Building a Green Closed-Loop Supply Chain – A Case Study in Plastic Injection Industry

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Abstract

For the past decades, the supply chain network has been significantly influenced by several major factors. Standing out of those is global warming which causes radical changes in traditional supply chain network. Therefore, environmental vulnerability with legality and economic benefits has made supply chain management to be as an important objective for companies and governments. Sustainability must be built-in supply chain network design (SCND), by striking the right balance between cost-cutting and environmental preservation. The goal of this paper is to develop a green closed–loop supply chain (G-CLSC) network by first, evaluating supplier selection with Multi-criteria decision-making (MCDM). Subsequently, a bi – objective Mixed-Integer Linear Programming (MILP) model is presented for facilities allocating and consolidate closed-loop flow, with two objectives: minimizing operating cost and minimizing CO2 emission. The model is testified by implying on the case of a Vietnamese plastic injection enterprise consisting of facilities spreading all over the country. The simulated result demonstrates the efficiency and validity of the proposed solution model. All possible solutions are measured thoroughly to identify the optimal design for prior environment protection. Ultimately, the solution model finalizes with a forward and a reverse supply chain network.

Keywords
Closed-loop Supply Chain (CLSC), Multi-criteria decision-making, Multi-objective optimization, Environmental supply chain design, Mix-Integer Linear Programming (MILP)

1. Introduction

With the growth of manufacturing industry, all domestic and global firms rely heavily on logistics and transportation systems to succeed. In traditional supply chain, customers are the destination of the process. Nevertheless, the products which do not satisfy customer's expectation and requirement still essentially have recycle value in them. To unlock that potential as well as protecting the environment, a reverse logistic and remanufacturing process must be applied. A Closed-loop Supply Chain (CLSC) targets to create sustainability in the growth of system's performance by combining forward and reverse logistics activities. From then, supply chain managers can proceed to convert the current direct non-returnable logistic into circular returnable. Environmental consequences for facilities throughout the operation of the CLSC network must also be taken into account. The facility's power usage and the insulating reaction of handling materials are two elements that determine the effect of CO2 emissions on facilities. In real-world management, environmental protection at a higher degree in facilities necessitates a higher expenditure in environment protection, but it may result in lower CO2 emissions. A well-functional Green Closed-loop Supply Chain (G-CLSC) can essentially assist firms in finding a fair balance between cost cutting and environmental conservation.

This paper aims to build a G-CLSC network, that can contribute to environment protection while on the other hand can optimize operation cost. The main objective of this study is to focus on designing a supply chain network of a plastic manufacturer in Vietnam (case company) that considers CLSC strategy for product transportation with environmentally friendly operation. For the initial stage, MCDM method is studied to examine ideals alternatives for supplier selection. Afterward, an optimized G-CLSC network is generated by executing a custom-developed MILP model. The output of total operation cost is expected to be minimized, bringing improved performance to the case company.

2. Literature review

As the economy growth, maximizing the profit is always top priority when it comes to corporation. The profit can be increased through many ways and adapt to a new locating strategy is one of them to gain more profit through optimizing location network. It is quite a challenge to achieve an appropriate structure, especially when dealing with a huge number of people, adding up to that is the constantly mutated information. Approaches to develop a supply chain network has been immersive. The simplest and most basic model was to reduce the distance between the manufacturer and multiple clients in a certain area (Weber & Friedrich, 1929), and then developed into many more studies like: the location of garbage collection stations (Wersan et al., 1962), the location of factories (Burstall et al., 1962), location of fire trucks (Valinsky, 1955), and many more.

Establishing a green and adaptable supply chain network (SCN), which can maximize production rate, capacity, and facilities location optimization, while still avoid fume exhaust, has gotten a lot of attention lately (Ilgin & Gupta, 2010). A closed-loop supply-chain (CLSC) network is an amalgamated system by combining forward logistic into reverse one. There have been several studies published on this subject, notably on the G-CLSC, such as consumer interrelation (Gao et al., 2018; Jian et al., 2020), channel selection for recycling (Choi et al., 2013; Huang & Nie, 2012), sales efforts (Gao et al., 2015; Sane Zerang et al., 2018), concerns over fairness (Yao & Liu, 2016), inventory model (Govindan et al., 2020), government financial aid (Chen et al., 2019; Zhu & Dou, 2011), etc.,. Jindal and Sangwan (2017) used the interactive ε-constraint method to build and optimize a multi-objective CLSC while examining unknown economic and environmental variables. The influence of logistic and carbon emission on remanufacturing was studied by Sarkar et al. (2017), suggested a closed-loop multi-echelon supply chain using 3PL (third party logistics). Sahebjamnia et al. (2018) devised a mixed approach toward the problem based on the red deer algorithm and concurrently accounted the effect of social and environment on a CLSC system by applying a multi-objective model. Later on, Lu Zhen et al. (2019) claimed that businesses can strengthen their long-term competitiveness by striking the right balance between cost reduction and environment protection. They first give an intuitive justification for the addition of new constraints. Considering the extreme case of uncertainty demand and environmental level, they will tend to locate many plants that will reduce the transportation costs and CO2 emission.

