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Total Cost and Carbon Emission Reduction of a Three-Level Supply Chain Rubber Industry in the Philippines

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Abstract. Rubber industry supply chain has a great impact in the world, already utilizing 12.3 million tons of natural rubber while the synthetic rubber production accounted for 14.46 million tons in 2015. Rubber is used as column guards for construction protection especially for walls and column structures. The main objective of this paper was to utilize the mathematical model created by Ong et al. [1] as an application for the reduction of total cost in the rubber industry supply chain in the Philippines. Utilizing Maple Software, the result of this study showed that interest played as the key parameter in the reduction of the total cost. The sensitivity analysis denounced parameters that could be used for interim financing. The parameters could be manipulated to favor the total cost for the different parties of the supply chain. Thus, this study could be used as a baseline for the rubber industries supply chain worldwide.

Keywords: supply chain, rubber industry, interest income

1. Introduction

Supply chain considers environmental, social, and economic aspects when dealing with total cost reduction [2]. It is said that the awareness of customers on the protection of the environment and sustainability has been rising globally which makes pressure on focusing studies in global supply chains. Numerous studies dealt with different models of the supply chain like the one done by Qi et al. [3] wherein they studied carbon cap regulation for two-echelon supply chain, decisions in pricing were manipulated to favor the one supplier two retailer system by incorporating the effect of carbon capping and strategies in minimizing total cost improving the pricing decision. Wangsa [4] showed the effect of a carbon tax on the two-level supply chain in a mathematical model. The mathematical model dealt with the direct and indirect emissions considering transportation and industrial carbon emission that would help create strategies in minimizing total cost and improving pricing decision. The factors considered would help future studies make a more specified mathematical model that deals with carbon emission of different aspects such as inventory and transportation. This was the basis of the model created by Ong et al. [1]. Other mathematical models had applications already and were proven since the creation. Ong et al. [1] claimed that it was created to be applied to any supply chain industry and that it considered general costs, carbon emission through energy consumptions, and transportation – the basic costs for a supply chain industry [1]. However, the model only had the theoretical application and has not been utilized by an existing supply chain industries.

In the Philippines, there has not been much experience of studying or having technology in improving the supply chains, specifically for the rubber industry as per the interview with the owner of a rubber industry corporation. Rubber industry utilizes natural rubber, mainly used in Asia, Africa, and Latin America, and these industrialized areas are considered as major natural rubber consuming countries around the world. Market Insider [5] stated that they shared about 75% of the global rubber consumption in 2016. The top six natural rubber producers in the world are Thailand, Indonesia, Malaysia, India, Vietnam, and China which contributed 86.5% to the global total output in 2016 [5]. The total consumption of rubber worldwide was 26.8 million tons, with natural rubber accounting for about 46% or 12.2 million tons while that of synthetic rubber was recorded at 54% and accounted for 14.6 million tons in 2015 according to IRSG. The natural rubber production of the world accounted for 12.3 million tons while the synthetic rubber production accounted for 14.46 million tons in 2015. Of these, 92% was produced in the Asia-Pacific region. The process involves a lot of energy consumption through electricity, cooling, and the like, which is the industrial carbon emission utilized by Ong et al. [1] in his model.

The supply chain of the rubber molding industry uses a three-echelon supply chain, which consists of the supplier of the natural rubber delivered to the manufacturer (rubber melding industry) and the end-user or customers. The industry considered follows the Single set-up multiple delivery (SSMD) policy as well, one focus of the application model. According to Kim et al. [6], SSMD policy is utilized for maximum delivery that can be done in a single set-up for a more optimized costing in transportation. This means that multiple deliveries are done with one type of material to lessen transportation and carbon emission costing. The rubber industry, not only in the Philippines but in Asia, is becoming more and more competitive and a proper simulation and optimization should be considered for this industry to enable efficient output [5].

The main objective of the study was to apply the mathematical model of Ong et al. [1] to determine the least total cost possible having different scenarios of multi-delay in payment of the supply chain and carbon emission for rubber compounding industry in the Philippines. Furthermore, the paper determined which scenario of multi-delay in payment would produce the best result for the supply chain to lower the total cost; and which parameter would greatly contribute to the total cost. This study gave further recommendations on the result of the application in the supply chain.

