Three-Level Closed-Loop Supply Chain Considering Carbon Emission of Industrial Cost for Self-Healing Packages

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Abstract

This study developed a mathematical model for a Closed-Loop Supply Chain (CLSC). It considered the Single Set-up Multiple Delivery Policy, carbon emission of industrial and transportation of the CLSC, and self-healing packages. The model was able to show that utilizing the self-healing packages can lessen the carbon emission and the total cost throughout the process. Moreover, the results show that most of the parameters had a significant change in the total cost after undergoing sensitivity analysis. This numeric behavior was evident due to the relation of the assumed equal demand throughout the whole process of the CLSC. However, there are also parameters that showed an inverse relationship and infinitesimal effect on the total cost. This occurred due to the utilization of the CSLC and self-healing packages. Lastly, the application of this study can benefit the optimization of the closed-loop supply chain and organizations that utilizes the CLSC and self-healing packages. Companies can utilize the model to have a competitive edge and promote a green supply chain.

Keywords
Carbon Emission, Closed-Loop Supply Chain, Optimization, Self-Healing Packages, Single Set-up Multiple Delivery Policy

1. Introduction
The current threat of global warming has raised awareness on the emission of greenhouse gases (United States Environmental Protection Agency, 2020). Ong et al. (2020) emphasized that the supply chain is one of the major contributors to the said societal issue. The contribution of carbon emission to the said dilemma was highlighted by the study of Wu et al. (2019), wherein the involvement of transportation in the processes of the supply chain contributes to the rampant carbon emission. Radford (2020) emphasized that the traditional supply chain processes, of well-known multinational companies, are responsible for one-fifth of the global carbon emission. This led researchers to study and alter the process of the supply chain to give a solution to the said cause.

Moradi et al. (2011) emphasized that the continuous study on the models of the supply chain aims for similar objectives. The researchers emphasized that operational productivity, profitability, competitiveness, and environmental friendliness are the common denominators of research and alteration. A study by Teng et al. (2015), for instance, optimized a model for products that has limited production quantity. Hishamuddin et al. (2015) dealt with multiple supplier that is subjected to supply and transportation disruptions. Bozorgi (2016) focused on a multi-product inventory model for cold items with cost and emission consideration.

According to Moradi et al. (2011), game theory, inventory control, negotiation models, production and pricing, seller-buyer problem, and simulation modeling are specifics of the continuous alteration and optimization of the traditional supply chain. As an example, Sarkar et al. (2019) focused on the closed-loop supply chain of self-healing packages under the SSMD Policy. They utilized non-preemptive goal programming, which means that the researchers set a goal that the model can meet. However, the applicability of the developed model is for a specific set of objectives. If these objectives were not met, then the model is not usable in real-life application. In contrast, Ong et al. (2020) used an algebraically based optimization of the supply chain. It considered the direct and indirect carbon emission of a general type of supply chain.

With the mentioned studies, there has been no model that considers self-healing packages of a closed-loop supply chain (CLSC) under the SSMD policy derived algebraically. This paper was an adaptation of the study of Sarkar et al. (2019) and Ong et al. (2020). The model also considered direct and indirect carbon emission, which would benefit the environmental and societal aspects. Ong et al. (2020) reiterated that algebraically based optimization would be easier to manipulate in an actual supply chain setting. In addition, the supply chain is said to be one of the major contributors to carbon emission (Ong et al., 2020). With this, studies have been conducted to put strategic changes in the operation of the supply chain. This includes the location of the processes, usage of plants, application of strategies on the distribution of inventory, and the tactical study on the flow of goods and raw materials that has to be allocated to the consumers (Ashtiani et al., 2015). Thus, the rampant carbon emission and the initiative of authorities to control the said issue is one of the factors that varied the process of the traditional supply chain.

1.1 Objectives

The aim of this study was to create a mathematical model of a closed-loop supply chain. The model was specific to the utilization of self-healing packages under the SSMD policy. This mathematical model also considered direct and indirect carbon emission from the industrial aspect, and direct carbon emission from the transportation of the supply chain. Having a closed-loop supply chain would involve the utilization of packages being returned after usage of one party (e.g. delivered from supplier to manufacturer – returned by manufacturer to supplier after use). The set-up imparts a total packaging solution in which it copes with the changes in its environment (intelligent), and to some extent reacts upon these said changes (active) (Vanderroost et al., 2014). Moreover, it also has a track and trace function to the inventory throughout its lifecycle, and a monitoring function inside and outside the package. This then can help the manufacturer, retailer, or consumer to monitor the inventory's condition at any moment (Schaefer and Cheung, 2018).

