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Supply Chain Optimization Modeling, a Case Study of a Glass Industry in Nigeria

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ABSTRACT

The application of processes and tools such as supply chain optimization mathematical programming tool, which ensures cost optimization or profit maximization of any establishment is of great importance in our ever-changing world. In this study, solution for supply chain optimization problem for a pre-deterministic demand of supplier to customer requirements in which demand uncertainties were not considered was carried out using a case study of a glass industry in Nigeria. A mathematical optimization model with cost minimization as its main objective function given all its sets of constraints was developed. The model was implemented using Generalized Algebraic Modeling System (GAMS) and results obtained were compared with that of LINGO solver. Generated data obtained from a glass industry in Nigeria was computed in the proposed models. The outcome of the results revealed that the objectives function Z (optimal cost) of the GAMS model was about 3% more than that of the LINGO model system. Besides, the raw material requirement analysis showed a difference of not more than 2% between the two models. From the GAMS results as compared to that of the test value, it was observed that there was an 8% reduction in the total operating cost of production when compared to that of the real value obtained. More so, the results of the raw material requirement obtained from both models showed slight variations as well, validating the results obtained from the model implemented. In addition, an affectability test with a 5% increase in the transportation cost impacted greatly on the overall cost of operation leading to a higher cost of production.

Keywords: *Optimization, model, supply chain, cost, glass industry*

INTRODUCTION

In the past, manufacturers produce and distribute goods at their own pace but in today's market, customers are the pace setters as manufacturers scramble to meet their everyday demand. Thus, the business world has no doubt shifted from manufacturers driven to customers driven. In the light of this, business strategies such as Six Sigma, Total Quality Management, Just-In-Time, Manufacturing Resource Planning, Quality Circle, etc has all been introduced at some point in the past to improve business performance and product delivery time. However, over time these strategies lose their shine and in recent years many businesses and companies are beginning to discover that effective supply chain management (SCM) is the way to go in order to increase market share and profit [14]. The use of modeling techniques in planning and optimization of supply chains (SC) activities in various industries is gaining widespread acceptance [1-3]. Despite the usefulness of such techniques, some entrepreneurs still lack the technical knowhow and the gains its acceptance and possible implementation would bring to their establishment. SC optimization process is primarily concerned with finding ways through which firms can reduce minimize overall operating cost, wastage and make the supply chain (SC) process more efficient and faster [4-6]. Therefore, designing a model that allows firms make better strategic and tactical decision rather than relying on personal judgment or experience for profit maximization is of great importance. Supply chain optimization is the practice of combining resources in a supply chain with the purpose of removing delays and any other problems that may interfere with the supply chain process thereby allowing it to function in an effective, smooth and timely manner [7-8]. Although, researchers has over the years continuously formulated methods and techniques to analyze the supply chain process for better decision making. However, designing an optimal SC network means the network must be able to meet the long-term strategic objectives of the company [9].

The usefulness of supply chain optimization model is numerous. It includes optimizing business operations to minimize cost or maximize profit, efficiency, speed at which finished products are delivered to customers, etc. In all, Customers value good products and the speed at which such products gets to them is very important, however, maximizing profitability by the manufacturer is equally important. There for, ensuring that products are delivered as fast and economical as possible without sacrificing quality is of paramount importance for an effective SCM system [10].