There is a modest number of researches contributed in the concept of CLCS in Vietnam such as Healthcare industry (Tseng et al., 2021), Electronics industry (Doan et al., 2019), Competitive Advantages and Firm Performance (Quynh & Huy, 2018) and few more. Nonetheless, research on CLSC context in Viet Nam are hardly typical examples relative to environmental aspect. Accordingly, this article proposes a Closed-loop Supply Chain network combined with Green aspect for plastic injection field in Vietnam. As the main objective of this study, a multi-objective optimization model is built with mixed integer linear programming to solve the G-CLSC problem. Based on the evaluated articles listed in Tab. 1, this research was conducted to find the unknown factors within supply chain and offer a solution as a mean to achieve green and robust modelling in the logistics network (Table

1-3). Furthermore, the research aims to contribute to Vietnam supply chain management as well as policy makers in order to support forming a new phase of greener operation for Vietnamese industrial organizations. To achieve the objective of G-CLSC, the study proposes various parameters relating to a green supply chain with the objective of minimizing costs, lessen habitat pollution, and promoting the network's civic duties and dependability (Table 4).

Table 1**.** Literature Comparison

Article	Type of network			Supplier Selection	Multi Materials	Multi Products	Multi levels of Capacity	Multi Periods	Expanding network
	Forward	Reverse	Closed-loop						
Jindal and Sangwan, 2017 (Jindal & Sangwan, 2017)			X	x					
Fathollahi-Fard, 2018 (Fathollahi-Fard et al., 2018)			X	x		x			
Tehrani, 2021 (Tehrani & Gupta, 2021)			X	x	x	x	x		x
Sahebjamnia and Fathollahi-Fard, 2018 (Sahebjamnia et al., 2018)			X	x		x			
Zhen and Huang (Zhen et al., 2019)			X	x		x	x		x
This study			X	x	x	x	x	x	x

3. Mathematical model

For this Green Closed-loop Supply Chain problem, Analytic Hierarchy Process (AHP) method is initially applied to solve the problem of supplier selection. Continuously, a multi-objective MILP model is applied to help decision makers decide whether to open distributor/recovery point or not. The supply chain has four base levels: supplier, manufacturer/re-production point, distributor/recovery point and customer. Criteria for selecting suppliers are based on internal survey. The MILP model involves multiple time periods, raw materials, products, and a single mode of transportation.

3.1 Supplier Decision Making Model

This section follows the standard process of the Analytical Hierarchy Process for management to choose among potential suppliers, which includes matrix constructions, pairwise comparison, finding eigenvectors, and choosing the ultimate option based on criteria. For supplier selection problem in the company, there are 6 alternatives of candidate suppliers. These suppliers come from different countries, they have different stands in the market and associate provision. Therefore, five criteria have been picked and rated by an internal survey of employees in the case company: Reliability, Distance, Profile Sufficiency, Quality, Agility. After the consistency calculation for all levels, the overall priority ranking must be calculated to choose the optimal option. The alternative weights can be obtained by sum of the multiplying each criteria score with supplier scores which are respect to that criteria. The AHP is proceeded by employing programing platform MATLAB, which makes the AHP's phases faster and automates many of its calculations.

3.2 Green Closed-Loop Supply Chain Model

The MILP model, comprising of indices, parameters, and variables, is introduced in this part, followed by the mathematical model, which includes a description of the model and its constraints.

Index:

I	*Number of supplier from* $i = 1,2, \ldots, I$
J	*Number of production plant/reproduction point from* $j=1, \ldots, J$

K	*Number of potential distributor-recovery from k=1, ..., K (Distribution center or DC)*
L	*Number of customer from l=1, ..., L*
R	*Number of raw material from r=1, ..., R*
P	*Number of product from p=1, ..., P*
G	*Set of production capacity level options for facilities from g=1, ..., G*
E	*Set of options for emission control level of the facilities from e=1, ..., E*
T	*Period (month) for t=1, ..., T*

Parameter:

f_{jge}	*Fixed cost of operating plant j at emission control level e with capacity level g*
f_{kge}	*Fixed cost of operating distribution center k at emission control level e with capacity level g*
fe_{ke}	*fixed CO2 emission of operating distribution center k with emission control level e*
D_{plt}	*demand of product p derived from customer l at time t*
c_p	*cost of producing one unit of product p*
a_{pk}	*handling cost at distributor k for handling one unit of product p*
a_{pj}	*cost of plant j to produce a unit of product p*
b_{pk}	*handling cost for recovering a unit of product p at recovery point k*
b_{pj}	*handling cost for re-manufacturing a unit of product p at reproduction point j*
H_r	*holding cost for a unit of material r*
H_p	*holding cost for a unit of product p*
d_{ij}	*distance between supplier i and plant j (in kilometer)*
d_{jk}	*distance between plant j and DC k*
d_{kl}	*distance between DC k and customer l*
V	*shipping cost per one unit of material over each kilometer*
U	*shipping cost per one unit of product over each kilometer*
Ve	*amount of CO2 emission per one unit of material shipped over each kilometer*
Ue	*amount of CO2 emission per one unit of product shipped over each kilometer*
m_{rp}	*amount of material r to produce one unit of product p*
Ca_{ri}	*supply capacity of supplier i for material r*
Ca_{jg}	*production capacity of plant j at level g*
Ca_{kg}	*product processing capacity of potential DC k at level g*
Cb_{jg}	*product processing capacity of potential DC k at level g re-production capacity of plant j at level g*
Cb_{kg}	*returned product processing capacity of potential DC k at level g*
re	*average return rate*
α	*weighted-sum coefficient*