It is affirmed that the rampant greenhouse gas emission comes from the operations of the supply chain. Therefore, the results of this study can aid in lessening the carbon emission due to its focus on utilizing the CLSC. Moreover, this study will be beneficial to the environment while promoting a competitive and useful managerial model for the real-life application of the three-level closed-loop supply chain. Lastly, the model that was developed in this paper can serve as a framework for researchers that has similar means and objectives.

2. Literature Review

Different supply chain studies considered optimizing the inventory. The study of Sana et al. (2019) dealt with the supply chain focusing on deteriorating items. Other studies, however, dealt with product-inventory (Sana, 2010), carbon emission of inventory products (Wangsa, 2017), pulp and paper mills inventory modeling (Zadjafar and Gholamian, 2018), and multi-constraint product inventory (Priyan and Uthayakumar, 2014). As the study of Gunasekaran et al. (2019) stated, the inventory in SCM should be heavily considered in optimizing the whole process.

The study of Schaefer and Cheung (2018) emphasized that traditional packaging is not enough to be able to cope up with the rising customer expectations, dynamic product complexity, global initiatives towards honing a circular economy while minimizing the carbon footprint. However, smart packaging imparts a total packaging solution in which it copes with the changes in its environment and to some extent, reacts upon these said changes (Vanderroost et al., 2014).

Moreover, Ong et al. (2020) emphasized that the supply chain is one of the major contributors to carbon emission. Studies have been conducted to put strategic changes in its operation. This includes the location of the processes, application of strategies on the distribution of inventory, and the tactical study on the flow of goods and raw materials, that must be allocated to the consumers (Ashtiani et al., 2015). The increased carbon emission and the initiative of authorities to control the said issue is one of the factors that varied the processes of the traditional supply chain. These alteration and optimization of the traditional supply chain dawned the variety of models (Moradi et al., 2011). This leads to a focus on closed-loop supply chain (Sarkar et al., 2019).

Kumar N. and Kumar R. (2013) discussed that there are a lot of mechanisms to promote environmentally healthy supply chain processes, namely: green Supply Chain Management (GrSCM), Reverse supply chain management (CLSCM), Reverse logistics (RL), Sustainable supply chain (SSC), and sustainable transport. However, the utilization of GrSCM gave birth to the concept of CLSC, in which organizations purport that GrSCM begets the "loop closing" in the whole supply chain mechanism which promotes an environmentally friendly process. They stressed that the remanufacturing concept in the process was able to help the organizations to lessen the waste and make their process profitable and environmentally aware. The utilization of CLSC is related to the consideration of using recyclable materials. According to Deen (2017), after the inventory has been transported and distributed by the retailer, the manufacturer that is under the mechanism of CLSC should encourage its retailers to return the items if it is no longer functional or needed. Thus, the concept of smart packaging is then going to be involved in the whole cycle. The review of Zhang et al. (2018) shows the connection of self-healing packages as the sub-group of smart packages. They emphasized the ability of self-healing packages to repair their physical damage or recover their functional features without any human intervention. Thus, the definition of self-healing packages and their recyclability can serve as a useful material in managing CLSC to be able to aid the utilization of the "closed-loop" process in the supply chain (Sarkar et al., 2019). The mechanism of self-healing packages dawned due to the ever-growing population and rampant carbon emission (Sahmaran et al., 2016). Greene (2019) emphasized that carbon emission has been the huge driver of climate change, and industries usually struggle to quantify the said gas emission, specifically in the process of the traditional supply chain.

There are numerous studies that have dealt with the inventory, and it was evident that these researches aim to optimize the whole process of the supply chain. However, this does not undermine the apparent applicability of the self-healing packages as a factor in studying the supply chain's development. Since society is dynamic and aware of the rampant carbon emission, the vitality of studying and applying innovative packaging is essential. It was apparent in the mentioned studies that the traditional supply chain is one of the contributors to the problem of greenhouse gas emission and considering the self-healing packages to solve this societal issue is a novel and radical solution. Moreover, these initiatives to alleviate carbon emission while promoting a competitive mathematical model altered the process of the supply chain. There were a lot of developed models that aim to promote a green environment while optimizing the cost of the whole process. However, since the self-healing packages are one of the trends that are highly considered nowadays, the dawn and development of the CLSC have been one of the focus of studies in the current research of the supply chain. Given these developments, it was affirmed that even if these alterations dawned different variations of the supply chain, they all have the same goal: to provide a competitive and environment-friendly model for the industry that will utilize it.