2. Model Definition and Notations

This section covers the total cost of the three-level rubber column guard supply chain considering the SSMD policy. As a general overview of the model, the supplier has its raw materials delivered by the sub-supplier having finished what is considered as a semi-finished product, from raw materials of pure rubber to bale, at a rate of *Ps* for the manufacturer. The manufacturer then builds its finished products, from bale to column guards, from the semi-finished one as its raw materials at a rate of *Pm*, delivered to multiple retailers, as column guards to assembly needed. Additionally, the manufacturer could pick-up their inventory materials from the supplier, likewise the retailer to the manufacturer. Moreover, the carbon emission considered in this model, are direct and indirect industrial and transport emissions that are being produced by each player of the supply chain measured through consumption of energy usage (kWh). Fig. 1 demonstrates the three-level supply chain being considered. Following which are the cost relationship of rubber industry supply chain incurred for the mathematical model application.

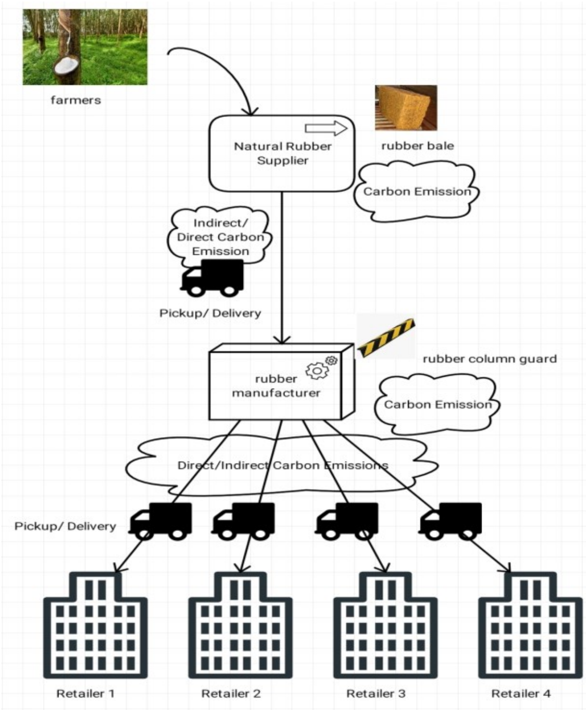

Fig. 1. Rubber industry supply chain

Presented in Table 1 are the notation and numerical data utilized for this study. The mathematical model was derived to determine the least total cost (*TC*) of the three-level supply chain. Presented in equation 1 is the formulation of cases:

$$\textit{Minimize } TC = \textit{Supplier Cost} + \textit{Manufacturer Cost} + \textit{Retailer Cost} \tag{1}$$

Since the model is a non-constraint linear programming mathematical model, no constraints were considered, only the objective function. Different scenarios (*c1-c4*) were illustrated in each total cost that demonstrates the condition of the whole supply chain in a real-life scene when it comes to credit payment by players in the supply chain. Four cases were generated considering multi-delay-in-payment as presented in equation 2-5. Equation 2 is for manufacturer (TC_{m1}) having less than the lead time compared to the interest income earned from supplier (TC_{s1}), likewise retailer to manufacturer (TC_{r1}). Equation 3 is TC_{m1} and TC_{s1} while retailer has larger lead time than interest income earned to manufacturer (TC_{r2}). Equation 4 has larger lead time of manufacturer and supplier than interest income (TC_{s2} and TC_{m2}), while TCr1. Lastly, Equation 5 is TC_{s2}, TC_{m2}, and TC_{r2}.

$$\textit{Total Cost}_{C1} = TC_{s1} + TC_{m1} + TC_{r1} \tag{2}$$
$$\textit{Total Cost}_{C2} = TC_{s1} + TC_{m1} + TC_{r2} \tag{3}$$
$$\textit{Total Cost}_{C3} = TC_{s2} + TC_{m2} + TC_{r1} \tag{4}$$
$$\textit{Total Cost}_{C4} = TC_{s2} + TC_{m2} + TC_{r2} \tag{5}$$

3. Results and Discussion

Maple software was utilized in this study to obtain the values for the least cost among the different cases presented. Upon final derivation, the total cost was least upon utilizing case 4 as seen on equation 6.