Decision Variables:

y_{keg}	*1 if DC k with emission control level e capacity level g is opened, 0 otherwise*
x_{rijt}	*quantity of material r shipped from supplier i to manufacturer j at time t*
x_{pjkt}	*quantity of product p transported from manufacturer j to DC k at time t*
x_{pklt}	*quantity of product p transported from DC k to customer l at time t*
h_{pjt}	*quantity of product p produced by manufacturer j at time t*
z_{pkjt}	*amount of product p transported from recovery point k to reproduction point j at time t*
z_{plkt}	*amount of product p transported from customer l to recovery point k at time t*

Objective functions:

$$Minimize\ Total\ cost\ Z1 = OC + SC + VC + CC$$
$$Minimize\ Total\ CO2\ Emission\ Z2 = FCO2 + SCO2$$

The first objective function (Z1) is to minimize the downright cost of the whole network, which includes shipping costs for delivering items, constant operating costs for the opening distribution center, variable costs for product processing, and holding costs. The objective function (Z2) is to determine the environmental consequence of the CLSC network in terms of gas emission. This function is intended to minimize overall CO2 emissions from transportation and facility operations. Breakdowns for two objective functions are precisely illustrated in Tab. 2.

Table 2. Objective Function Breakdown

Component	Meaning
Objective Function $\boldsymbol{Z_1}$	

$$OC = \sum_{e=1}^{E}\sum_{g=1}^{G}\left(\sum_{j=1}^{J} f_{jge} + \sum_{k=1}^{K} y_{egk} * f_{kge}\right)$$	The overhead cost (fixed cost) of all facilities
$$SC = \sum_{t=1}^{T}\left[\sum_{r=1}^{R}\sum_{i=1}^{I}\sum_{j=1}^{J} d_{ij} * V * x_{rijt} + \sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{k=1}^{K} d_{jk} * U * (x_{pjkt} + z_{pkjt}) + \sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{l=1}^{L} d_{kl} * U * (x_{pklt} + z_{plkt})\right]$$	The shipping cost (transportation cost) for forward and reverse process
$$VC = \sum_{t=1}^{T}\left[\left(\sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{k=1}^{K}(a_{pj} * x_{pjkt} + b_{pj} * z_{pkjt})\right) + \left(\sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{l=1}^{L}(a_{pk} * x_{pklt} + b_{pk} * z_{plkt})\right)\right]$$	Variable cost of manufacturing, distribution, recovery, and re-manufacturing.
$$CC = \sum_{t=1}^{T}\left[\sum_{r=1}^{R}\sum_{p=1}^{P}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{l=1}^{L} H_r * x_{rijt} + H_p * (x_{pjkt} + z_{pkjt} + x_{pklt} + z_{plkt})\right]$$	Product carrying cost (holding cost) of storing product at manufacturers and distributors.
Objective Function $\boldsymbol{Z_2}$	
$$FCO2 = \sum_{e=1}^{E}\sum_{g=1}^{G}\sum_{k=1}^{K} fe_{ke} * y_{egk}$$	Fixed amount of CO2 emissions resulting from opening facilities.
$$SCO2 = \sum_{t=1}^{T}\left[\sum_{r=1}^{R}\sum_{i=1}^{I}\sum_{j=1}^{J} d_{ij} * Ve * x_{rijt} + \sum_{p=1}^{P}\sum_{j=1}^{J}\sum_{k=1}^{K} d_{jk} * Ue * (x_{pjkt} + z_{pkjt}) + \sum_{p=1}^{P}\sum_{k=1}^{K}\sum_{l=1}^{L} d_{kl} * Ue * (x_{pklt} + z_{plkt})\right]$$	Total quantity of CO2 released from material and product shipping process.

Subject to:

$\sum_{p=1}^{P} m_{rp} * h_{pjt} = \sum_{i=1}^{I} x_{rijt} \; for \; \forall r, j, t$ (1)

In constraint (1), the number of raw materials imported by suppliers for each raw material throughout each period equals the quantity of raw material required for manufacturing.

$h_{pjt} = \sum_{k=1}^{K} x_{pjkt} \; for \; \forall p, j, t$ (2)

Constraint (2) depicts that each month, the quantity of products produced equals the number of products transported to distribution centers.

$\sum_{j=1}^{J} x_{rijt} \le Ca_{ri} \; for \; \forall r, i, t$ (3)

Constraint (3) ensures selected suppliers supply within capacity.

$\sum_{k=1}^{K} x_{pklt} = D_{plt} \; for \; \forall p, l, t$ (4)

Constraint (4) ensures that all products *p* shipped from distributors *k* to customer *l* must satisfy the demand of customer *l* at period *t*.