3. Methods

3.1 Model Definition

This study utilized a three-level closed-loop supply chain that considers a single self-healing product that revolves around one supplier, one manufacturer, and multiple retailers. This paper considered the Single Set-up Multiple Delivery (SSMD) policy (Sarkar et al. 2019; Ong et al., 2020). In the model, every aspect of the supply chain is considered in the total cost, including self-healing packages, inventory cost, transportation of goods, and carbon emission. This study also considered the direct and indirect carbon emissions from inventory and transportation as one of the factors considered in the Kyoto Protocol. The three-level closed-loop supply chain considers specific carbon emissions of direct and indirect inventory and direct transportation. The model also aims to optimize the total cost and lessen the carbon emission throughout the process (Ong et al., 2020). Both shipped and returned, the self-healing packages have a constant state. The state of the packages would be assumed the same throughout. The demand is always met; thus, shortages are not permitted in this model. The ordering and holding costs are considered the same for all the retailers. The demand is the same throughout the process of the supply chain. The cycle time is assumed to be an integer and has the same value from the process in the supplier to the manufacturer. The manufacturer to retailer, and supplier to manufacturer connection are assumed that can obtain and collect products. Throughout the processes in the supply chain, all its aspects are assumed to be the same, specifically, but not limited to, shipping, manufacturing carbon emission, and the amount of energy rate.

As an overview of the developed model (Figure 1), the supplier possesses the raw materials that are delivered by the sub-supplier. This is considered as a semi-finished product that has a rate of P_s for the manufacturer. Sequentially, utilizing the delivered semi-finished product, the manufacturer then processes its finished products at a rate of $P_{m,}$ delivered to multiple retailers. The manufacturer can pick-up their inventory materials from the supplier, similar to the relation between the retailer and the manufacturer. Lastly, the carbon emission that is regarded in this model is indirect and direct industrial and transport emission being emitted by each party of the CLSC.

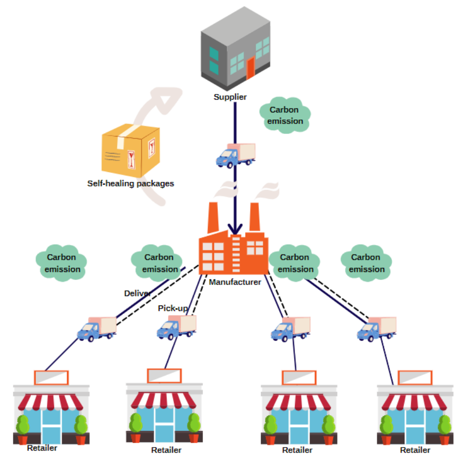

Figure 1. Supply Chain Model

3.2 Mathematical Model

The supplier and manufacturer considered possible costs such as cost per order, cost of set-up production, holding cost for the raw materials to semi-finished product, self-healing packages, maintenance and procurement, and costs for the indirect and direct emission of carbon for industrial and transportation. The cost of buying, inventory keeping costs, direct industrial and transport carbon emission costs are taken into account by the retailer. The sum of the total costs was considered to formulate the mathematical model of the closed-loop supply chain (Equation 1).

