

## MODELING A CLOSED LOOP SUPPLY CHAIN NETWORK DESIGN FOR A NIGERIAN MANUFACTURING PET BOTTLE WASTE FIRM

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### ABSTRACT

*The objective of this research is to develop a multi-stage closed loop supply chain (CLSC) optimization model with the goal of minimizing overall costs within the supply chain (SC) network. Additionally, the model will handle facility location and product allocation in both forward and backward flows. As part of the process of developing the CLSC mathematical model for a beverage manufacturing company that uses polyethylene terephthalate (PET) for product packaging, a multi-stage mixed integer programming (MILP) approach is applied. According to the findings of the models that were developed, the establishment of the distribution of facilities and the flow of materials throughout the whole supply chain network can be accomplished at lower costs. This is confirmed by the fact that the overall costs are reduced. The findings point to the optimal overall cost of the network, which takes into account the expenses of the forward and backward flow of activities with this supply chain network. In addition, the findings provide information regarding the number of facilities that will be utilized, the facilities that will be established, and the quantity of things that will be transferred between facilities between each interval. Comprehensive sensitivity analysis and scenario optimizations are carried out in order to investigate the influence that shifts in demand, capacity, and reversal rates have on the overall cost of the CLSC network. As a result, it is recommended to make use of scientific approaches for the design and management of the CLSC in order to guarantee the coordination of operations within the supply chain network.*

**Keywords:** CLSC, MILP, Polyethylene Terephthalate (PET).

### INTRODUCTION

The onset of a new business period, characterized by constant change, has rendered the success and survival of businesses increasingly challenging (Shahin, Khalili, & Pourhamidi 2017). Consequently, firms have identified supply chain (SC) as an important strategy that integrates system of facilities and activities which involves and coordinates interrelated business functions of material procurement, material transformation to final products and also distribution of these products to the end users (Fathollahi, Ghalian-Jouybari, Paydar, & Hajiaghaei-Kesheti 2018). Thus, supply chain management (SCM) is also

viewed as the management of all parties' concerns in SC such as movement and replenishment of raw materials and finished goods alongside transportation decisions (Koc, 2017). Supply chain is also a network of organizations collaborating to regulate, oversee, and enhance the movement of products and information from suppliers to end customers (Jaklic, Trkman, Groznik & Stemberger, 2006). SCM is the strategic and methodical coordination of conventional business processes, as noted by (Nakov, Acevski, and Zareski 2014), which enables the distribution network between clients

and the internal operations of the organization (Barraza, Davila & Garcia, 2016). Despite the fact that research has focused on enhancing particular aspects of reverse logistics (such as product recovery, remanufacturing, and recycling), Guide, Jayaraman, and Srivastava (2015) asserted that there is a need for more cohesive methods that take into consideration the relationship between reverse and forward logistics. In order to accomplish this, it is necessary to investigate the ways in which reverse logistics influences forward logistics operations (such as sourcing, production, inventory, distribution, and logistics), as well as to devise methods for effectively coordinating and synchronizing these particular activities. The argument that they presented was that there is a pressing need for more unified planning that take into account the connection between forward and reverse logistics. In order to accomplish this, it is necessary to investigate the ways in which reverse logistics impacts forward logistics operations and to discover methods for effectively coordinating and synchronizing these activities respectively. According to Zeng, Zhang, Li, and Leung (2018), the rapid advancement of technology necessitates a better understanding of how developing digital technologies, such as blockchain, the Internet of Things (IoT), and artificial intelligence, might be appropriately utilized to enhance the predictability, coordination, efficiency, traceability, and transparency of closed-loop supply chains. This is because of the fact that these technologies are constantly evolving. According to Genovese, Lenny, and Acquaye (2017), the design of closed-loop supply chain (CLSC) networks is shaped by dynamic changes such as the introduction of new laws, the development of new technologies, and the requirements of their respective markets. They asserted that there is a requirement for the development of dynamic modeling and optimization approaches that are able to respond to these changes and make it possible to construct a CLSC that is both sustainable and adaptive over time. As to the findings of Staniškis, Chockalingam, and Raut (2019), it is recommended that additional research should concentrate on the manner in which supply chain network architecture incorporates concepts related to circular economy. In order to

accomplish this, it is necessary to examine the ways by which the network is designed, such as the recycling of materials, the remanufacturing of products, and the reuse of products, in addition to assessing the financial and environmental benefits of implementing circular economy concepts. In their study, Ramezani and Kimiagari (2013) highlight the importance of examining the various methods that can be utilized to incorporate stochastic demand and end-of-life product returns into CLSC network design models. This necessitates the creation of robust optimization models that take into account the uncertainty of demand, the variability of product returns, and the effects that these factors have on network configuration, capacity allocation, and inventory control.