$\sum_{k=1}^{K} z_{plkt} = D_{plt} * re \; for \; \forall p, l, t$ (5)

Constraint (5) guarantees all returned product p from customer l must be fully gathered at recovery point k at period t.

$\sum_{j=1}^{J} x_{pjkt} \ge \sum_{l=1}^{L} x_{pklt} \; for \; \forall p, k, t$ (6)

$\sum_{j=1}^{J} z_{pkjt} = \sum_{l=1}^{L} z_{plkt} \; for \; \forall p, k, t$ (7)

Constraints (6-7) indicate the forward/reverse flow of product.

$\sum_{k=1}^{K}\sum_{t=1}^{T} z_{pkjt} \le \sum_{k=1}^{K}\sum_{t=1}^{T} x_{pjkt} \; for \; \forall p, j$ (8)

Constraint (8) ensures that a certain type returned product can only be sent back to plants, which are available for its production.

$\sum_{p=1}^{P}\sum_{k=1}^{K} x_{pjkt} \le \sum_{g=1}^{G} Ca_{jg} \; for \; \forall j, t$ (9)

$\sum_{p=1}^{P}\sum_{j=1}^{J} x_{pjkt} \le \sum_{e=1}^{E}\sum_{g=1}^{G} y_{egk} * Ca_{kg} \; for \; \forall k, t$ (10)

$\sum_{p=1}^{P}\sum_{l=1}^{L} z_{plkt} \le \sum_{e=1}^{E}\sum_{g=1}^{G} y_{egk} * Cb_{kg} \; for \; \forall k, t$ (11)

$\sum_{p=1}^{P}\sum_{k=1}^{K} z_{pkjt} \le \sum_{g=1}^{G} Cb_{jg} \; for \; \forall j, t$ (12)

Constraints (9-12) control the processing rate based on the capacity of each facility.

$\sum_{e=1}^{E}\sum_{g=1}^{G} y_{egk} \le 1 \; for \; \forall k$ (13)

Constraint (13) verifies that there can be one capacity level and one level of environmental protection for each distributor.

$$x_{pjkt}, x_{pklt}, z_{plkt}, z_{pkjt} \geq 0 \ for\ \forall p, j, k, l, t \quad (14)$$

$$y_{egk} \in \{0,1\} \quad (15)$$

Constraint (14) and (15) ensure the binary and non-negativity variables.

4. Method

The Weighted-Sum approach is employed to find solution of this multi-objective MILP model. By weighting each objective, a group of goals is combined into a single goal in this method. The advantage of this approach is that it allows the decision maker to adjust and assign weights to the objectives customized to their needs. A set of optimal solutions is obtained by integrating two objective functions into a single unified objective by using objective coefficient.

$$Minimize\ Z = (1 - \alpha) * Z_1 + \alpha * Z_2$$

The coefficient α's weighted value ranges from 0 to 1. The priority of the environmental preservation objective in practice is shown by the value α. Synthetically, the model will be solved for α from 0.1 to 1, to find out the best solution for case problem.

5. Numerical Example

Dataset for numerical example is collected from the case company, data pre-processing is completed to prepare raw data and making it appropriate for a model, including cleaning outliers and duplicates, imputing missing values, verifying abnormal data with the case company. The network considers 6 potential suppliers, 3 manufacturing plants, 27 potential distributors, and 5 wholesale customers. As the case of this study, Hoang Nam Production is a medium Vietnamese firm that has been involved in the plastic injection industry for more than 20 years. The company's system covers the whole country as their facilities spread all over three regions of the country. Data for cost and demand are collected directly from historical data of Hoang Nam for 12 months of 2019 and it is assumed to follows the same pattern and has negligible changes after COVID-19 normalization. The prospective placements of all distribution facilities are based on population distribution and product demand data in regions. Nevertheless, environmental correlated data cannot be obtained due to lacking resources. Therefore, environmental parameters $(fe_{ke}; Ve; Ue)$ is adapted based on the numerical input of (Zhen et al., 2019).

6. Result analysis

6.1 Supplier selection by AHP

After constructing pair-wise comparison matrix for each criterion following standard procedure of AHP method, consistency ratio is obtained as 0.084 which is smaller than 0.1 indicating that the judgements of pairwise comparisons are consistent and objective. After the consistency calculation for all levels, the overall priority ranking to select the best alternative is obtained. The final weights for all alternative suppliers are observed in Figure 1. It is statistically proven that alternative number 4, 3, 6 and 1 are four suppliers that obtain the highest score out of six alternatives. Hence, the final ranking for supplier choosing is obtained, from which the supply chain design finally has the grounded platform to initiate solving the Multi-Objective MILP Problem in the next section (Figure 1-3).

