specifically, the model involves a joint economic lot sizing considering a single set-up-multiple-delivery (SSMD) policy with a multi-delay payment, aiming to minimize the total cost and the total carbon emission of the three-level supply chain.

The objective of the model is to minimize the total cost of the sustainable supply chain by deriving the model using an algebraic approach. In addition, revenue earned, and alternative cost will be considered because of the multi-level in credit payment scenarios to determine which delay-in-payment scenario would be beneficial to the whole supply chain. The optimum result was obtained among the four scenarios by using numerical examples. This study will also address how the penalty and incentive policies of carbon capping will affect total cost. Lastly, sensitivity analysis was made to check the optimality of the findings. The conclusions from this paper may benefit managers in different sectors of a three-level supply chain mainly because it provides a general model for the total costing incurred is provided, and because the optimal result will minimize total cost and carbon emissions. Lastly, under the Kyoto Protocol, the
model will serve as a platform to determine which part of the supply chain or costing to manipulate to reduce cost and emissions.

The model utilized numerical examples and sensitivity analysis to determine the optimal result of the proposed mathematical model. The study developed the model with Maple Software for the derivation and computation. The rest of the paper is organized as follows: the review of literature for the second section, model definition, notation, and then assumptions, followed by the mathematical model without the permissible payment for credit for the third section, the model having permissible payment for credit policy and incentive and penalty for carbon tax for the fourth section, and conclusion and recommendation for the fifth section.

2. Methods
This study discusses related literature to find the gap in the studies relating to supply chain dealing with carbon emissions. Several studies (summarized in Table 1) have examined reducing carbon emission, but they still have a long way of improvement for international application because incorporating all carbon emission factors is difficult in a small scale. The study of Wangsa (2017) considered indirect and direct carbon emission from transportation and industrial sources which could be used when extending a study. The focus on the specified emissions should be taken seriously for increase in the improvement of the reduction of carbon emission (Almer and Winkler, 2017).

To reduce carbon emissions, governments have implemented carbon cap-and-trade and carbon taxes for major carbon emitters (He et al., 2014). A carbon cap is the amount of permitted carbon emissions that may be produce by a certain system, for which emission in excess would result in a penalty payment. The cap-and-trade system trades an amount of carbon emission that was unused to other supply chains through a specific carbon market. A carbon tax is a constant rate in payment given to a level of carbon emission produced.

One model that is usually created deals with a Single-Set-up-Multiple-Delivery (SSMD) Policy. This is because the multiple delivery incorporated in the supply chain deals greatly on the decision-making factor in the total cost reduction (Chan et al., 2018). Transportation as one factor causes not only cost but carbon emission as well. The study of Chen et al. (2018) deals on how the combination of the multiple delivery helps in the reduction of total cost of the supply chain system in a real-life scenario. The coordination of the single supplier to multiple buyer helps in the manipulation of the total cost. In the study of Beck et al. (2017), the conditions set for the different shipment set-up for multiple buyers were considered. The shipment policies considered showed promise for future researches to adapt. Both studies of Chen et al. (2018) and Beck et al. (2017) covered SSMD policy but did not consider carbon emission.

Business industries are currently dealing with much when it comes to sustainability. This is mainly because of the knowledge the market gains due to the customer demand of having greener production processes and commodities (Zadjafar and Gholamian, 2018). For example, Daryanto et al. (2019) considered carbon emission focusing on deteriorating items of a three-echelon supply chain. The study dealt with a single supplier to a single buyer. Moreover, Daryanto et al. also did a study in 2018 covering sustainable inventory management in deteriorating items and imperfect quality items that considered carbon emission without affecting the profitability of the supply chain. In addition, the study of Zadjafar and Gholamian (2018) also dealt with sustainable inventory model but focused on items such as pulps and mills.

The global competitive environment is high when it comes to supply chains, which are dealing greatly on minimizing their total costs. Different studies were formulated in-order to minimize costing, which discovered that considering the total supply chain would be beneficial for cost manipulation rather than individual systems of the supply chain (Priyan and Uthayakumar, 2014). Like the study done on multi-commodity supply chain of a two-echelon supply chain by Sadjady and Davoudpour (2011), they considered lead time and inventory costs. They also dealt with the lot-size and location and planning both tactical and strategic considered. The study covered mainly the inventory and lead times to
minimize the costs. Their strategy involved a heuristic solution algorithm but needs further research when it comes to the capacity limitations and transportation modes.