Mehrnaz, Hamed, & Agnieszka (2023) conducted research that looked at the architecture of supply chain networks within the context of disturbance and uncertainty. A robust fuzzy probabilistic optimization methodology with a dynamic aspect was utilized as the method applied. Nevertheless, the authors did not apply their models across a number of different timeframes in relation to the facility location and product allocation problem that they intended to answer. This was the case even though the data demonstrated that the used solution strategies were superior to alternatives. Utilizing mixed integer linear programming, a multi-criteria decision-making technique, and a multi-objective optimization technique, Ebrahim, Liping, and Saman (2023), Abolghasem, Ali, Reza, and Kennan (2023) investigated the design of a sustainable SC network with the intention of addressing a single product within a limited timeframe. This was done with the intention of addressing a multi-objective scenario and supply chain uncertainty. In spite of this, it is absolutely necessary to establish a closed-loop supply chain network in order to accurately portray the challenges that are confronting manufacturing organizations in a scenario that spans many periods. As a result, the researcher contends that the subject matter is not yet finished and that it is essential to expand the existing body of knowledge on CLSC in relation to the manufacturing sector in Nigeria. This study's main aim is to design optimization models for closed loop supply chain (CLSC) network using

the Nigerian Bottling Company (NBC), a locally based manufacturing firm and PET (Polyethylene Terephthalate) bottle user in Nigeria. Specifically, the objectives of this study are to: (i.) synthesize a closed loop into the supply chain network to minimize total cost, (ii.) determine the volume of materials and product allocation in the network and to, (iii.) determine the optimum facility allocation within the supply chain network.

## LITERATURE REVIEW

As indicated by the reviews carried out by Fleischmann et al. (1997), Angell and Klassen (1999), Dekker et al. (2004), Inderfurth et al. (2006), Akcali et al. (2009), Souza (2013), Raza (2020), the management of CLSC has received a substantial amount of attention over previous decades. In a related study, the evaluation, design, and incorporation of return flows and reprocessing of utilized products including recovery, collection, and have received significant attention. Additionally, forward-related operations within comprehensive networks have also been taken into consideration (Rajesh, 2018).

### Closed loop supply chain network (CLSCN)

The CLSCN concept encompasses multiple levels and periods (Fathollahi, Gholian-Jouybari, Paydar, Hajiaghahi-Keshteli 2017). Like other traditional supply chain networks, CLSC network is incorporated into production, purchasing, distribution, collecting, and returns activities. The forward logistics component of the model consists of five layers: suppliers, producers, distributors, warehouses, and customer centers. The term forward logistics refers to the process by which suppliers convey materials to factories. Warehouses and distribution facilities facilitate the transfer of finished goods from producers to consumers in order to fulfill their expectations. The term "reverse logistics" refers to the process by which collecting and inspection facilities receive returned products from consumers and then assess them (Pauhl & Voss, 2014). For the purpose of the reverse chain, the model takes into account four treatment procedures for returned goods:

- (i) **Redistribution activities:** here, products that have been returned from customer zones to be remade or repaired are distributed back to customers for further use.
- (ii) **Remanufacturing activities:** the products that have been returned are made again and made available for use.
- (iii) **Recycling activities:** this involves the recycling of product which is sent back to the original suppliers.
- (iv) **Disposal activities:** any returned goods that are not up to acceptable standard are discarded.

Meanwhile, there are also governmental policies in place in a number of countries that demand manufacturing businesses to reduce their wastes, which are additional factors that drive this trend (Van et al., 2022; Nnajofofor et al., 2024). Furthermore, in this study, we investigate the relevant literature that combines a variety of components into the mathematical models that are offered for CLSC design decisions.

### Single-Objective Models

"CLSC's strategic and tactical decisions are substantially impacted by the presence of ambiguity (Fathollahi et al., 2022). In light of this, we have identified a great number of stochastic models that can be utilized in the building of closed-loop supply chains. For example, Amir, Mostafa and Sedeyedali, (2018) proposed a CLSC network that would make use of a stochastic programming approach. For the purpose of reducing the amount of uncertainty that is associated with product quality, he considers products, requests, and return rates to be stochastic. A multi-period multi-product mix integer nonlinear programming (MINLP) model is presented by Ozceylan and Paksoy (2013).

This model is intended to optimize strategic decisions for the CLSC. It specifically addresses uncertainties in capacities, demand, reverse rates, and objectives. The primary objective of the model is to minimize total costs associated with transportation, purchasing, refurbishing, and fixed expenses (Lawal & Abdullahi, 2024). It is

true that reversal rates make mathematical models significantly more difficult to understand (2016). The framework that they have presented takes into account the subjective and usually unclear levels that the logistic managers want for the aforementioned uncertain components. This is accomplished through implementation of fuzzy theory. In a situation that is analogous, Alamdar et al. (2018) conducted research on decision-making in CLSC while uncertainty was present. They evaluate the performance of all facilities in networks, including manufacturing centers that consist of a collector and a retailer, by analyzing fuzzy pricing and sales demand inside a game-theoretic mathematical framework.