Study revealed that multiple periodic (MILP) model provided solutions to factory load allocation problems. The model was able to determine the production lines, production and finished products delivery number and raw material procurement of the supply chain process [11]. Similarly, [12] evaluated global SCM at digital equipment cooperation and in their design approach; a multi-cycle MILP model was developed for the supply chain process. In other to minimize total cost of the SC, factors such as transportation cost, inventory cost, taxes, production cost, etc were considered for the model. A real world case was used to test the model indicating a reduction in the total cost of the SC process. Also, [13] proposed a non-separable, nonlinear, MILP for a class of location-allocation problem involving several echelons for the planning and scheduling of parallel semi-continuous processes. A successive MILP algorithm where solution is constrained within trust region was used in solving the model. [14] Considered a stochastically varying production and transportation cost supply chain network optimization model design. A two-stage supply chain was proposed with the first being a MILP, solved to provide solution for the second model. In the study, variables with noise (stochastic model) were compared to those without noise (deterministic model) using Gaussian, Lognormal and Pareto distribution. Research study on linear programming model has been implemented in [15-16]. However, [17-20] demonstrated the use of high-level algorithms in supply chain optimization. [21-22] Developed an integer-programming model for transportation optimization of oil products. In his study, distances and cost minimization were set as the objective function in other to obtain the refinery-to-deport optimal assignments. In his approach adopted to run the program using I-Log software. Real case study data were selected and the resulting established are highly feasibly in reality to obtain the best outcome. [23] Developed a mathematical model of multilevel cost optimization for SC in the form of mixed integer linear programming (MILP) for optimizing the supply chain from the prospective of a logistics provider. Production, distribution and transportation cost were adopted as an optimization criterion and the model was implemented in the mathematical modeling package "LINGO" environment.

Researchers has proposed and implemented various optimization tool and algorithm for solving supply chain management problems. However, large amount of research work still needs to be done on minimization or maximization of the entire supply chain process (supplier, production, distribution, inventory, transportation and location) for better optimality of the process. More so, works still needs to be done in model validation and raw material requirement with respect to customer's demand.

MATERIALS AND METHODS

Problem Structure and Model Formulation

As shown in Fig. 1, a four echelon SC process was considered with a given sets of suppliers, fixed factories and distribution centers that delivers finished products to its multiple customers. Sets of logical constraints for each of the SC echelon were developed to ensure coherence in the SC decisions model.

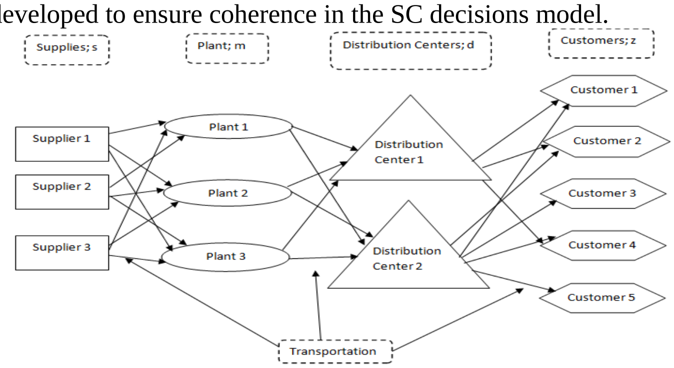

Fig. 1 Four echelon supply chain network representation

The problem undertaken is a pre-deterministic demand of supplier to customer requirements in which demand uncertainties were not considered. Thus, it is a deterministic problem and a mixed integer linear programming (MILP) model is being proposed. A mathematical optimization model with cost minimization as its main objective function given all its sets of constraints was developed. The proposed optimization model was taken into account (four participants via suppliers, manufacturing plants, distribution centers and customers) in trying to optimize or having a near to optimal solution. The model was implemented using Generalized Algebraic Modeling System (GAMS) and results obtained were compared with that of LINGO solver (a more advanced solver) for results validation. The assessed information (data) for the model was obtained from a glass company in Nigeria and computed in the proposed models. The variables of the mathematical model are defined as shown in Table 1.

