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A Linear Programming Model for the Production, Distribution and Inventory Systems of a Bottling Company

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ABSTRACT: The situation covered in this study is the Nigerian Bottling Company (NBC), which is looking to make a profit. The major goal of such an establishment in this regard is to maximize (optimize) profit. This study focuses on applying linear programming techniques (model) to maximize profit from soft drink production for a Nigerian bottling company. Linear Programming of the company's operations was formulated, and the best results were determined using software, indicating that two specific things should be produced even if the company had to meet needs for other less profitable items in the vicinity of the facilities. The goods are delivered to a number of locations where the demand for each item is known. The interest problem entails deciding what items should be produced, how much of each product should be produced, and where production should occur. The company's goals are to reduce total operating costs while also increasing total sales revenue based on a series of decisions that include demand, capacity limits, and budget constraints. Linear programming software called Linear Programming Solver is used to solve the model, which has three (3) variables and five (5) constraints. The findings show that production without the optimization principle yields a profit margin of five billion, forty-two million, four hundred and thirty-one thousand, two hundred naira (-N-5,042,431,200.00K), whereas production with the optimization principle yields a profit margin of five billion, sixty-six million, eight hundred and ninety thousand naira (-N-5,042,431,200.00K) (-N-5,066,890,000.00K)
Keyword: Linear Programming Solver, Optimization Principle, Demand, Capacity Limits, Budget Constraints

I. INTRODUCTION

Production planning is critical in most Manufacturing and Fast-Moving Consumer Goods (FMCG) companies, such as the Nigerian Bottling Company, because proper multi-echelon supply chains with many production facilities, systems, and depots necessitate determining what products should be made, how much of each product should be produced, and where production should take place. These supply chain processes have become critical to company objectives, particularly as the drive to reduce total cost of operations while also increasing total sales revenue based on a set of decisions, such as demand, capacity constraints, and budget constraints, has become critical to companies' operations and serves as key performance indicators (KPIs) with stakeholders.

Sales and operations are at the heart of today's enterprises, and decisions made in these areas have a significant impact on the organization's financial performance, operational efficiency, and service level. Three multi-objective fuzzy mixed integer linear programming models of the sales and operations planning process will be developed in this manuscript. The fully integrated fuzzy model's performance is then compared to that of a similar crisp model in terms of total supply chain cost and customer service level. All of the models were created for a multisite manufacturing corporation that deals with a variety of raw material suppliers, third-party logistics, distribution centers, and customers who have a variety of product families. Finally, the models are used to solve a real-world problem in an Iranian FMCG manufacturing company. The final results support the fuzzy model's superiority over the crisp model. In addition, a sensitivity analysis is performed to investigate the impact of a few critical criteria on the benefits of SC planning integration. (Nemati and Alavidoost, 2019).

Efficient long-term capacity management is a critical component for the efficient operation of any industrial company. It improves competitive performance by lowering costs, increasing delivery speed, increasing dependability, and increasing flexibility. Capacity is a structural decision category in every production setup, and it usually deals with long-term changes in demand levels and dynamic capacity increase. Sales and operation planning (S&OP) is a component of factory planning and control systems that is used to plan long-term production levels in relation to sales. Resource planning is used in S&OP to determine the proper capacity levels to support the production plan. This article aims to combine manufacturing strategy with sales and operation planning for an FMCG company, providing outcomes in terms of long-term capacity improvement investment needed to satisfy long-term future demand with the lowest delivery cost (Jain and Tyagi, 2019).

The findings of this study revealed the different types of distribution channels used by fast moving consumer goods companies, as well as some of the issues they face, such as payment defaults, stolen goods, poor infrastructure, the presence of counterfeit goods in the market, quality issues, discriminatory trade offers, and so on.

The outcomes of this study imply that various distribution channels may have an impact on FMCG companies' profitability, sales turnover, market share, productivity, and revenue. Furthermore, to ensure the efficacy of distribution strategies, FMCG firms must be willing to evaluate their territory management, company state, financial capabilities, and infrastructure compliance. (Odupitan, 2017).