This allows them to evaluate the effectiveness of manufacturing centers. There are three pillars that make up sustainability, and one of them is environmental. Environmental sustainability encompasses all aspects that have an impact on the environment, such as carbon dioxide emissions and excessive resource extraction (Aisha & Abdullahi, 2024). In order to contribute to the preservation of the environment and, thus, to sustainability, carbon emissions should be reduced. Zohal and Soleimani (2017) develop a multifunctional CLSC model for the gold industry with the objective of reducing the amount of carbon emissions and the overall expenses of the supply chain. A methodology known as ant colony optimization is utilized by them in order to locate answers that are close to ideal. In order to address environmental concerns and reduce the number of business days that are missed, Soleimani et al. (2017) propose for a CLSC that is environmentally friendly. Additionally, in order to solve the problem, they use a genetic algorithm.

### ***Bi-objective or Multi-criteria Models***

“A multi-objective model for a CLSC is presented by Altiparmak et al. (2006). The purpose of this model is to minimize the total network cost while simultaneously maximizing the fulfillment rate of customer demands within the available timeframe and ensuring that distribution centers have balanced capacity utilization. In order to handle a real-world scenario, specifically a plastic manufacturing company in Turkey, they make use of simulated annealing. A three-stage stochastic multi-objective model for closed-loop supply

chains is proposed by Amin and Zhang (2013). This model makes use of both qualitative and quantitative criteria. The evaluation of suppliers, remanufacturing subcontractors, and rework facilities, as well as the creation of the network and the distribution of orders, are all included in the three stages. To overcome the uncertainty that is associated with demand, fuzzy set theory is utilized.

It is necessary to determine the quantities of items that will be discarded, reprocessed, and acquired from suppliers so as to achieve the goals of optimizing predicted earnings while simultaneously minimizing procurement expenses and expenditures related with refurbishing locations and remanufacturing subcontractors. Based on the findings, it can be concluded that the predicted earnings decrease as the level of demand uncertainty increases. The authors Pishvae et al. (2010) develop a mixed-integer linear programming (MILP) fuzzy/possibilistic mathematical model for a closed-loop supply chain (CLSC) that is centered on a single period and features a bi-objective function.

Within the context of the logistic network problem, the first objective seeks to simultaneously minimize the overall costs associated with facility openings, variable processing, and transportation. The reduction of the overall influence on the environment, as determined by an eco-indicator, is the focus of the secondary objective. In addition to that, they consist of things like operating expenses, shipping fees, delivery times, product return rates, and swings in demand. The model is converted into a comparable auxiliary crisp model by the utilization of a two-stage solution approach. Subsequently, compromise solutions are determined through the utilization of the  $\epsilon$ -constraint method. In order to examine the notion, a practical scenario is utilized that makes use of medical equipment, such as syringes, that can either be recycled or burnt in reverse at facilities that are dedicated to collecting or disassembling waste. Based on the findings, it appears that the solution approach has the potential to strike a fair and sustainable equilibrium between the two goals.



## METHODOLOGY

For the purpose of this study, a case-study research approach is utilized in order to improve and optimize an existing supply chain network while simultaneously incorporating the closed-loop concept into the network. The case study research design involves an in-depth analysis of a specific case or multiple cases in order to gain profound insights into the subject matter that is being investigated. The firm under consideration for this study is the Nigerian Bottling Company (NBC). The choice of the firm is due to the firms' vast supply chain facilities spanning across the six geopolitical zones of Nigeria, and its diverse utility of its product packaging ranging from PET bottles, aluminum to glass bottles. Thus, the facilities that are part of the supply chain network of the Nigerian Bottling Company's (NBC) goods and packaging bottles (PET) in Nigeria are included as the research's population.

The facilities, which include manufacturing plants, distribution centers, warehouses, inspection centers, disposal centers, and disassembly centers, were selected within the South-South, South-East, and South-West geopolitical zones of Nigeria. The selection of these facilities was based on the demand for the product as well as the utilization of PET bottles in these regions. The facilities were utilized in order to synthesize and evaluate sustainability within the city where the study was carried out, as well as to scientifically optimize total costs. For the objective of optimization, the study examined data from supply chain networks spanning a period of five years. It is appropriate to say that the time periods that have been provided adequately reflect the particulars that are involved in the optimization of the models. In order to conduct its analysis, this study makes use of secondary data. It is possible to deduce information regarding supply, manufacture, inventory, transportation, distribution, redistribution, disposal, inspection, repair, remanufacturing quantities and capacities, reverse rates, sales, and annual demand from the various articles that have been studied.

Firstly, the mixed integer linear programming (MILP) technique is used to formulate the optimization problems because output values of some variables are expected to be in integers and some others in non-integer of continuous form that is, in fractional form from the model. The mathematical model was implemented in the General Algebraic Modeling System (GAMS) software using the IBM CPLEX solver. The optimal results were achieved for the product allocation among facilities in the network in such a way the total cost is achieved using the period (five years).