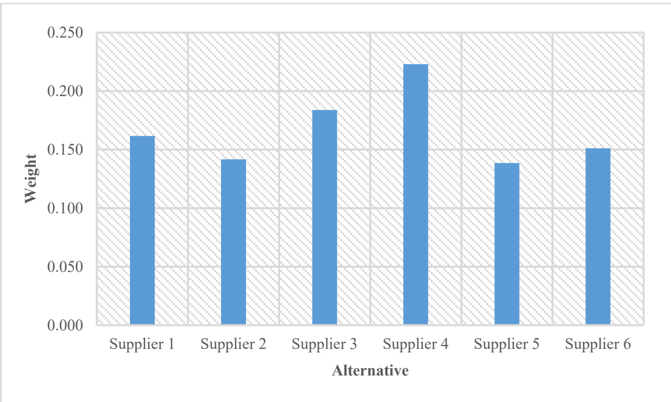

Figure 1. Weight of Each Alternatives

6.2 Results coefficient value (α)

After acquiring four desired suppliers from the previous part, the solution model begins to initiate. First of all, we obtained all the optimal solutions of the Weighted Sum. IBM-CPLEX optimizer is employed to solve the model for each value of α from 0.1 to 0.9. Tab. 3 demonstrates results for both Objective 1 and Objective 2 from every run from the optimizer.

Table 3. Sensitivity of objective function value with changing alpha

Weights		**Objective**		
W1	W2	Z1	Z2	Z
0.1	0.9	10,077,000	1,733,200	2,567,546
0.2	0.8	10,060,000	1,735,800	3,400,551
0.3	0.7	10,057,000	1,736,300	4,232,571
0.4	0.6	10,040,000	1,746,300	5,063,916
0.5	0.5	10,040,000	1,746,300	5,893,328
0.6	0.4	10,026,000	1,765,000	6,721,522
0.7	0.3	10,016,000	1,781,600	7,545,863
0.8	0.2	9,994,700	1,847,400	8,365,208
0.9	0.1	9,990,000	1,876,400	9,178,667

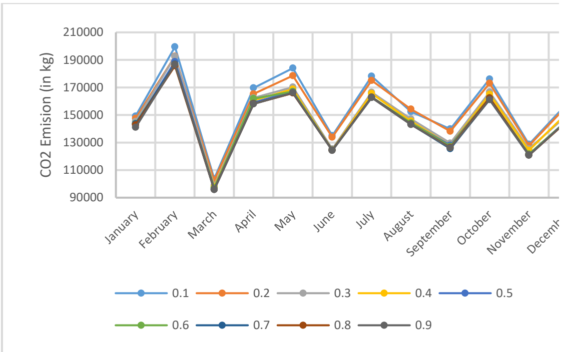

Figure 2. CO2 Emission through Transportation for Each value of alpha

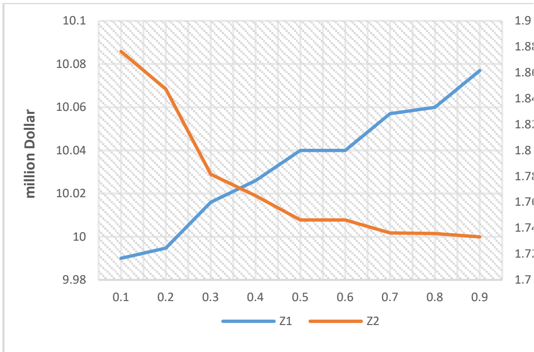

Figure 3. CO2 Emission through Transportation for Each value of alpha

As we can see from the line chart in Figure 2, there are significant fluctuations of carbon dioxide discharge's data of above α values in twelve months period. Literally speaking, despite various adjustments in the amount of α, the corresponding tendencies of below nine values' CO2 emission weight are relatively similar. After April, as the two- or three-month period, there was a considerable increase in the amount of carbon dioxide emission before plunging again to interchangeable results, at between 120,000 and 190,000 kilograms. Notably, the higher the variable α is applied, the lower the quantity of CO2 emission is recorded. The line chart in Figure 3 clearly shows that, while the total cost declined considerably, the carbon dioxide amount has upward tendency as α increases. Moreover, it seems that α is proportional to the CO2 reduction rate, for the higher α is, the lower the CO2 emission as well as higher total cost (Figure 4-9).

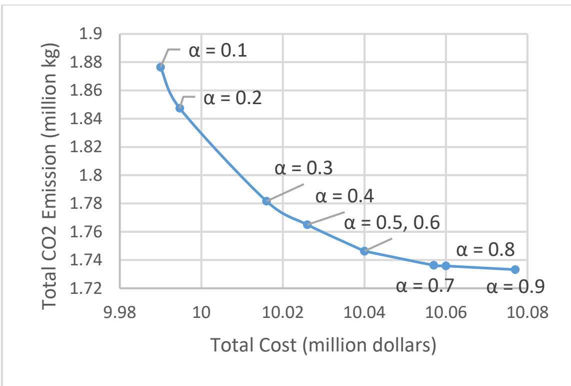

Figure 4. Total cost and Total CO2 emission per alpha

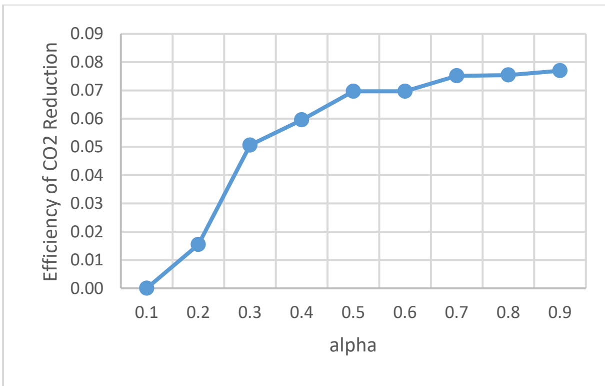

Figure 5. Emission-Reduction Efficiency with different alpha values.