Table 1. Variables of the Mathematical Model

Variable	***Sets and Indices***	***Definitions***
r	Raw material type, r=1, 2,……………	R
m	Manufacturing plant, m=1, 2, ……..,	M
p	Product type, p=1, 2,..…………..,	P
s	Supplier, s=1, 2,………………….,	S
d	Distribution center, d=1, 2,………,	D
z	Customers, z=1, 2,………………..,	Z

Input parameters	
$T_{r(sm)}$	Unit transportation cost for raw material, r, from supplier, s, to manufacturing plant, m.
C(rs)	Unit cost of crude material, r, for provider, s, to assembling plant, m.
Fm(m)	Fixed expense for assembling plant, m
H(pd)	Inventory holding cost per unit of item, p, at dissemination focus, d.
Cp(pm)	Unit cost of item, p, at assembling plant, m.
Tp(md)	Unit transportation cost for item, p, from assembling plant, m, to circulation focus, d.
L(pd)	Inventory level of item, p, at circulation focus, d.
Ud(pz)	Demand of item p by client, z.
Decision variables	
Ur(rsm)	Number of units of crude material, r, secured from provider, s, to assembling plant, m.
Up(pm)	Number of units of item, p, delivered at assembling plant, m.
U(pmd)	Number of units f item, p, transported from assembling plant, m, to circulation focus, d.
Binary variables	
Xm(m)	1, if fabricating plant, m, is open; 0, assuming something else.
Xd(d)	1, if conveyance focus, d, is open; 0, assuming something else.
Xc(dz)	1, if dispersion focus serves client, z; 0, assuming something else.

Mathematical Formulation

The expression for the cost optimization of the entire supply chain (SC) process as formulated based on the objective function shown in Equations (1) to Equation (4);

$$Min \quad Z_1 = \sum_{r=1}^{R} \sum_{s=1}^{S} \sum_{m=1}^{M} (C_{rs} + T_{r(sm)}) U_{r(rsm)} \tag{1}$$

$$+ \sum F_{m(m)} X_{m(m)} + \sum_{p=1}^{P} \sum_{m=1}^{M} C_{p(pm)} U_{p(pm)} \tag{2}$$

$$+ \sum_{d=1}^{D} F_{d(d)} X_{d(d)} + \sum_{p=1}^{P} \sum_{m=}^{M} \sum_{d=1}^{D} U_{pmd} T_{p(md)} + \sum \sum H_{pd} L_{pd} X_{c(dz)} \tag{3}$$

$$+ \sum_{p=1}^{P} \sum_{d=1}^{D} \sum_{z=1}^{Z} T_{d(dz)} U_{d(pz)} X_{c(dz)} \tag{4}$$

The objective function (Z_1) consists of four echelon and defines the costs of the entire supply chain process. Equation (1) consists of all related cost associated with getting the raw material to the manufacturing plant. Equation (2) consists of all variable cost associated with producing the product and getting it to the distribution center, while Equation (3) on the other hand consists of cost associated with setting up of the distribution center and holding cost, and Equation (4) represent all related cost of getting the products delivered to the customers.

More so, the cost of the entire supply chain process is subject to observed constraints which include: availability constraint which ensures that the total produced product do not exceed the plant's capacity; demand constraint, which specify that the number of units of products produced in the manufacturing plant equals that shipped from the plant; constraint which ensures that the total number of units of products shipped from the distribution center satisfies demand; storage capacity constraint which ensures that the numbers of unit of product do not exceed its storage capacity; plant capacity constraint which ensures that the produced products do not exceed the plant capacity; supplier capacity which ensures that the raw materials supplied are within the supplier's capacity and the non-negativity constraint.

Model Implementation

Implementation of the model is done with the use of two (2) different MILP systems; the General Algebraic Modeling System (GAMS) and the LINGO system, with the former being the main solver while the latter is implemented to compare and validate the main model.

General Algebraic Modeling System Model

The General Algebraic Modeling System (GAMS) is a mathematical optimization tool designed for modeling and solving nonlinear, linear and mixed-integer optimization problems. GAMS systems are adapted for large-scale, complex modeling applications. The system uses the branch and cut approach for solving MILP problems. The approach is a type of branch and bound solver that involves a combination of cutting plain and LP relaxation method with its algorithm as shown in Table 2.