$$\begin{aligned}
&TC_4(C_T, M_{CT}, R_{CT}, S_R, M_R)\\
&= \Bigg(\frac{C_T}{2}\Bigg(R_{CT}\Bigg(\frac{h_{sr}M_{CT}{D_s}^2}{S_R P_s} + \frac{2h_s{D_s}^2}{M_R P_s} - \frac{h_s M_{CT}{D_s}^2}{P_s} + \frac{h_s{D_s}^2}{P_m} + h_s M_{CT} D_s - h_s D_s - \frac{h_m{D_m}^2}{P_m} + h_m D_m\\
&- C_m I_{se} M_{CT} D_m + C_m I_{mp} D_m - C_r I_{me} D_m\Bigg)\Bigg) + \frac{2h_m{D_m}^2}{P_m} - h_m D_m + \sum_{i=1}^{n}(h_r D_{ri} + C_r I_{rp} D_{ri})\Bigg)\\
&+ \Bigg(\frac{1}{C_T}\Bigg(\frac{1}{R_{CT}}\Bigg(\frac{A_s + O_s S_R}{M_{CT}} + \frac{C_s I_{sp} D_m X^2}{2M_{CT}} - \frac{C_m I_{se} D_m X^2}{2M_{CT}} + A_m + O_m M_R + \frac{C_m I_{mp} D_m Y^2}{2} + \frac{C_m I_{mp} D_m X^2}{2}\\
&- \frac{C_r I_{me} D_m Y^2}{2} - \frac{C_r I_{me} D_m X^2}{2}\Bigg)\Bigg) + O_r + \sum_{i=1}^{n}\Big(\frac{C_r I_{rp} D_r Y^2}{2} - \frac{p I_{re} D_r Y^2}{2}\Big)\Bigg)\\
&+ \Bigg(C_T\Bigg(M_{CT}\Bigg(\frac{D_s \Delta_{I1}(\mathrm{H_{em}} + \mathrm{C_{em}} + \mathrm{E_{em}})\mathrm{E_I C_{tax}}}{\mathrm{S_s}} + \frac{D_s \Delta_{I2} \mathrm{C_{tax}}}{S_s} + \frac{\gamma\delta(2\mathrm{d_s} + \mathrm{d_m})}{S_s}\\
&+ \frac{\mathrm{C_{tax}}[D_s \Delta_{T1} \mathrm{W} + \gamma(2\mathrm{d_s} + \mathrm{d_m})]}{S_s}\Bigg)\Bigg)\\
&+ \Bigg(R_{CT}\Bigg(\frac{D_m \Delta_{I1}(\mathrm{H_{em}} + \mathrm{C_{em}} + \mathrm{E_{em}})\mathrm{E_I C_{tax}}}{\mathrm{S_m}} + \frac{D_m \Delta_{I2} \mathrm{C_{tax}}}{S_m} + \frac{\gamma\delta(2\mathrm{d}_m + \mathrm{d}_r)}{S_m}\\
&+ \frac{\mathrm{C_{tax}}[D_m \Delta_{T1} \mathrm{W} + \gamma(2\mathrm{d}_m + \mathrm{d}_r)]}{S_m}\Bigg)\Bigg) + \frac{D_r \Delta_{I1}(H_{em} + C_{em} + E_{em})E_I C_{tax}}{S_r} + \frac{\Delta_{T1}\gamma(2\mathrm{d_r})\mathrm{C_{tax}}}{S_r}\\
&+ \frac{D\Delta_{I1}(H_{em} + C_{em} + S_{em} + E_{em})E_I C_{tax}}{S_r} + \frac{\Delta_{T1}\gamma(2\mathrm{D_r})\mathrm{C_{tax}}}{S_r} + \frac{\mathrm{D}\theta}{S_r}\Bigg) + C_m I_{se} D_m X - C_m I_{mp} D_m X + C_r I_{me} D_m Y\\
&- \sum_{i=1}^{n}(C_r I_{rp} D_{ri} Y)
\end{aligned} \tag{6}$$

As seen in Table 2, the summary of the costs is listed and the case with the least cost was used for the sensitivity analysis to determine the parametric values influencing the mathematical model application. This was done by changing the values to an increase and a decrease of low (25%), mid (50%), and high (75%). These percent changes were considered since the result for the sensitivity analysis deduces the change in total cost concerning the increase or decrease of the parameter's value. Values that are lower or higher than ±25%, ±50%, and ±75% had no significant effect [7]. The reason why Sarkar et al. [8,9] and Ong et al [1] considered these percent changes is that their sensitivity analysis showed trends that can conclude the parameters affecting the total cost.