The Pareto frontier illustrated in Figure 4 provides an excellent strategic approach to optimal solutions. Each node on the curve represents an optimal objective solution for each coefficient α. We can clearly confirm that if the network wants to achieve high level of CO2 reduction, a scarification on total cost must be made. The idea of CO2 Emissions Reduction Efficiency in Figure 5 is proposed to reflect the performance in environment protection, which is expressed as the ratio of CO2 emissions reduction to cost increases when α increases, thus deciding the weight coefficient selection. In this case, the solution model reaches maximum CO2 Reduction Efficiency at α of 0.9. Therefore, the most appropriate choice for environment reservation occurs when weight for Objective 1 and Objective 2 equal to 0.1 and 0.9 respectively.

6.3 Model result analysis

In this section, the model will be assessed to maximize profit while depleting environmental effect. As mentioned above, the model reaches the maximum emission-reduction efficiency as $\alpha = 0.9$. Analysis of the result will focus on cost, CO2 emission and variables for each period. The value of binary variable was generated as first, whose result shows all the optimal location for DC opening. After filtering a mass amount of output solutions, the final locations off all facilities including plants, distribution centers, and customers are illustrated in Figure 6. The distribution centers are located in various industrial zones such as Nam Son-Hap Linh, Duc Hoa, Linh Trung 2, Vinh Loc, Dong Nam and Tan Phu Trung.

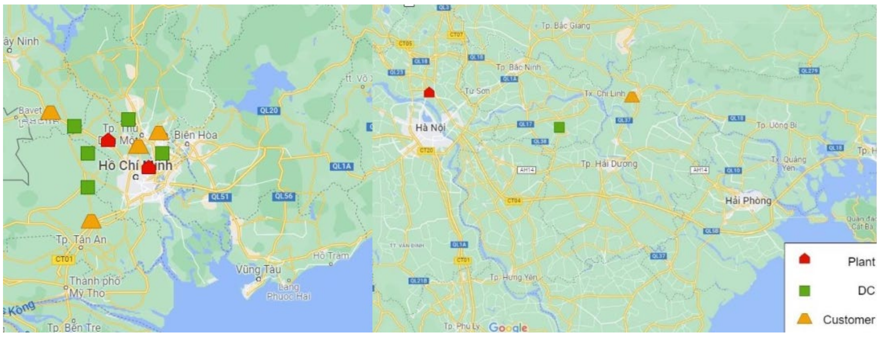

Figure 6. Facility Locations

Table 4. Optimal Objective results

Objective Z1	Value	Objective Z2	Value
Optimal Solution	10,077,000 dollars	Optimal Solution	1,733,200 kilograms
Fixed Cost	1,013,200 dollars	Fixed CO2 Emission	847 kilograms
Transportation Cost	147,600 dollars	Transportation CO2 Emission	1,732,300 kilograms
Variable cost	5,407,300 dollars		
Holding Cost	3,508,700 dollars		

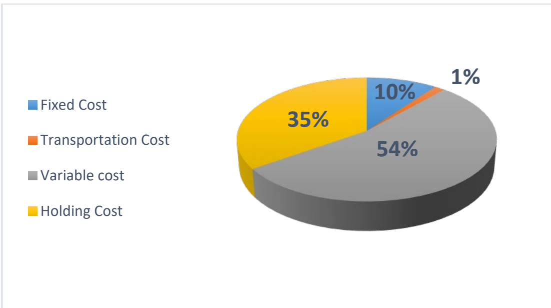

Figure 7. Cost Comparison

Tab. 4 represents all solution and cost for both objective functions Z1 and Z2, while Figure 7 illustrates the comparison of costs in Objective Z1. It seems that the adjustment of variable cost is the main reason of total cost change. There is a huge gap between variable for objective function one. While the variable cost reaches peak with around 5.4 million dollars and possesses approximately 50% of total cost, transportation cost is barely acknowledgeable with around 147,600 dollars. Still, the largest gap belongs to fixed CO2 emission and transportation CO2 emission from objective 2. With only just 847 kilograms, fixed CO2 emission is nothing than just a small ant compared to the emission from transportation, which is about 1.73 million kilograms.