### *Model assumptions*

During the configuration of the network, the following assumptions and constraints are made:

- i. Supplier, customer, and second-customer centers have established and known locations. In a stable operation, this is usually the case.
- ii. Every step of the process, from factory and warehouse location to distribution, redistribution, recycling, remanufacturing, collecting and inspection, and disposal, is precisely known.
- iii. In both forward and reverse logistics, the flows can only be sent between two successive phases. Moreover, facilities at the same tier do not have defined flows. This is usually the situation, such as when a networked supplier is unable to send or receive goods from another supplier.
- iv. The parameters' quantities are deterministic in character.
- v. For every period, the cost of product movement between all levels stays constant. This makes the issue easier to understand and demonstrates that transportation costs are constant throughout time.
- vi. The cost of transportation from customers to collection and inspection centers includes the cost of inspecting the returned goods. This lowers the number of optimization parameters, but if these costs vary significantly, the optimization procedure must be repeated.

- vii. Every request from the client should be met. In any supply chain, this is a realistic expectation, and failing to satisfy it can negatively impact the operation as a whole.
- viii. The model is single-product and multi-period. This represents the network's current operational status; any modifications will necessitate redesigning the design.

### Model formulation

This study adapted the model formulated by Pourjavab, (2018) that addressed the problem of facility location and allocation was adapted for a closed loop supply chain network and is adapted

Fixed Cost =

$$\begin{aligned} \sum_{p \in P} \sum_{t \in T} fc_p O_{pt} + \sum_{w \in W} \sum_{t \in T} fc_w O_{wt} + \sum_{d \in D} \sum_{t \in T} fc_d O_{dt} + \sum_{i \in I} \sum_{t \in T} fc_i O_{it} + \sum_{m \in M} \sum_{t \in T} fc_m O_{mt} \\ + \sum_{l \in L} \sum_{t \in T} fc_l O_{lt} + \sum_{j \in J} \sum_{t \in T} fc_j O_{jt} + \sum_{k \in K} \sum_{t \in T} fc_k O_{kt} + \sum_{n \in N} \sum_{t \in T} fc_n O_{nt} \end{aligned} \quad (1a)$$

Manufacturing Cost =

$$\sum_{p \in P} \sum_{w \in W} \sum_{t \in T} mc_{pt} X_{pwt} + \sum_{p \in P} \sum_{d \in D} \sum_{t \in T} mc_{pt} X_{pdt} \quad (1b)$$

Recycling cost =

$$\sum_{i \in I} \sum_{l \in L} \sum_{t \in T} rc_{lt} X_{ilt} \quad (1c)$$

Remanufacturing cost =

$$\sum_{j \in J} \sum_{i \in I} \sum_{t \in T} ec_{jt} X_{ijt} \quad (1d)$$

Recovering cost =

$$\sum_{k \in K} \sum_{i \in L} \sum_{t \in T} bc_{kt} X_{ikt} \quad (1e)$$

Disposal cost =

$$\sum_{m \in M} \sum_{i \in L} \sum_{t \in T} dc_{mt} X_{imt} \quad (1f)$$

Transportation cost =

(1g)

for this study. Hence, the problem is formulated as a mixed-integer linear programming model. Hence, according to Pourjavab, (2018) the typical CLSC models are defined in the following as follows:"

### “Objective function for the closed loop supply chain

The objective function of the proposed Closed-Loop Supply Chain model seeks to minimize the overall cost.

**Min z** Total Cost = fixed costs + production costs + recycling costs + remanufacturing costs + recovery costs + disposal costs + transportation costs + material costs + shortage costs + collection costs.

$$\begin{aligned} & \sum_{w \in W} \sum_{p \in P} \sum_{t \in T} tc_{pw} X_{pwt} + \sum_{d \in D} \sum_{p \in P} \sum_{t \in T} tc_{pd} X_{pdt} + \sum_{w \in W} \sum_{c \in C} \sum_{t \in T} tc_{wc} X_{wct} + \sum_{d \in D} \sum_{c \in C} \sum_{t \in T} tc_{dc} X_{dct} + \sum_{c \in C} \sum_{i \in I} \sum_{t \in T} tc_{ci} X_{cit} + \\ & \sum_{i \in I} \sum_{m \in M} \sum_{t \in T} tc_{im} X_{imt} + \sum_{i \in I} \sum_{l \in L} \sum_{t \in T} tc_{il} X_{ilt} + \sum_{i \in I} \sum_{j \in J} \sum_{t \in T} tc_{ij} X_{ijt} + \sum_{i \in L} \sum_{n \in N} \sum_{t \in T} tc_{ln} X_{int} + \\ & \sum_{j \in J} \sum_{n \in N} \sum_{t \in T} tc_{jn} X_{jnt} + \sum_{k \in K} \sum_{n \in N} \sum_{t \in T} tc_{kn} X_{knt} + \sum_{f \in F} \sum_{n \in N} \sum_{t \in T} tc_{nf} X_{nft} \end{aligned}$$