Table 1 lists the related literature summary for the proposed model considering transportation, inventory, carbon emission, carbon tax, and multi-delay in payment.

| Author                  | Specific Item | Transportation | Inventory | Multi-delay in payment | Carbon Emission | Carbon Tax |
|-------------------------|---------------|----------------|-----------|-------------------------|-----------------|------------|
| Sarkar et al. (2016)    | ✓             | ✓              | ✓         | ✓                       |                 | ✓          |
| Ghosh et al. (2017)     | ✓             | ✓              | ✓         | ✓                       |                 | ✓          |
| Beck et al. (2017)      | ✓             | ✓              | ✓         | ✓                       |                 | ✓          |
| Qi et al. (2017)        | ✓             | ✓              | ✓         | ✓                       | ✓               | ✓          |
| Tang et al. (2017)      | ✓             | ✓              | ✓         | ✓                       | ✓               | ✓          |
| Wangsa (2017)           | ✓             | ✓              | ✓         | ✓                       | ✓               | ✓          |
| Chan et al. (2018)      | ✓             | ✓              | ✓         | ✓                       |                 | ✓          |
| Manupati et al. (2018)  | ✓             | ✓              | ✓         | ✓                       |                 | ✓          |
| Daryanto et al. (2018)  | ✓             | ✓              | ✓         | ✓                       |                 | ✓          |
| Sarkar et al. (2018)    | ✓             | ✓              | ✓         | ✓                       |                 | ✓          |
| Zadjafar and Gholamian, (2018) | ✓     | ✓              | ✓         | ✓                       |                 | ✓          |
| Marchi et al. (2019)    | ✓             | ✓              | ✓         | ✓                       |                 | ✓          |
| Daryanto et al. (2019)  | ✓             | ✓              | ✓         | ✓                       |                 | ✓          |
| Our 4 model             | ✓             | ✓              | ✓         | ✓                       | ✓               | ✓          |

3. Result and Discussion
The cost summation of the players of the supply chain, as generally seen in equation (1), will be optimized to determine the least cost that may be incurred of the whole system.

Total cost = Supplier Costs + Manufacturer Costs + Retailer Costs

The cumulative cost of the three-level supply chain is simplified in equation (2).

\[
TC(C_{T}, M_{CT}, R_{CT}, S_{R}, M_{R}) = \left( \frac{C_{T}}{2} \left( R_{CT} \left( \frac{h_{s}M_{CT}D^2}{S_{R}P_{S}} + \frac{2h_{m}D^2}{P_{m}} + \frac{h_{s}D^2}{P_{m}} + h_{s}M_{CT}D - h_{s}D - \frac{h_{m}D^2}{P_{m}} + h_{m}D \right) \right) + \left( 1 \frac{1}{R_{CT}} \frac{A_{s} + O_{s}S_{R}}{M_{CT}} \right) + A_{m} + O_{m}M_{R} \right) + O_{r} +
\]

\[
\left( C_{T} \left( M_{CT} \left( \frac{D\Delta_{1}(H_{em} + C_{em} + S_{em} + E_{em})E_{f}C_{tax}}{S_{s}} + \frac{D\Delta_{2}C_{tax}}{S_{s}} \right) + \right)
\]
\[
\frac{y\delta(2D_s+D_m)}{S_s} + \frac{C_{\text{tax}}[D\Delta_T W + y(2D_s+D_m)]}{S_s} + \left( R_{CT} \left( \frac{D\Delta_{I1}(H_{em} + C_{em} + S_{em} + E_{em})E_{I}C_{\text{tax}}}{S_m} + \frac{D\Delta_{I2}C_{\text{tax}}}{S_m} + \frac{y\delta(2D_m+D_r)}{S_m} + \frac{C_{\text{tax}}[D\Delta_T W + y(2D_m+D_r)]}{S_m} \right) \right) + \frac{D\Delta_{I1}(H_{em} + C_{em} + S_{em} + E_{em})E_{I}C_{\text{tax}}}{S_r} + \frac{C_{\text{tax}}[D\Delta_T W (2D_r)C_{\text{tax}}]}{S_r} \tag{2}
\]