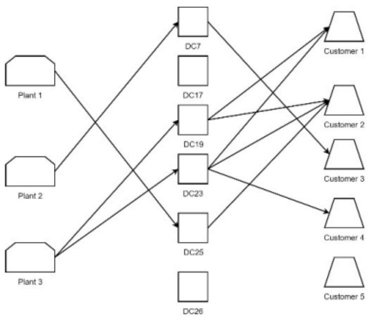

Figure 8. Forward Flow of Product 1

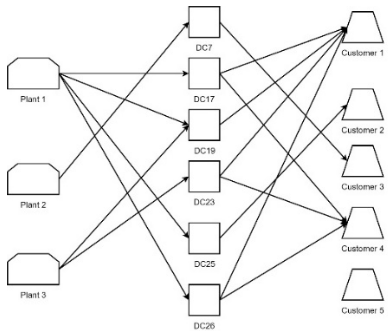

Figure 9. Forward Flow of Product 2

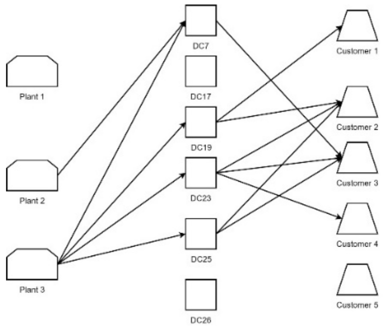

Figure 10. Forward Flow of Product 3

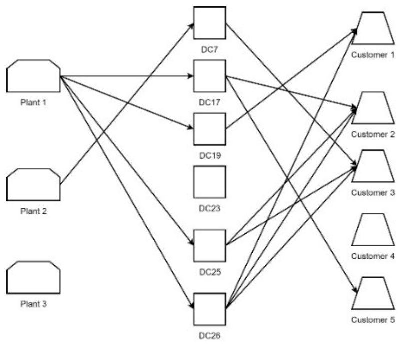

Figure 11. Forward Flow of Product 4

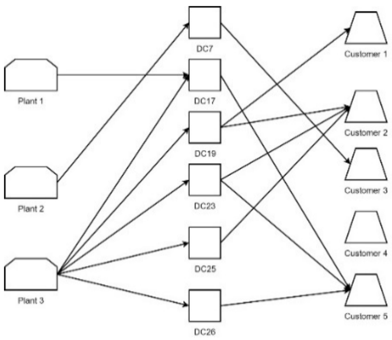

Figure 12. Forward Flow of Product 5

The forward flow (Figure 8- 19) of all 5 products are presented in Figure 8 to Figure 12. It can be observed that Product 1 is mass produced in all plant to provide such high demand of Customer 1, 2 and 3. For this product, DC 17 and DC 26 do not distribute any of it. For Product 2, while Plant 2 only supplies DC 7, Plant 1 and Plant 3 share the production for the rest demand due to high level of production capacity. Furthermore, all customers require this product except customer 5. The flow of Product 3 is demonstrated in Figure 10. Plant 1 is not needed for this type of product. After production, all batches of Product 3 are transported to all DC except DC 17 and 26. The network in Figure11 shows the flow of Product 4 throughout the whole system. It is fascinating that Plant 3 is not assigned to produce this product. All batches of finished goods are transported to all distributor except Distribution Center 23. Lastly, the flow of Product 5 can be seen through the sketch in Figure 12. The solution model has indicated that all plant is needed for this production. Moreover, Plant 2 is linked with Distribution Center 7 and Plant 1 and 3 share connection with the rest.