TABLE I. NOTATION AND NUMERICAL DATA

Parameters	Supplier	Manufacturer	Retailer
Ordering Cost, O_s, O_m, O_r	Php 400/order	Php 280/order	Php 70/order
Setup Cost, A_s, A_m	Php 150/setup	Php 200/setup	
Finished Product Holding Cost, h_s, h_m, h_r	Php 115/unit/yr.	Php 150/unit/yr.	Php 150/unit/yr.
Raw Material Holding Cost, h_{sr}	Php 80/unit/yr.		
Production rate, P_s, P_m	6667 units/yr.	5000 units/yr.	
Demand rate of ith retailer, D_s, D_m, D_r	150 units		
Purchasing Cost, C_s, C_m, C_r	Php 110/unit	Php 180/unit	Php 300/unit

Selling Price, p			Php 900/unit
Carbon emission, C_{TAX}	Php 1000/ton CO2 (Wangsa, 2018)		
Weight of a unit part, W	15.4 lbs./ unit		
Fuel Price, δ	Php 39/ L		
Fuel Consumption, γ	4.35 L/ miles		
Distance from supplier to manufacturer, d_s	5 miles		
Distance from manufacturer to retailer, d_m		9 miles	
Distance from retailer to manufacturer, d_r			9 miles
Indirect transport emission factor, Δ_{T1}	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, H_{em}	180487.8049 kwh		
Cooling energy consumption, C_{em}	14634.14634 kwh		
Heating energy consumption, S_{em}	165853.6585 kwh		
Energy Loss rate, E_l	1% (Wangsa, 2018)		
Alternative Cost, I_{sp}, I_{mp}, I_{rp}	I_{sp} = 0.05/yr	I_{mp} = 0.08/yr	I_{rp} = 0.08/yr
Revenue earned, I_{se}, I_{me}, I_{re}	I_{se} = 0.06/yr	I_{me} = 0.06/yr	I_{re} = 0.06/yr
Permissible delay in credit (years)		X = 0.30 & 0.70	Y = 0.30 & 0.70

TABLE II. SUMMARY RESULT FOR THE FOUR CASES

Cases	M_{CT}	R_{CT}	S_R	M_R	C_T	Total Cost
1	1	17	1	1	0.000945	137475.83
2	1	17	1	1	0.000945	160631.21
3	1	3	1	1	0.00202	239460.06
4	2	32	1	1	0.000678	132296.02

Case 4 deals with having a larger permissible delay in payment of credit given to the manufacturer by the supplier compared to lead time and retailer by the manufacturer as well. It could be seen that Php 132, 296.02 would be the least cost with 2 for M_{CT}, 1 for S_R and M_R, 32 for R_{CT}, and 0.00068 total cycle time C_T.

Among the 4 cases, case 4 is seen to be the least cost having Php 132,296.02 as compared to the other cases. The current annual expense was said to be Php 180,000 as compared to the estimated Php 150,000 as per the interview with the owner of One's Rubber and Industrial Supply Corporation. The result for Case 4 shows that Php 132,300 may be the least cost for the rubber industry supply chain; a 26.5% improvement from the current costing and 11.8% for the estimated annual cost. This shows that having a larger permissible delay in payment is beneficial for Ones Rubber and Industrial Supply Corporation. The factor that differs in the four cases is the amount of interest as revenue for the parties of the supply chain. The parties of the supply chain in case 4 would gain profit from the interest due to a larger amount of permissible delay in payment. While lower interest encourages more people to invest [10], income from those interests will be significantly higher with higher interest given. The study of Berisha et al. [11] showed that high-income earners derive their income from the interest of different rates and showed a statistically significant result. Therefore, the total cost will be lower if the profit increases. Due to the rate of interest becoming higher from both echelon of the rubber industry supply chain, case 4 will be considered ideal. To further decipher the cases for this supply chain, a sensitivity analysis was carried out to provide managerial insights into the study, seen in Table 3.