Table 2. Describes the basic syntax of GAMS mathematical

Nomenclature	GAMS Syntax
Minimum	MIN(.,.)
Addition	+
Equality in an operation	=
Summation	SUM(set domain, element)
Multiplication	*
Subtraction	-
Product	PROD(set domain, element)

modeling language

LINGO Model

The LINGO is a high – level optimization modeling tool for solving mathematical optimization problems. The model is designed to solve and analyze linear, stochastic, integer, quadratic and nonlinear optimization problems. LINGO provides a completely integrated package that includes a powerful language for expressing optimization models and a set of fast built-in solvers. In LINGO, MILP problems are solved using the branch and bound technique. The algorithm for solving MILP in LINGO is as stated in Table 3.

Table 3. The syntax mathematical modeling language as represented in LINGO

Nomenclature	LINGO Syntax
Minimum	MIN=
Addition	+
Equality in an operation	=
Summation	@SUM(set domain, element)
Multiplication	*
Subtraction	-
Product	@PROD(set domain, element)
X ϵ integer	(ginX)
X ϵ {0,1}	@bin(X)
j=1,…..,M for each customer(j) in the set of customers	@FOR(customers(j))

RESULTS AND DISCUSSION

The generated data were inputted separately into the GAMS and LINGO modeling framework of the MILP problem environment. The outcome yielded the following results as shown in Table 4. As observed from the results in Table 4, the objective function Z (optimal cost) of the GAMS model was about 3% more than that of the LINGO modeling framework (See Appendix A1 and A2). The raw material requirement when looked at demonstrated a distinction of not more than 2% between the two models. This shows a low distinction in the outcome acquired between the two models (GAMS and LINGO) when looked at as a framework for tackling the MILP studied. There for, validating the results obtained from the main model in view (GAMS). More so, the LINGO results obtained as compared to the GAMS results indicates that the LINGO mathematical tool is a more efficient and superior tool for finding solutions to SC optimization as researched [17].

Table 4. GAMS and LINGO modeling system results

Model Solver	Parameters				
	Cost (₦)	Raw Material 1	Raw Material 2	Raw Material 3	Raw Material 4
GAMS	66,881,645.4545	3,620	2,840	2,230	1,710
LINGO	64,844,564.2586	3,550	2,780	2,195	1,675
Difference	2,037,081	170	60	35	35
% Difference	3.045	1.93334	2.1127	1.5695	1.4619

Table 5. GAMS and Real value result

	Cost	Raw Material 1	Raw Material 2	Raw Material 3	Raw Material 4
GAMS	66,881,645.4545	3,620	2,840	2,230	1,710
Real Value	72,684,204	3,810	3,000	2,405	1,875
Difference	5,802,559	190	160	175	165
% Difference	7.9837	4.9869	5.3333	7.2765	8.8000

Table 5 shows the results obtained from the model (GAMS) and that of the test values (company's value). From the GAMS results as compared to that of the test value, it can be seen that there is an 8% reduction in the total operating cost of production when compared to that of the test value obtained. The 8% decrease achieved which is about N5.8 million is a very significant variation as this additional cost can incredibly affect the unit cost of each products produced, it can also affect the company's competitiveness and on the overall smooth running operations of the company. The reduction in cost observed was largely due to the reduction in the quantity of raw material obtained from the model that should be ordered in relation to customers demand as shown in the Table 5. Consequently, for the organization to accomplish such decrease and limit its working expense according to its clients' demand, the amount of raw material as gotten from the GAMS model should be implemented.

An affectability examination on a portion of the results obtained uncovers that changes was affected adversely or emphatically on the output data of the model. Through this the impact of uncertainty on the output of the optimal solution can be known. A sensitivity analysis test was done on the quantity of raw material required as to how its changes would affect the result of the optimal solution (cost).

Figure 2 shows a raw material graph. From it, for as low as a 5% increase in the quantity of raw material ordered, there is a corresponding rise in the cost of operation. Indicating that if the proper analyses are not carried out on the right quantity of raw material to be ordered with respect to its customers demand, the organization will incur more operational cost of production. Therefore, knowing the right amount of raw material needed for producing a certain amount of goods in any organization is of paramount importance.