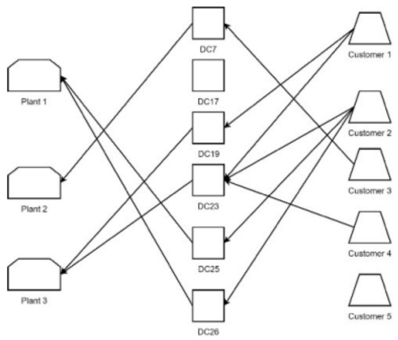

Figure 13. Reverse Flow of Product 1

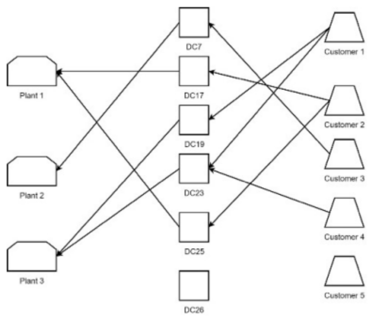

Figure 14. Reverse Flow of Product 2

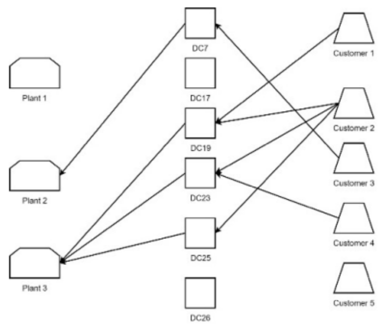

Figure 15. Reverse Flow of Product 3

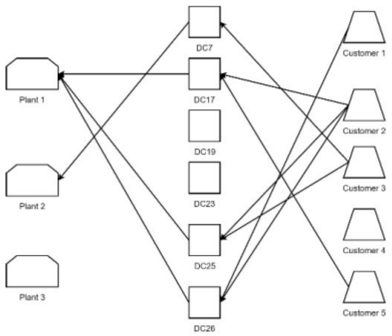

Figure 16. Reverse Flow of Product 4

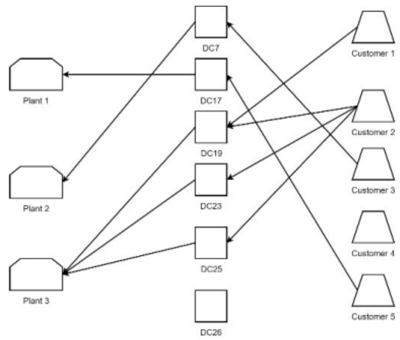

Figure 17. Reverse Flow of Product 5

The solution model provides the knowledge that the reverse process mostly syncs up with some aspects the forward one, with reverse flows of 5 products illustrated in Figure 13 to Figure 17. While the reverse flows of Product 2 to 5 share the similar trend that the network starting from customers is less complicating than the forward, Fig. 13 illustrating the reversed flow of Product 1 shows a different sense. In specific, there is an apparent support from Distribution Center 26 for the returning progress of Product 1, which cannot be seen in the Plant-to-Customer flow. Moreover, an insignificant adjustment of Distribution Center 19 has simultaneously been created. Mentioning to other Figure (14-17), the procedures of returning goods have been minimized and optimized as several contributors are no longer obligatory and diverse rearrangements are conclusively assembled. For instance, when a link between Customer 3 and Distribution Center 25 is made for the returning protocol for Product 3's flow, the process of Product 4 reveals that Distribution Center 19 is not required for the process anymore. However, no matter how considerable the modifications of links between distribution centers and customers are, the required plants where goods finally returned remain unchanged.

From the above analysis, all aspects of the solution model are obtained, with no constraint is violated. As observation, the node link for forward process is denser than the reverse one. This is mostly due to the mass transportation between each node of the forward logistic requires more facilities to involve in the process to satisfy demand of customers. The optimal solution considers the trade-off between cost control and environmental preservation, resulting a G-CLSC network which is both economically and environmentally friendly. The final G-CLSC design is illustrated in Figure 18 and Figure 19.

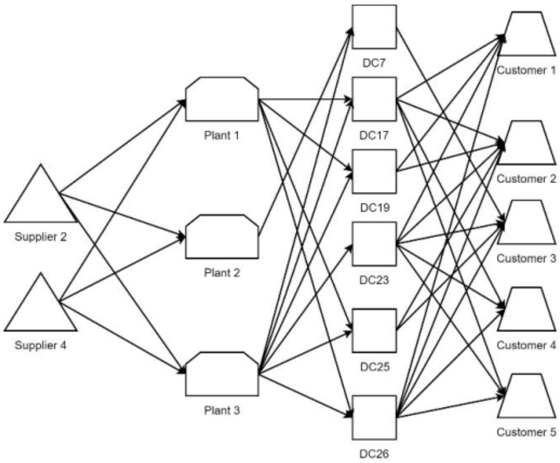

Figure 18. Final Forward Supply Chain Network

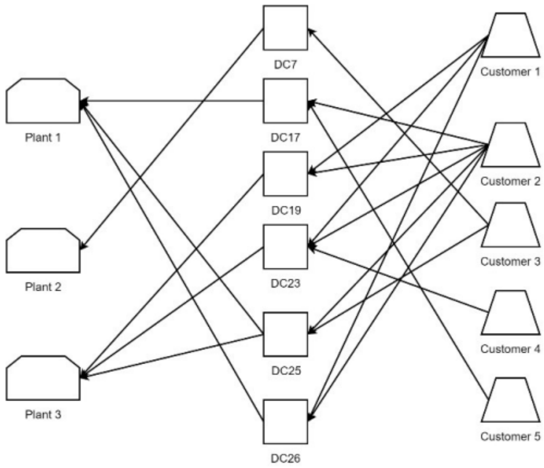

Figure 19. Final Reverse Supply Chain Network

7. Conclusion

With the aim of accomplishing the Green Closed-Loop Supply Chain application to improve the efficiency and profitability of plastic injection industry in Vietnam, this journal utilizes Analytic Hierarchy Process to evaluate supplier selection and Mixed Integer Linear Programming to build a Green Closed-Loop Supply Chain Network, which both help diminish cost and CO2 emission. This paper provides approaches to develop a Green Closed-Loop Supply Chain to improve the efficiency and profitability of plastic injection industry in Vietnam. By using AHP method to evaluate supplier selection and Mixed Integer Linear Programing to build a Green Closed-Loop Supply Chain Network that both minimize cost and CO2 emission.
By implementing the historical data of a Vietnamese firm in 2019, four industrial sites have been chosen as the optimal location to open new distribution center. These locations are guaranteed to generate a profit and deplete environment pollution in 12 months, which would be breakeven with the accepted goal of case company. Furthermore, through analyzing, this new network has achieved validity since differentiation between all optimal cost and CO2 emission for each α are very negligible (0.29% and 2.17% respectively).

However, the demand, transportation and fix cost data used for the model are historical data from the past and may change considerably in future due to COVID-19, this limitation may decrease the proposed model accuracy and reliability. Moreover, even though demands used in this model is real but, it is uncertain. With this, it can be convinced that there are rooms for improvements and adjustments for G-CLSC problem. Thus, further research is crucial to help the solution model to be able to comb with the fluctuate and dynamic changes of future market.

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