$$
\begin{aligned}
TC(C_T, M_{CT}, R_{CT}, S_R, M_R) &= \Bigg[\frac{C_T}{2}\Bigg(R_{CT}\Bigg(\frac{h_{sr}M_{CT}D^2}{S_R P_s} + \frac{2h_s D^2}{M_R P_s} - \frac{h_s M_{CT} D^2}{P_s} + \frac{h_s D^2}{P_m} + h_s M_{CT} D - h_s D - \frac{h_m D^2}{P_m} + h_m D\Bigg)\Bigg) \\
&+ \frac{2h_m D^2}{P_m} - h_m D + h_r D\Bigg] \\
&+ \Bigg[\frac{1}{C_T}\Bigg(\frac{1}{R_{CT}}\Bigg(\frac{A_s + O_s S_R}{M_{CT}} + A_m + O_m M_R + \frac{S_{m1} D}{X_m}\Bigg)\Bigg) + O_r + \frac{S_{S2} D}{X_s} + \frac{S_{m2} D}{X_m} + \frac{S_{S1} D}{X_m M_{CT} M_R}\Bigg] \\
&+ \Bigg[C_T\Bigg(M_{CT}\Bigg(\frac{D\Delta_{I1}(H + C + S + E)E_I C_{tax}}{S_s} + \frac{D\Delta_{I2} C_{tax}}{S_s} + \frac{\gamma\delta(2D_s + D_m)}{S_s} \\
&+ \frac{C_{tax}[\Delta_{T1} W D + \gamma(2D_s + D_m)]}{S_s}\Bigg)\Bigg) \\
&+ \Bigg(R_{CT}\Bigg(\frac{D\Delta_{I1}(H + C + S + E)E_I C_{tax}}{S_m} + \frac{D\Delta_{I2} C_{tax}}{S_m} + \frac{\gamma\delta(2D_m + D_r)}{S_m} \\
&+ \frac{C_{tax}[D\Delta_{T1} W + \gamma(2D_m + D_r)]}{S_m}\Bigg)\Bigg) + \frac{D\Delta_{I1}(H + C + S + E)E_I C_{tax}}{S_r} + \frac{\Delta_{T1}\gamma(2D_r)C_{tax}}{S_r}\Bigg] \\
&+ DV_{s1}(opt) + DV_{m1}(opt) + \frac{DV_{s1}(opt)}{X_s} + \frac{DV_{m2}(opt)}{X_m}
\end{aligned}
$$

Equation 1. Total Supply Chain Mathematical Model

The decision variables considered were: (C_T) regular cycle time to multiple retailers (year), (M_{CT}) manufacturer's cycle time as a multiplier, (R_{CT}) retailer's cycle time as a multiplier, (S_R) inventory received from sub-supplier in a cycle time, and (M_R) inventory received from supplier in a cycle time. In order to obtain the least value, decision variables ran into derivation, algebraically as seen in the following equations:

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

$$= \frac{\left(C_T\sqrt{K_1 + K_2 + \frac{K_3}{2} + \frac{K_4}{2}} - \sqrt{A}\right)^2}{C_T} + 2\sqrt{(K_1 + K_2 + \frac{K_3}{2} + \frac{K_4}{2})(A)}$$

Once the decision variable is with regard to C_T, the overall cost equation approaches the minimum value.

$$C_T^* = \sqrt{\frac{A}{K_1 + K_2 + \frac{K_3}{2} + \frac{K_4}{2}}}$$

The different decision variables were derived in the same manner, obtaining the following equations.

$$R_{CT}^* = \sqrt{\frac{J_2\emptyset_2 + J_3\emptyset_2}{J_1 L}} \quad M_{CT}^* = \sqrt{\frac{(\varphi_5 S_{S1} D)}{\varphi_4 Z + J_4\varphi_1}} \quad S_R^* = \sqrt{\frac{A_s h_{sr} D^2}{P_s(O_s\varphi_0 + X_m O_s \alpha_1)}} \quad M_R^* = \sqrt{\frac{R_s D(2(X_m)^2 O_s h_s D^3 A_s h_{sr} + \varphi_4 S_{S1} + \varphi_5 S_{S1} X_m}{X_m P_s(\emptyset_{15}\varphi_5 S_{S1} D\varphi_4)}}$$

For the supply chain, the final overall cost equation is equated to equation 2.

$$EJTC = 2\sqrt{(\varphi_5 S_{s1} D\varphi_4 Z)} + 2\sqrt{(R_s D(2(X_m)^2 O_s h_s D^3 A_s h_{sr} + \varphi_4 S_{s1} + \varphi_5 S_{s1} X_m)\big(X_m P_s(\emptyset_{15}\varphi_5 S_{s1} D\varphi_1)\big)} + \sqrt{J_{11}} + J_3$$

Equation 2. Final Expected Joint Total Cost

3.3 Variable notation

$\Psi_0 = h_s D\left(1 - \frac{D}{P_s}\right)$

$L = O_r + F_{m_1} + F_{m_2} + \frac{S_{s_2}D}{X_s} + \frac{S_{m_2}D}{X_m} + \frac{S_{s_1}D}{X_s M_{CT} M_R}$