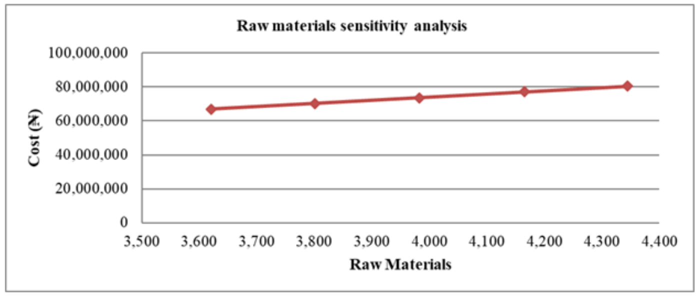

Fig.2 Raw material sensitivity analysis

The affectability examination was likewise done to show how an expansion or a diminishing in the stock level would influence the optimal solution (cost). As appeared in Fig. 3, a 10% expansion in the stock level brought about a comparing increment in the overall cost of production. In this manner, the higher the stock level an association keeps the higher it's operational cost.

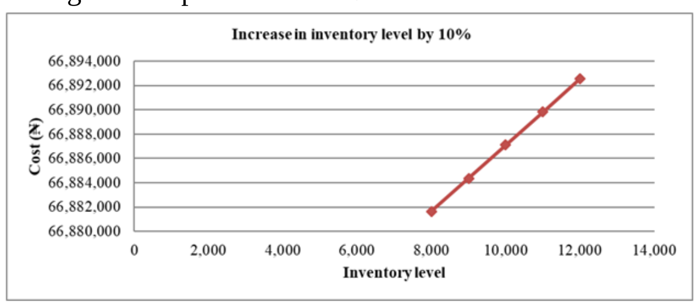

Fig.3 Inventory level sensitivity analysis

Affectability investigation was similarly done on the transportation cost for shipping items to client zones and its corresponding effect on the operational cost is as shown in Fig. 4. From the plots of the transportation cost of conveying the items to the client's zone against its operational cost, a corresponding relationship diagram was set up. It was seen from the plot that as low as a 5% expansion in the transportation cost affected enormously on the general expense of activity prompting a greater cost of production. This was as an aftereffects of increment in fuel, mileage and support cost that has huge impact on the general expense. Then again, if there is a decrease of cost of maintenances and fuel there would be a comparing decrease in the general working expense.

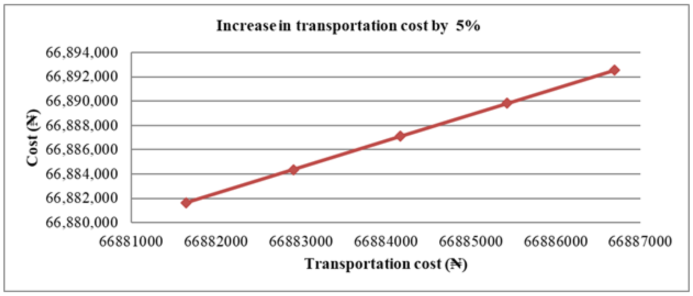

Fig. 4 Transportation sensitivity analysis

CONCLUSION

Conclusively, the developed model proved to be an effective and efficient for providing solution to SC optimization problem in the glass industry. The MILP tool adopted (GAMS) for cost optimization of the problem undoubtedly facilitated its solution as compared and validated using a more superior mathematical programming package (LINGO). Implementation of both models allowed for obvious variation of the overall cost of production, raw materials requirement, and number of products produced as compared to the real values obtained from the glass industry. Based on the experimental results and analysis, the study revealed a significant reduction in the overall cost of operation of about 8% which is about N5.8 million when compared to that of the real value obtained. The model implemented also showed an appropriate and appreciable measure of performance when affectability analysis was performed on some of its input parameters. Therefore, a well formulated and implemented mathematical modeling tool can assist an organization in make useful decisions in supply chain management.

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