As seen in the sensitivity analysis in Table 3, a large impact or effect was valued having a percent change of 0.1 and above according to the study done by Sarkar et al. [8]. The parameters including the purchasing cost of the retailer (C_r), retailer's selling price (p), and indirect industrial carbon emission (Δ_{I1}) would have a huge impact inversely proportional to the total cost on the rubber industry supply chain. This is because the retailer will be considered as the last part of the supply chain. With that, the total cost would increase because the price of the product will increase as it goes down the supply chain, thus having a higher total cost. Also, the selling price of the retailer would increase as well to gain profit from the sales [12]. Since profit will be gained after products are sold as it goes down the supply chain, then profit increases, the total cost will therefore decrease. Indirect industrial carbon emission would have an inverse effect on the total cost, meaning it will lower the total cost because in this case, the indirect industrial carbon emission comes from the manufacturing part of the product, column guard. Since the column guard manufacturing is only a minimal part of the processes done in the supply chain, it does not necessarily affect an increase in the total cost. While manufacturer and retailer are holding cost (h_r and h_m), direct transportation (Δ_{T1}) and industrial carbon emission cost (Δ_{I2}), the weight of the product (W), fuel consumption (γ), and cooling energy consumption (C_{em}) showed a directly proportional increase while total cost increases, but with minimal effect. With minimal effect are values with 0.01 percent change and lower as seen from the study of Sarkar et al. [8]. The reason for this is that these parameters lay in the equilibrium of the total mathematical model, thus has a small impact on the output [9]. Moreover, the manufacturer and retailer's holding cost (h_r and h_m) would increase total cost because only expense has been considered in these parameters. Holding cost is incurred in products that have been manufactured but has not yet been sold and therefore profit is not yet considered. This shows an increase in expenses, thus an increase in the total cost [13]. Direct transportation (Δ_{T1}) and industrial carbon emission cost (Δ_{I2}) are also increasing the total cost directly proportional because expenses together with the fuel consumption (γ) when products are being made together with delivery increases the total cost for the supply chain [14]. The weight of the product (W) increases total cost as well because according to Lapinskaite and Kuckailyte [15], logistics covers transportation and product or material management, meaning they are correlated with each other. Thus, the increase in transportation also affects the product being delivered may it be weight, amount, or volume. Lastly, cooling energy consumption (C_{em}) has increased the total cost because the manufacturing of column guards spend time for the product to cool down. With that, the company invested in the cooling system to hasten the cooling of the column guards.

The parameters that have great impact –values with 0.1 and higher change [8] on the total cost are the manufacturer's ordering cost (O_m), set-up cost (A_m), purchasing cost (C_m) – because of these covers and includes the personnel cost, consumable materials, etc. Capital alternative cost (I_{mp}), interest earned (I_{me}), and retailers interest earned (I_{re}) increase the total cost as well because interest brings the supply chain to more expensive and therefore counteracts the profit gain [16]. Also, the carbon emission factors such as energy lost rate (E_l), heating (H_{em}), and electricity (E_{em}) play a role in the total cost of the supply chain. This is because the energy consumption of the parameters covers the whole processes including the production, manufacturing, administration works, etc. This consumption of energy is considered to be operating expenses and thus increases during an increase in demand [17]. These parameters are considered large and are directly proportional to the total cost. As could be seen from the results in table 3 – values with 0.1 and higher percent change [8], interest was the factor why case 4 had the lowest cost among the different cases. This is because Creedy and Gemmell [16] had a study resulting in lower investment to low-interest rates. From the result of the sensitivity analysis, the interest from the manufacturer and retailer had the largest impact relative to case 4 (i.e. I_{re}, I_{mp}, I_{me}) because the value is much higher with 0.6 as the percent interest rates.

Comparing the result from the main study to this study's result showed a difference wherein the numerical example done showed that case 1 had the least cost for Ong et al. [1] while this study showed case 4. It could be seen that their study utilized a lesser value of 0.04 value for the interest earned (I_{me}) while this study utilized 0.06, thus lower investment [16]. From Ong et al. [1] and this study, the interest earned whether from the manufacturer or retailer side had a great impact directly proportional to the total cost. Interest earned reduces total cost due to greater profit.

Table III. Sensitivity Analysis of Key Parameters

Parameter	% Change	Case 4	Parameter	% Change	Case 4
O_m	-75	-7.8952	Δ_{I1}	-75	-3.54
	-50	-5.1285		-50	-1.74
	-25	-2.5001		-25	-0.34
	+25	2.5000		+25	0.34
	+50	5.1285		+50	1.74
	+75	7.8952		+75	3.54
A_m	-75	-5.5150	Δ_{I2}	-75	-1.10600