$\Psi_1 = \frac{h_{sr}D^2}{S_R P_s} + \Psi_0$

$J_1 = \propto_2 + \Psi_2$

$\emptyset_3 = D\Delta_{I1}(H + S + C + E)E_I C_{Tax}$

$\propto_0 = \frac{h_s D^2}{P_m} - h_s D - \frac{h_m D^2}{P_m} + h_m D$

$J_2 = \Psi_3$

$\emptyset_4 = D\Delta_{I2} C_{Tax}$

$\propto_1 = \frac{2h_{sr}D^2}{M_R P_S} + \frac{h_s D^2}{P_m} - h_s D - \frac{h_m D^2}{P_m} + h_m D$

$J_3 = K_3 + K_4$

$J_4 = A_m + M_R\emptyset_{15} + \frac{S_{m_1}D}{X_m}$

$\Psi_2 = M_{cr}\Psi_1 + \propto_1$

$J_5 = \Psi_1\emptyset_1 + J_4 J_6 \propto_1$

$J_6 = Z(\Psi_4 + \Psi_5)$

$\propto_2 = \frac{2h_m D^2}{P_m} - h_m D + h_r D$

$Z = O_r + F_{m_1} + F_{m_2} + \frac{S_{s_2}D}{X_s} + \frac{S_{m_2}D}{X_m}$

$K_1 = \frac{R_{CT}\Psi_2 + \propto_2}{2}$

$K_2 = \frac{2R_{CT}\Psi_3}{2}$

$K_3 = M_{CT}\Psi_4$

$K_4 = \Psi_5$

$J_7 = \frac{\Psi_4 S_{s_1} D}{M_R} + 2\Psi_5 + J_5$

$J_8 = \frac{\Psi_5 S_{s_1} D}{M_R} + X_m\emptyset_1 \propto_1$

$\emptyset_1 = A_s + O_s S_R$

$\emptyset_{15} = O_m + F_{S_1} + F_{S_2}$

$\emptyset_2 = \frac{\emptyset_1}{M_{CT}} + A_m + M_R\emptyset_{15} + \frac{S_{m_1}D}{X_m}$

$A = \frac{\emptyset_2}{R_{CT}} + O_r + F_{m_1} + F_{m_2} + \frac{S_{s_2}D}{X_s} + \frac{S_{m_2}D}{X_m} + \frac{S_{s_1}D}{X_s M_{CT} M_R}$

$$\propto_3 = DV_{s_1}(opt) + DV_{m_1}(opt) + \frac{DV_{s_2}(opt)}{X_s} + \frac{DV_{m_2}(opt)}{X_m} \qquad \Psi_3 = \frac{\emptyset_3 + \emptyset_4}{S_m}$$

$$J_9 = \frac{\Psi_4 S_{s_1} D}{X_m M_R} + \frac{O_s h_{sr} D^2}{P_S} + J_4 J_6 \propto_1 + 2\Psi_5 + \frac{\Psi_5 S_{s_1} D}{M_R} + \propto_1 X_m A_s + A_s \Psi_0 \qquad \Psi_4 = \frac{\emptyset_3 + \emptyset_4}{S_s}$$

$$J_{10} = \frac{O_s h_{sr} D^2}{P_S} + J_4 J_6 \propto_1 + 2\Psi_5 + \propto_1 X_m A_s + A_s \Psi_0 \qquad \Psi_5 = \frac{\emptyset_3}{S_r}$$

$$J_{11} = A_s h_{sr} D^2 P_s O_s(\Psi_0 + O_s \propto_0) + J_{10} + \Psi_5 S_{s1} D \Psi_1 \left(A_m + \frac{S_{s1} D}{X_m}\right)$$

4. Data Collection

The data that were utilized for interpretation of the model were adapted from the study of Sarkar et al. (2019) and Ong et al. (2020) (Table 1). The adaptation was carried in order to yield the total cost functions expectation considering the decision variables of total time for every retailer (C_T), the manufacturer's integer multiplier (M_{CT}) and retailer (R_{CT}), and the supplier's received inventory (S_R) and manufacturer (M_R). In this section, the developed mathematical model to optimize a sustainable supply chain is expounded. The optimal determined are shown in Table 2.