The decision variables were derived algebraically to get the least value. (Appendix A shows all variable notations)

\[TC\ (C_T, M_{CT}, R_{CT}, S_R, M_R) = C_T \left( K_1 + K_2 + \frac{K_3}{2} + \frac{K_4}{2} \right) + \left( \frac{A}{T} \right) \tag{3} \]

\[= \frac{(T \left[ K_1 + K_2 + \frac{K_3}{2} + \frac{K_4}{2} - \sqrt{A} \right]^2}{T} + 2 \sqrt{(K_1 + K_2 + \frac{K_3}{2} + \frac{K_4}{2})} (A) \tag{4} \]

The total cost equation reaches minimum value when the decision variable with respect to \(C_T\) is

\[C_T^* = \sqrt{\frac{A}{K_1 + K_2 + \frac{K_3}{2} + \frac{K_4}{2}}} \tag{5} \]

The minimum value of the total cost would become

\[TC_1(M_{CT}, R_{CT}, S_R, M_R) = 2 \sqrt{(K_1 + K_2 + \frac{K_3}{2} + \frac{K_4}{2})} (A) \tag{6} \]

Since the optimal value for \(C_T\) depends on the other decision variables, \(M_{CT}, R_{CT}, S_R, M_R,\) these would be derived from the equation containing the specific variable as seen in equation (46) for the \(R_{CT}\) variable.

\[TC_1(M_{CT}, R_{CT}, S_R, M_R) = 2 \sqrt{(K_1 + K_2 + \frac{K_3}{2} + \frac{K_4}{2})} (A) \tag{7} \]

Which translates to

\[TC_1(M_{CT}, R_{CT}, S_R, M_R) = 2 \sqrt{\left( \frac{\phi_2}{R_{CT}} + O_r \right) \left( \frac{\phi_2 R_{CT} + \alpha_2}{2} + \frac{2R_{CT} \phi_3}{2} + \frac{M_{CT} \phi_4}{2} + \frac{\phi_5}{2} \right)} \tag{8} \]

Simplifying,

\[= 2 \sqrt{\left( \frac{\phi_2}{R_{CT}} + O_r \right) \left[ R_{CT} \frac{l_2}{2} + \frac{l_2}{2} + \frac{l_3}{2} \right]} \tag{9} \]

Solving for the decision variable \(R_{CT}\), the optimal value would be equation (46).

\[= 2 \sqrt{\left( \frac{\phi_2 R_{CT} + \alpha_2}{R_{CT}} \right)^2 + 2 \sqrt{\phi_2} \sqrt{J_2 O_r \sqrt{\phi_2} + J_3 \phi_2 + J_1 \phi_2 + J_2 O_r + J_3 O_r} \tag{10} \]

\[R_{CT}^* = \sqrt{\frac{J_2 \phi_2 + J_3 \phi_2}{O_r J_1}} \tag{11} \]

The resulting cost function after deriving \(R_{CT}\) with respect to the other decision variables \(M_{CT}, S_R, M_R\), would be equation (12).

\[TC_1(M_{CT}, S_R, M_R) = \sqrt{2} \left( \sqrt{\phi_2} + \sqrt{O_r J_2} \right) \tag{12} \]

The portion with the decision variable \(M_{CT}\) was obtained to get equation (13).
\[
\sqrt{\varnothing_9} = \sqrt{O_r (\varphi_4 M_{CT} + \varphi_5) + M_{CT} J_5 (\varphi_1) + \frac{\varnothing_{11} \varphi_1}{M_{CT}} + J_6}
\]

The optimal value for \( M_{CT} \) would therefore be

\[
M_{CT}^* = \frac{\varnothing_{11} (\varphi_1)}{O_r \varphi_4 + O_r \varphi_5 + J_5 \varphi_1}
\]