Material cost =

$$\sum_{s \in S} \sum_{p \in P} \sum_{t \in T} pc_{st} X_{spt} - \sum_{s \in S} \sum_{l \in L} \sum_{t \in T} (pc_{st} - rc_{lt}) X_{lst} \quad (1h)$$

Shortage Cost =

$$\left( \sum_{c \in C} \sum_{t \in T} de_{ct} - \sum_{w \in W} \sum_{c \in C} \sum_{t \in T} X_{wct} - \sum_{d \in D} \sum_{c \in C} \sum_{t \in T} X_{dct} \right) sc \quad (1i)$$

Collection cost =

$$\sum_{c \in C} \sum_{i \in I} \sum_{t \in T} tc_{ci} X_{cit} \quad (1j)$$

**Model constraints**

**Capacity constraints**

$$\sum_{p \in P} X_{spt} \leq O_{st} ca_{st} \quad \forall s \in S, t \in T \quad (2)$$

$$\sum_{w \in W} X_{pwt} + \sum_{w \in D} X_{pdt} \leq O_{pt} ca_{pt} \quad \forall p \in P, t \in T \quad (3)$$

$$\sum_{p \in P} X_{pwt} \leq O_{wt} ca_{wt} \quad \forall w \in W, t \in T \quad (4)$$

$$\sum_{p \in P} X_{pdt} \leq O_{dt} ca_{dt} \quad \forall d \in D, t \in T \quad (5)$$

$$\sum_{c \in C} X_{cit} \leq O_{it} ca_{it} \quad \forall i \in I, t \in T \quad (6)$$

$$\sum_{i \in I} X_{imt} \leq O_{mt} ca_{mt} \quad \forall m \in M, t \in T \quad (7)$$

$$\sum_{s \in S} X_{lst} + \sum_{n \in N} X_{jnt} \leq O_{lt} ca_{lt} \quad \forall l \in L, t \in T \quad (8)$$

$$\sum_{n \in N} X_{knt} \leq O_{kt} ca_{kt} \quad \forall k \in K, t \in T \quad (9)$$

$$\sum_{l \in L} X_{lnt} + \sum_{j \in J} X_{jnt} + \sum_{k \in K} X_{knt} \leq O_{nt} ca_{nt} \quad \forall n \in N \quad (10)$$

Constraint (2) ensures that the total flow from suppliers to all producers does not above the

suppliers' capacity. Constraint (3) demonstrates that the total number of products sent from

producers to distributors and warehouses during each period is less than the producers' capacity. According to constraint (4), the total flow of producers entering warehouses during any given period cannot be greater than the warehouses' holding capacity. Constraint (5) guarantees that the total flow entering from producers to distributors throughout each time does not exceed the relevant distributor's capacity.

Constraint (6) declares that no product entered into a collection and inspection center exceeds the appropriate capacity after being collected from client centers. Constraint (7) makes sure that the

total amount of flow coming into disposal centers from collecting and inspection centers doesn't surpass the disposal centers' capacity. Constraint (8) ensures that the total amount of recycled goods shipped to suppliers and redistributors does not exceed the capacity of the appropriate recycling facility. Constraint (9) ensures that the total amount of recovered goods sent to redistributors from recovery centers does not exceed the applicable capacity. According to constraint (10) redistributors' holding capacity cannot be exceeded by the whole flow entering from recycling, remanufacturing, and recovering centers

### Balance Constraints

$$\sum_{s \in S} X_{spt} + \sum_{j \in J} X_{jpt} = \sum_{w \in W} X_{pwt} + \sum_{d \in D} X_{pdt} \quad \forall p \in P, t \in T \quad (11)$$

$$\sum_{p \in P} X_{pwt} + \sum_{c \in C} X_{wct} \quad \forall w \in W, t \in T \quad (12)$$

$$\sum_{p \in P} X_{pdt} + \sum_{c \in C} X_{dct} \quad \forall d \in D, t \in T \quad (13)$$

$$\sum_{c \in C} X_{cit} = \sum_{m \in M} X_{imt} + \sum_{l \in L} X_{ilt} + \sum_{j \in J} X_{ijt} + \sum_{k \in K} X_{ikt} \quad \forall i \in I, t \in T \quad (14)$$

$$\sum_{c \in C} ry_t X_{cit} = \sum_{l \in L} X_{ilt} \quad \forall i \in I, t \in T \quad (15)$$

$$\sum_{l \in L} X_{ilt} = \sum_{n \in N} X_{lnt} + \sum_{s \in S} X_{lst} \quad \forall l \in L, t \in T \quad (16)$$

$$\sum_{c \in C} rv_t X_{cit} = \sum_{k \in K} X_{ikt} \quad \forall i \in I, t \in T \quad (17)$$

$$\sum_{i \in I} X_{ikt} = \sum_{n \in N} X_{knt} \quad \forall k \in K, t \in T \quad (18)$$

$$\sum_{c \in C} rd_t X_{cit} = \sum_{m \in M} X_{imt} \quad \forall i \in I, t \in T \quad (19)$$

$$\sum_{l \in L} X_{lnt} + \sum_{j \in J} X_{jnt} + \sum_{k \in K} X_{knt} = \sum_{f \in F} X_{nft} \quad \forall n \in N, t \in T \quad (20)$$