Table 1. Numerical Example

Parameters	Supplier	Manufacturer	Retailer
Ordering Costs	O_s=\$300/order	O_m=\$150/order	O_{rj}=\$30/order
Setup Cost	A_s=\$500/setup	A_m=\$200/setup	
Finished Product Holding Costs	h_s=\$0.6/unit/yr	h_m=\$5/unit/yr	h_{rj}=\$5/unit/yr
Raw Material Holding Cost	$h_{s'}$=\$0.4/unit/yr		
Production Rate	P_s=2990 units/yr	P_m=1900 units/yr	
Demand rate of the retailer		D=100 units	
Self-healing package purchase	S_{s1}=\$0.5/unit	S_{m1}=\$0.4/unit	
Self-healing package maintenance cost	S_{s2}=\$0.01/unit	S_{m2}=\$0.009/unit	
Shipment package capacity	X_s=4 units	X_m= 7 units	
Carbon emission tax		C_{tax} =\$20/ton CO_2	
Weight of a unit part		W=12 lbs/unit	
Fuel Price		δ=\$1.02/L	
Fuel Consumption		γ=0.63569 L/miles	
Distance from supplier to manufacturer	d_s=600 miles		
Distance from manufacturer to retailer		d_m=50 miles	
Distance from retailer to manufacturer			d_r=50 miles
Indirect transport emission factor	Δ_{TI}=0.01268-ton CO_2/L		
Indirect industrial emission factor	Δ_{I1} =0.02264-ton CO_2/Kwh		
Direct industrial emission factor	Δ_{I2} =0.00965-ton CO_2/ unit		
Electricity energy consumption		E=154, 556 Kwh	
Steaming Energy Consumption		S=115, 917 Kwh	
Cooling Energy Consumption		C=77, 278 Kwh	
Heating Energy Consumption		H=38, 639 Kwh	
Energy Loss rate		E_l=1%	

5. Results and Discussion

The developed model presented the total cost of the three-level closed-loop supply chain by applying the direct and indirect carbon emission out of the system's transport together with the industrial components. As shown in Table 2, it is evident that the value of 1 in M_{CT}, 10 in R_{CT}, 1 in S_R, and 36 in M_R yielded the total cost's lowest optimal value of 6,771.66 when having the value of 0.378723 in the cycle time C_r.

Table 2. Optimum Result

M_{CT}	R_{CT}	S_R	M_R	C_T	Total Cost
1	9	1	36	0.378723	6885.13
1	**10**	**1**	**36**	**0.378723**	**6771.66**
2	9	1	36	0.378723	8661.35
2	10	1	36	0.378723	8771.50

5.1 Numerical Results

In determining the area of the effect, sensitivity analysis was carried between varied main parameters, as seen in Table 3. This includes the costs' order, set-up cost, manufacturer's holding costs, and the holding cost of the retailer. The analysis also considered the self-healing packages and procurement cost. Moreover, the considered general parameters are carbon emission tax, fuel price, fuel consumption, unit weight, direct and indirect carbon emission of transport and industrial sectors, and each party's emission from heat, electric, cool, and steam. Lastly, the utilized percent shifts in the sensitivity analysis were -75, -50, -25, +25, +50, and +75.

Table 3. Sensitivity Analysis

Parameter	% Change	% Change EJTC	Parameter	% Change	% Change EJTC
O_m	75	18.75363832	S	75	6.083264306
	50	11.76687057		50	2.407031664
	25	5.55654255		25	1.022941
	-25	-5.55654255		-25	-1.022941
	-50	-11.76687057		-50	-2.407031664
	-75	-18.75363832		-75	-6.083264306
A_m	75	0.588369711	C	75	2.407031664
	50	0.391491712		50	2.115770343
	25	0.195382891		25	0.094565689
	-25	-0.195382891		-25	-0.094565689
	-50	-0.391491712		-50	-2.115770343
	-75	-0.588369711		-75	-2.407031664
h_m	75	5.240679569	γ	75	0.000039
	50	3.433815343		50	0.000039
	25	1.687947534		25	0.000038734
	-25	-1.687947534		-25	-0.000038734
	-50	-3.433815343		-50	-0.000039
	-75	-5.240679569		-75	-0.000039
h_r	75	19.92333781	S_{m1}	75	0.080102952
	50	12.45508632		50	0.053400628
	25	5.862477884		25	0.026712565
	-25	-5.862477884		-25	-0.026712565
	-50	-12.45508632		-50	-0.053400628
	-75	-19.92333781		-75	-0.080102952
Δ_{I1}	75	43.93995183	X_m	75	-0.390509827
	50	25.55096409		50	-0.130483965
	25	11.32826823		25	-0.043506728
	-25	-11.32826823		-25	0.043506728
	-50	-25.55096409		-50	0.130483965
	-75	-43.93995183		-75	0.390509827
	75	0.002961991		75	0.002236311