The total cost becomes equation (15) with respect to the other decision variables, \( S_R, M_R \).

\[
TC_1(S_R, M_R) = \sqrt{J_6 + 2\sqrt{\left(\varnothing_{11} \varphi_1\right)^2 + \left(J_5 \varphi_1 + O_r \varphi_4 + O_r \varphi_5\right)}}
\]

By simplifying and solving for the equation containing the decision variable \( S_R \), the optimal variable is,

\[
S_R^* = \frac{A_s h_s D^2}{P_s (\varphi_0 O_s)}
\]

The remaining variable in the equation is \( M_R \) and the total cost function becomes,

\[
TC_1(M_R) = \sqrt{\left(J_5 \alpha J_7\right)^2 + 2\sqrt{\left(\frac{A_s h_s D^2}{P_s} \varphi_0 O_s\right)}}
\]

Taking the equation containing \( M_R \), as equation (20),

\[
J_5 (\alpha J_7) = (A_m + O_m M_R) (O_r \varphi_4 + O_r \varphi_5) (J_5 J_7 \alpha) \left[\frac{2h_s D^2}{P_s M_R} + \frac{h_s D^2}{P_m} - \frac{h_m D^2}{P_m} + h_m D\right]
\]

Simplifying,

\[
= \left(\varnothing_{15} \varphi_0 O_m - \frac{2J_7 A_m h_s D^2}{P_s M_R}\right)^2 + 2\sqrt{\left(J_7 O_m \left(\frac{2J_7 A_m h_s D^2}{P_s}\right)\right)}
\]

The optimum result for variable \( M_R \) is

\[
M_R^* = \frac{2J_7 A_m h_s D^2}{P_s (J_7 O_m)}
\]

The final total cost equation for the supply chain becomes equation (59).

\[
ETC = 2\sqrt{\frac{A_s h_s D^2}{P_s} \varphi_0 O_s} + J_8 + J_{10} + 2\sqrt{O_m J_9 \frac{2J_7 A_m h_s D^2}{P_s}}
\]

### 4. Conclusion

This study formulated a three-level supply chain that considers multi-level credit payments. This model would be considered as a platform for interim financing wherein the costs would be monitored in order to boost total profit from the sales.

The results of the model show great differences when applying multi-level-credit payment policy. From the numerical example, giving ample time for the payment would result in an increase in the profitability of the system due to the revenue, but the time-period should not be longer than the cycle time. Moreover, the allowance of delays in payment period would result in a good partnership after a positive outcome. The result showed a better profitability from 17.05% to 43.72%. It could then be seen from the result that giving enough time for the payment per player of the supply chain would give rise to a higher profitability because of the revenue income but not longer than the cycle time. In addition, the delay in payment period would result in a good partnership amongst players of the supply chain after
a positive result (Priyan and Uthayakumar, 2014). The result also shows that the eco-friendly model and economic costing will help not only the industry, but the consumers and the environment as well. Managers would be able to utilize the model to create a better trade-off on running the system to have minimum cost for all players of the supply chain. Lastly, having to manipulate the period of payment delay in credit would result in a better profitability, noting that the higher holding cost for the retailer compared to the permissible allotted time for payment would not result to the optimal solution. Considering the cycle time and the allowed time in credit payment would be the key strategy in creating an optimized total cost that would be beneficial to all the players of the supply chain.

This would be beneficial to the parties of the supply chain as a benchmark in deciding on the best outcome for their system regarding the optimality of the costing based from the different illustrated (i.e. holding, transport, industrial, carbon emission, carbon tax, interest payment). Optimum minimization would be beneficial for applying the SSMD policy if the industrial cost considering the carbon emission would be less than the holding cost. In addition, the algebraic approach done for the paper presents a positive outcome and would be easier to manipulate in real-life scenarios. Compared to integrated derivations where results are sometimes difficult to manipulate for the application of the different supply chains in the industry, this model is flexible for adaptation to a supply chain’s needs. The presented numerical example and sensitivity analysis for the main parameters would be easily manipulated for application purposes of different SSMD policy-applied industries. The study could be extended if the demand will be made in a stochastic approach to simulate a real-life scenario when it comes to inventory.

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