Constraint (11) indicates the movement of materials between suppliers, remanufacturing centers, and producers is always equal to the flow of material between producers, warehouses, and distributors. The sum of the flows into and out of warehouses from producers and customer centres

is equal to zero at the end of each period. Constraint (12) indicates this. Constraint (13), which specifies a total flow from distributors to customer centers, ensures that the flow arriving from producers is equal to that total flow in each period. Constraint (14) indicated that for every



given time, the total flows from consumers to collecting and inspection centers, and from these centers to recovery, remanufacturing, recycling, and disposal facilities, is equal. All products returned from client centers must be shipped to remanufacturing centers after a mandatory assessment at collecting and inspection centers, as stated in constraints (15) and (16). During each phase, this ensures that manufacturers and redistributors will have access to all items. During each period, all products that have been collected from client centers and transferred to

recovery centers must be provided to redistributors after passing the necessary inspections at the collection and inspection centers, as specified in constraints (17) and (18). All returned products given to disposal centers must be disposed of within each time period, as stated in Constraint (19). Redistributors' throughput to second customer centers must match the overall throughput to recycling, remanufacturing, and recovery facilities for each given time period, according to Constraint (20).

$$\sum_{s \in S} O_{st} \leq S \quad \forall t \in T \quad (21)$$

$$\sum_{p \in P} O_{pt} \leq P \quad \forall t \in T \quad (22)$$

$$\sum_{w \in W} O_{wt} \leq W \quad \forall t \in T \quad (23)$$

$$\sum_{d \in D} O_{dt} \leq D \quad \forall t \in T \quad (24)$$

$$\sum_{i \in I} O_{it} \leq I \quad \forall t \in T \quad (25)$$

$$\sum_{m \in M} O_{mt} \leq M \quad \forall t \in T \quad (26)$$

$$\sum_{l \in L} O_{lt} \leq L \quad \forall t \in T \quad (27)$$

$$\sum_{k \in K} O_{kt} \leq K \quad \forall t \in T \quad (28)$$

$$\sum_{n \in N} O_{nt} \leq N \quad \forall t \in T \quad (29)$$

Constraints (21) – (29) limit the maximum number of allowable locations. In fact, these constraints do not allow the supply chain to have more nodes than relative possible limitations.

$$\sum_{w \in W} X_{wct} + \sum_{d \in D} X_{dct} = de_{ct} \quad \forall c \in C, t \in T \quad (30)$$

$$\sum_{i \in I} X_{cit} = de_{ct} \quad \forall c \in C, t \in T \quad (31)$$

$$X_{spt}, X_{pwt}, X_{pdt}, X_{wct}, X_{dct}, X_{cit}, X_{int}, X_{ijt}, X_{ikt}, X_{jpt}, X_{jnt}, X_{nft}, X_{lst}, X_{knt}, X_{kdt} \geq 0 \quad (32)$$

$$O_{st}, O_{pt}, O_{wt}, O_{dt}, O_{it}, O_{mt}, O_{jt}, O_{lt}, O_{nt}, O_{kt} \in \{0,1\} \quad (33)$$

All of the customer's needs should be satisfied in the customer center, according to the

constraint (30), which ensures that this happens. Constraint (31) ensures that all products must be

retrieved from customers or other predetermined locations. Both the non-negativity and integrality of variables are represented by the constraints (32) and (33) respectively.

## RESULTS AND DISCUSSIONS

The data is presented in terms of numbers of facilities within the supply chain network, and is given below as follows:

Suppliers, $s =$	3	Warehouses, $w =$	3
Producers, $p =$	2	Distribution centres, $d =$	2
		Collection and inspection centre, $i =$	2
		Disposal centre, $m =$	3
		Recycling centre, $l =$	2
		Redistribution centre, $n =$	2
		Recovery centre, $k =$	2
		Customer zones, $c =$	4
		Time period, $t =$	5