Δ_{I2}	50	0.001987706	S_{s1}	50	0.001503775
	25	0.001013012		25	0.000771235
	-25	-0.001013012		-25	-0.000771235
	-50	-0.001987706		-50	-0.001503775
	-75	-0.002961991		-75	-0.002236311
C_{tax}	75	43.93995183	S_{s2}	75	0.002807707
	50	25.55096409		50	0.001884699
	25	11.32826823		25	0.000961708
	-25	-11.32826823		-25	-0.000961708
	-50	-25.55096409		-50	-0.001884699
	-75	-43.93995183		-75	-0.002807707
E	75	10.03326538	X_s	75	-0.12164439
	50	4.828873463		50	-0.040555237
	25	0.094565674		25	-0.013496257
	-25	-0.094565674		-25	0.013496257
	-50	-4.828873463		-50	0.040555237
	-75	-10.03326538		-75	0.12164439
H	75	-1.022941	V_{s2}	75	-0.027735367
	50	-2.115770343		50	-0.018501457
	25	-3.184730876		25	-0.009269251
	-25	3.184730876		-25	0.009269251
	-50	2.115770343		-50	0.018501457
	-75	1.022941		-75	0.027735367
V_{s1}	75	0.110917334	F_{m2}	75	-0.133123
	50	0.073930491		50	-0.088722
	25	0.036970968		25	-0.044361
	-25	-0.036970968		-25	0.044361
	-50	-0.073930491		-50	0.088722
	-75	-0.110917334		-75	0.133123
F_{m1}	75	0.133122566	F_{s1}	75	1.60458
	50	0.088721948		50	1.064042
	25	0.044360688		25	0.529225
	-25	-0.044360688		-25	-0.529225
	-50	-0.088721948		-50	-1.064042
	-75	-0.133122566		-75	-1.60458
E_I	75	43.93995183			
	50	25.55096409			
	25	11.32826825			
	-25	-11.32826825			
	-50	-25.55096409			
	-75	-43.93995183			

In carrying the sensitivity analysis, manufacturer's package shipment capacity (X_m), supplier's package shipment capacity (X_s) , and heating energy consumption (H) have a significant inverse change in annual total cost throughout the supply chain. This implies that if the quantities of the parameters increase, the total cost of the supply chain decreases. Similarly, when the value of the parameters decreases, then the annual total cost increases.

Furthermore, the manufacturer's ordering cost (O_m), set-up cost (A_m), finished product holding cost (h_m), holding cost of retailer's inventory (h_r), manufacturer's cooling energy (C_m), Indirect industrial emission factor (ΔI_1), rate of energy lost (E_I), Carbon tax (C_{tax}), electric energy consumption (E), steam energy consumption (S), cost of fixed transportation in forward logistics (F_{s1}), cost of fixed transportation in reversed logistics (F_{s2}), cost of variable transportation in forward logistics (V_{s1}), cost of variable transportation in reversed logistics (V_{s2}), forward logistics fixed transportation cost (F_{m1}), and reversed logistics fixed transportation cost (F_{m2}), showed a significant change in

EJTC as the said parameters increased. This case is considered as direct change, in which it states that when the value of parameter increases, the total cost of the supply chain also increases.

To further expound the significant changes, the increase in the manufacturer's ordering cost (O_m), set-up cost (A_m), finished product holding cost (h_m), and holding cost of retailer's inventory (h_r) is related to one another. According to Chan (2015), the ordering cost's direct increase to the total cost means that the assumption in the study that the demand is the same and affects the parameter directly. Thus, if the demand increases, the ordering cost of the manufacturer also increases. With this, the effect of the increase in demand affects the A_m, since the order of the manufacturer from the supplier also increases, then the set-up cost to start processing a product will escalate (Bragg, 2018). After the manufacturer has finished the product, the relation of h_m in the process is also evident. With the idea of the direct increase of finished products, the manufacturer's holding cost will also increase. Sequentially, given the concept of demand in the model, since the manufacturer's finished product increases, then the h_r also increases. The concept that when the retailer orders a product with respect to the demand of the CLSC, then its holding cost will also increase (Ali, 2019). With these related notions, the results show that while these concepts change, the parameters relating to carbon emission and energy are also affected.