	-50	-3.6103		-50	-0.75118
	-25	-1.7732		-25	-0. 37141
	+25	1.7732		+25	0.37141
	+50	3.6103		+50	0. 75118
	+75	5.5151		+75	1.10600
h_m	-75	-0.130	Δ_{T1}	-75	-0.0064
	-50	-0.087		-50	-0.0043
	-25	-0.043		-25	-0.0021
	+25	0.043		+25	0.0021
	+50	0.087		+50	0.0043
	+75	0.130		+75	0.0064
h_r	-75	-0.0043	H_{em}	-75	-0.516
	-50	-0.0029		-50	-0.344
	-25	-0.0014		-25	-0.172
	+25	0.0014		+25	0.171
	+50	0.0029		+50	0.346
	+75	0.0043		+75	0.517
C_m	-75	-0.6137	C_{em}	-75	-0.0454
	-50	-0.5772		-50	-0.0302
	-25	-0.1208		-25	-0.0151
	+25	0.1208		+25	0.0151
	+50	0.5772		+50	0.0302
	+75	0.6137		+75	0.0453
C_r	-75	61.874	E_{em}	-75	-0.5623
	-50	51.960		-50	-0.3742
	-25	-35.100		-25	-0.1867
	+25	-35.105		+25	0.1867
	+50	-51.967		+50	0.3741
	+75	-61.874		+75	0.5623
E_I	-75	-1.131	γ	-75	-0.6317
	-50	-0.751		-50	-0.5386
	-25	-0.374		-25	-0.2353
	+25	0.374		+25	0.2353
	+50	0.750		+50	0.5386
	+75	1.130		+75	0.6317
p	-75	66.9793	δ	-75	-0.754
	-50	57.4879		-50	-0.502
	-25	40.3389		-25	-0.250
	+25	-40.3388		+25	0.249
	+50	-57.4879		+50	0.501
	+75	-66.9791		+75	0.753
I_{mp}	-75	-17.5059	W	-75	-0.0026
	-50	-11.0271		-50	-0.0017
	-25	-5.2255		-25	-0.0009
	+25	5.2255		+25	0.0009
	+50	11.0271		+50	0.0017
	+75	17.5059		+75	0.0026
I_{me}	-75	3.24331	I_{re}	-75	-2.005
	-50	2.18584		-50	-1.671
	-25	1.10499		-25	-1.366
	+25	-1.10499		+25	1.366
	+50	-2.18584		+50	1.671
	+75	-3.24331		+75	2.005

Overall, the mathematical model created by Ong et al. [1] utilized an electronic industry supply chain and claimed that it could be employed with other types of the supply chain. With the result of this study, it could be seen that utilizing the rubber industry supply chain would also be applicable. The model could be used to other types of the supply chain. As per the study, this model could be used for interim financing and consider the parameters with great factors directly or inversely proportional to manipulate the total cost favoring all parties of the supply chain. Lastly, having an algebraic approach to using the mathematical model was easy to use as a deterministic approach especially in a small to medium supply chain industry. Managers would easily use this type of mathematical model for the benefit of their supply chain.

The outcome of this benefits other industries that may have similar movement in the supply chain because it will provide them guidance on which factors may greatly affect their business. Furthermore, the outcome of the paper benefits the whole rubber industry in which there will be a model that can be patterned for their use. Lastly, improving the supply chain of rubber can help our economy reduce carbon emissions, conserve energy, and be more profitable.

4. Conclusion

Focusing on a specific rubber industry in the Philippines, interest played a great influence on the different cases and total cost of the supply chain. The parameters from the manufacturer's ordering cost, set-up cost, purchasing cost, capital alternative cost (Imp), interest earned (Ime), retailers interest earned (Ire), the carbon emission factors such as energy lost rate, heating, and electricity would greatly affect the total cost of the supply chain. These main parameters could be manipulated to favor the total cost of the supply chain to the different parties involved. Carbon emission was reduced together with the total cost as well.

This mathematical model could also be used as interim financing for the different supply chains, not only in the Philippines [18-20]. Giving ample time for payment would benefit the parties of the supply chain due to interest income earned. Lastly, because the mathematical model created was a deterministic algebraic approach, it easily gave exact data for managers to utilize. This would be a great platform for the rubber industry to use for its competitive edge in the market having high profit for any parties of a three-level supply chain.

This study resulted that utilizing multi-supplier to a single manufacturer and multi-retailer mathematical model, or multi-supplier, manufacturer, and retailer type of mathematical model. This could be done to see how a rubber industry would be influenced by having multiple suppliers and or manufacturers. The total cost may be reduced further due to lower price materials. Moreover, applying different products under the rubber industry other than column guards may also be done to easily segregate better scenarios for the reduction of the total cost for all parties of the three-level supply chain. Multi-delay in payment considering pick-up and delivery while carbon emission was considered influenced the supply chain to have a better trade-off among different parties of the supply chain.

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