**Table 5.1:** Capacities, costs, demands, return rates parameters

	2019	2020	2021	2022	2023
$pc_{st}$	22	22	22	22	22
	24	24	24	24	24
	26	26	26	26	26
$mc_{pt}$	5	6	7	3	6
	4	8	5	3	4
$de_{ct}$	300	400	300	300	300
	300	250	200	300	300
	300	300	400	300	300
	300	250	400	300	300
$bc_{kt}$	5	5	4	4	4
	4	4	4	4	4
$dc_{mt}$	5	5	4	4	4
	4	4	4	4	4
	3	3	3	3	3
$rc_{lt}$	4	4	4	4	4
	4	4	4	4	4
$ry_t$	0.2	0.15	0.3	0.1	0.2
$rv_t$	0.4	0.35	0.3	0.3	0.3
$rd_t$	0.4	0.5	0.4	0.6	0.5
$y_{ct}$	0.25	0.25	0.1	0.1	0.3
$def_t$	200	250	100	100	100
	100	50	100	100	100
	100	100	100	100	100

$ca_{st}$	1000	1500	2000	1000	1300
	1000	1500	2000	2000	2000
	1000	1500	2000	3000	2200
$ca_{pt}$	3000	3000	3000	3000	3000
	4000	4000	4000	4000	4000
$ca_{wt}$	1000	1000	1000	1000	1000
	1500	1500	1500	1500	1500
$ca_{dt}$	1000	1000	1000	1000	1000
	2000	2000	2000	2000	2000
$ca_{it}$	1000	1000	1000	1000	1000
	2000	2000	2000	2000	2000
$ca_{mt}$	2000	2000	2000	2000	2000
	3000	3000	3000	3000	3000
	1500	1500	1500	1500	1500
$ca_{lt}$	2000	2000	2000	2000	2000
	1000	1000	1000	1000	1000
$ca_{kt}$	1500	1500	1500	1500	1500
	2000	2000	2000	2000	2000
$ca_{jt}$	3000	3000	3000	3000	3000
	4000	4000	4000	4000	4000
$ca_{it}$	900	900	950	900	950
	850	900	900	850	900
$ca_{nt}$	1000	1000	1000	1000	1000
	2000	2000	2000	2000	2000

**Source:** Researchers survey

Table 5.2: Transportation and fixed cost, environmental and social impact data

	Transportation Cost in Thousand		Fixed Cost In Million
$tc_{pd}$	3.2	$fc_p$	25
$tc_{pw}$	2.2	$fc_w$	5
$tc_{we}$	2.2	$fc_i$	2
$tc_{de}$	2.2	$fc_m$	0.5
$tc_{ci}$	2.2	$fc_l$	2
$tc_{im}$	3.2	$fc_j$	25
$tc_{il}$	3	$fc_k$	3
$tc_{ij}$	3	$fc_n$	5
$tc_{ik}$	3	$sc$	150
$tc_{ls}$	2		
$tc_{jp}$	3		
$tc_{ln}$	4		
$tc_{jn}$	3		
$tc_{kn}$	2		
$tc_{nf}$	4		

Source: Researchers survey, 2024

“

This case study employs secondary data, as illustrated in Table 5.1. The forecast for demand regarding new and returned products is based on sales data obtained from customer centers. Distributors can assess customer demands through the analysis of sales records for both new and recovered goods, alongside comparable products from competing firms. Forward chain distributors facilitate the distribution of recovered products within the reverse chain. The expenses related to the collection and inspection of returnable products encompass incentives for customer returns to collection centers, storage costs, essential activities for product retrieval, and related margins. The firm employs road-based transportation for shipping activities. Transportation expenses for products encompass operational costs and associated services, including salaries, wages, fuel charges, insurance, and depreciation. The transportation cost for each

utility product is determined. In addition to the input parameters that are detailed in Table 5.2, the fixed costs that are associated with establishing producers, opening warehouses, and forming contractual agreements with collection and inspection centers for returned products, as well as with disposal, recycling, and recovery centers for processing these products, are taken into consideration. Costs that are fixed do not alter over the course of several time periods.

The above mathematical equations were modeled with the General Algebraic Modelling System (GAMS) software in order to handle the model complexity using the IBM CPLEX solver. The results for the product allocation among facilities in the network for an optimal total cost using the period (five years) are shown in table 6.1. Hence, the total cost obtained for the CLSC network is found to be ₦26, 347,000,000 for all five periods.

Table 6.1: Distribution flow in ‘000’ between utilities for a five (05) year period

S/N	FACILITIES	2019	2020	2021	2022	2023
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<b>1</b>	<b>SUPPLIERS</b>	900	1200	1300	800	850
		300	0	0	400	500
<b>2</b>	<b>PRODUCERS</b>	0	0	0	0	0
		0	0	0	0	0
		1200	1200	1300	1200	1250
<b>3</b>	<b>WAREHOUSE</b>	0	0	0	0	0
		1200	1200	0	1200	1200
<b>4</b>	<b>DISTRIBUTORS</b>	0	0	0	0	0
		0	0	1300	0	0
<b>5</b>	<b>COLLECTION &amp; INSPECTION CENTRES</b>	900	950	1000	900	1200
		300	250	300	300	350
<b>6</b>	<b>DISPOSAL</b>	0	0	0	0	0
		0	0	0	0	0
		480	600	520	720	900
<b>7</b>	<b>RECYCLING</b>	0	180	0	0	0
		240	0	390	120	200
<b>8</b>	<b>RECOVERY</b>	200	420	390	360	500
<b>9</b>	<b>REDISTRIBUTORS</b>	280	0	0	0	0
		100	150	200	200	200
		300	250	100	100	200