The explanation of C_{tax}, E_I, and $\Delta I1$'s direct change also shows a correlation to each other. Since it is evident that when the prices for carbon emission contribute to carbon tax, the overall cost will also be affected directly (Giraldo et al., 2020). As for the E_I, its increase is caused by advancing the sustainable system which significantly affected the total cost (Iqbal et al., 2020). For $\Delta I1$, it is apparent that as the customer's demand increases, the total indirect carbon emission of the industrial operations escalates. This is due to the direct activities of the company that is essential for product processing. Thus, this will affect the total cost. Moreover, with the increase of the industrial operation, the relation of this to the C, E and S is also evident. This correlation implies that when there are rigorous industrial activities due to an increase of demand, then the consumption of energy also increases (Wangsa, 2017). However, H shows an inverse relation as the demand increases. This behavior is due to the utilization of CLSC and self-healing packages, the reusability of the packaging materials causes this inverse relation to the total cost (Sarkar et al. 2019). With CLSC affecting the total cost of the model, there are parameters that show a significant change with respect to this utilized concept.

The assumed equal demand and adaptation of SSMD policy in the model greatly affects the majority of the parameters. For instance, F_{s1},F_{s2}, V_{s1}, V_{s2}, F_{m1}, and F_{m2} evidently shows its direct increase in the total cost due to the increase in demand. Thus, if the demand escalates, then the enumerated parameter's effect on the total cost also increases, and vice versa. However, since the model is a CLSC and it utilized the self-healing packages, there is an inverse relation on the X_m and X_s. This behavior is caused due to the concept of CLSC in which there is a two-way process that when the transportation goes back from the delivery, there is no waste of transportation due to the reversed logistics.

The results yielded for the direct emission industrial factor(ΔI_2), cost of maintenance per self-healing package after return (S_{S2}), and price of the self-healing package for every purchase shows a minimal but direct change in the annual total cost of the supply chain.

Due to the utilization of CLSC, there are parameters that showed an infinitesimal or has no change at all to the total cost after the said analysis, namely, retailer's cooling energy consumption (C_r), indirect transportation emission factor (ΔT_1), consumption of fuel(γ), unit weight(W), and manufacturer's maintenance cost per self-package after return (S_{m2}).

The aspects to take in attempting to optimize and alleviate the total cost of the CLSC system are the primary parameters that had significant changes after the sensitivity analysis. This can be utilized in order to help any industry that uses a three-level closed-loop supply chain to lower the total cost, and thereby increase the total profit. Similarly, the decrease in total cost would also lessen the carbon emission (Ong et al., 2020).

5.2 Proposed Improvements

In utilizing a mathematical model for further development of the CLSC, applying the different cases of Sarkar et al. (2018) is highly recommendable. Moreover, on a managerial level, manipulating the different parameters that apply to an industry can optimize the total cost and maximize the usage of funds. With this, further researchers that have a similar objective and means on this study can consider manipulating the parameters that had significant changes after the sensitivity analysis (Table 3). Lastly, with the emerging popularity of self-healing packages and the concerning threat of global warming, utilizing this new technology can be a solution in lessening the rampant carbon emission. Thus, it is highly recommendable for further researchers to consider the self-healing packages in developing and studying supply chain optimization.

6. Conclusion

This study was able to develop a mathematical model of a closed-loop supply chain that took into account the SSMD policy, self-healing packages, and the direct and indirect carbon emission from the industrial and transportation aspect of the CLSC. It was evident in this study that the notion of Ong et al. (2020) applies to the mathematical model that was developed in this study, in which it states that when total cost decreases, the carbon emission also decreases. These said concepts also provided a competitive advantage for the business while taking into account the expenses that the Kyoto protocol and carbon tax can bring. Moreover, the utilization of the self-healing packages in this study showed a novel solution to the problem of rampant greenhouse gas emissions and innovative packaging for businesses. Thus, it provided a solution not only to the cost that the traditional packaging can bring but also to the problem of the traditional supply chain as one of the contributors to carbon emission.

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