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Source: Researcher's compilation

#### FINDINGS

Firstly, the total cost is obtained by designing and optimizing the CLSC network for the Nigerian Bottling Company. Secondly, the amount of product to be allocated within the multi-stage network is obtained for the Nigerian Bottling Company. Thirdly, the optimum facility

allocation within the network is obtained for the Nigerian Bottling Company. Furthermore, the findings of the study are specifically explained below as follows:

The initial three rows of Table 6.1 present the unprocessed ingredients acquired from suppliers. The results indicate that two of the three evaluated vendors are suitable for supplying raw materials. The producers did not engage supplier 3 during periods 2 and 3, as indicated in Table 6.1. The same applies to suppliers 2. One producer was active for this case study, and a potential location for the formation of a new producer was identified. According to the ideal solution (Table 6.1), only Producer 2 is mandated to manufacture products. In this situation, a single manufacturer would suffice to meet the requisite client requests, considering the surrounding circumstances. Determining the warehouses necessary for the distribution of finished goods is one of the most critical strategic decisions in the study. In this case study, the SC managers aimed to identify the most suitable locations for a warehousing contract. The results indicate that this business must get into a distribution deal with one of these warehouses. Table 6.1 indicates that 73% of customer requests are satisfied via a warehouse. The company is actively pursuing appropriate partners for product distribution, currently engaging one active distributor and contemplating an additional contractual distributor if required. The data indicates that a single distributor suffices for the company's supply chain. It is significant to acknowledge that 27% of completed items are sent from manufacturers to consumers through a distributor. Two centers were established to manage returns from customer regions, and the results demonstrate that these two collection and inspection locations are vital. These centers are employed to gather returned merchandise at all times. This case study analyzed two possible disposal centers and one active center within the stated supply chain, concluding that the active disposal center is adequate for the study. Furthermore, the corporation is not required to establish a formal agreement with the prospective disposal centers. Table 6.1 indicates that disposal facility 3 has been continuously utilized for processing returned products across all periods. A further strategic decision for the company's supply chain managers is to locate essential recycling sites for returned merchandise. Two potential sites for recycling facilities have been identified. Table 6.1 indicates that both centers



are necessary. Recycling center 1 was employed throughout period 2, whilst center 2 functioned in periods 1, 3, and 4. Notably, 930 returned products were recycled at the two specified sites. The findings confirm that both recycling sites are utilized across the supply chain. Nonetheless, the corporation may enter into a contractual arrangement only with recycling center 2, given that recycling center 1 was engaged with merely 180 items within a single period. By utilizing recycling facility 2 for all returned products, the corporation circumvents additional fixed costs. These findings aid supply chain managers in ascertaining the requisite number of recovery facilities for the repair of returned items. Table 6.1 demonstrates the necessity of both prospective recovery centers. Recovery center 1 is employed to restore 1,370 items over all periods, whilst recovery center 2 is tasked with recovering 280 returned products in period 1.

## CONCLUSIONS AND RECOMMENDATION

The literature relevant to the areas of interest was studied, and results from earlier supply chain optimization research indicate that studies did not adequately address the issues that were jointly recognized. Creating cooperative models for a multi-stage CLSC network that include the majority of the tactical and strategic choices encountered in the actual world is the aim of this. This study's main goal is to reduce the overall cost incurred throughout a number of time periods and across all stages. The problem description served as the basis for defining the underlying assumptions, variables, and limitations. An optimal total cost was determined after the network was designed. Additionally, a thorough sensitivity analysis was conducted to look into how changes in capacity, demands, and reversal rates would affect the overall cost of the network. Additionally, the advantages of an optimized network were demonstrated by comparing the developed optimal network for this industrial example with the existing operating conditions. The study's findings dictate which facilities

should be opened, how many facilities (suppliers, producers, etc.) should be used, and how many items should be moved between facilities over time. Furthermore, some recommendations were made based on the findings obtained in this study. Firstly, the manufacturing company should always adopt the use of optimization techniques rather than the use of analytical methods. This ensures efficiency in the use of the company's resources. Second, any similar businesses who need to create a suitable supply chain (SC) network in order to lower their costs will find the optimization techniques used here and the mixed integer linear programming (MILP) developed here to be good starting points. Thirdly, manufacturers should endeavour to implement and convert their manufacturing activities from linear economy to circular by closing the loops using optimization methods in their supply chain activities. Therefore, managers, and industrial engineers must take a close look into their networks scientifically, to smoothing these uncertain parameters in order to avoid disruptions in their daily operations.

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