The project investigates the scheduling of production in a real-world consumer goods business. The packing stage is the biggest bottleneck in the production facility, which comprises of numerous continuous steps. The continuous packing stage is modeled using an immediate precedence and a unit-specific general precedence-based mixed integer linear programming (MILP) model. To avoid infeasible timetables, constraints connected to the operation of earlier manufacturing phases, as well as maintenance limits, are taken into account. For practical problem situations with reasonable computational times imposed by the plant, two MILP-based decomposition algorithms are presented as a solution. Industry-validated scheduling methods have been directly compared against schedules created by operators using simulation tools. Significant reductions in change over time are accomplished, resulting in an increase in overall plant productivity.

Company executives are frequently confronted with decisions about the allocation of scarce resources. Men, materials, and money are examples of these resources. In other sectors, there are inadequate resources to do everything that management desires.
The issue is how to identify which resources should be allocated to achieve the optimal result, which could be based on profit, cost, or both.

Multi-echelon supply chains have been a focus of research for nearly three decades. As a result, models for supply chain control in a variety of formats and operational disciplines are now accessible. Because of the large number and variety of these models, surveys with diverse scopes and foci are common (Inderfurth, 1994).

Microeconomics and firm management, such as production, inventory, planning, transportation, distribution, technology, and other concerns, rely largely on linear programming. Despite the fact that the modern management challenge is error correction, most businesses want to maximize cost with limited resources. As a result, many situations can be classified as linear programming issues.

II. METHODOLOGY

Emphasis on the necessity of optimization approaches, a thorough model for Nigerian Bottling Company (NBC) will be constructed, with all parameters substituted as needed.

The data used in this project work was collected from NBC Kaduna plant in Kaduna and Challawa plant in Kano. All in the North-western Zone of the country.

Data for this project work was collected from NBC. This data includes: estimated demand for products at depot in a given time interval, maximum shipping weight of truck, unit weight of each product depending on bottle type, unit production time of products at plant, maximum available time for production of products at plant, fixed set up cost of production facilities, transportation cost from plant to depot, unit cost of product production at a plant in a particular time interval, inventory level at their warehouse and depot, maximum warehouse storage capacity for each product, fixed vehicle cost, etc.

The following is a list of the types of information gathered:
Production-related:

i. Unit production time of products at plant.
ii. Maximum unit time available at each plant.
iii. Fixed set-up cost of production facilities.
iv. Unit production cost of products.
v. Warehouse-related:
vi. Products demanded at depot.
vii. Inventory level.
viii. Inventory holding cost

ix. Maximum storage capacity of products.
x. Distribution/Sales-related:
xi. Cost of direct travel from plant to plant.
xii. Fixed vehicle cost per route travelled.
xiii. Unit weight of product.
xiv. Maximum shipping weight of truck.
xv. Total budget.
xvi. Sales revenue.

a) Methods

LiPs, or Linear Programming Solver, is a simple and effective tool for solving linear, integer, and quadratic programming problems. These issues arise in the fields of commerce, industry, research, and government.

ai) The Working Principles of the Linear Programming Solver, LiPs

The Linear Programming Solver (LiPS) is a program for solving linear, integer, and goal programming problems. The Lips' most distinguishing characteristics are:

i. LiPs is a large-scale problem solver based on an efficient implementation of the modified Simplex method.

ii. You can use LiPs to study linear programming because it delivers not only an answer but also a full solution procedure as a series of simplex tables.

Analysis of changes in the right sides of constraints, analysis of changes in the coefficients of the objective function, and analysis of changes in the column/row of the technology matrix are all sensitivity analysis procedures provided by LiPs, allowing us to study the behavior of the model when its parameters are changed. Such data could be incredibly beneficial in the implementation of LP models in the real world.

Goal programming approaches such as Lexicographic and weighted GP are also available in LiPs. Methods of goal programming are used to solve multi-objective optimization issues.

aii) Model Editor

The model editor lets you create, edit, save, and load models. The system has its own input format linear programming solver, LPX, as well as a standard format model programming solver, MPS. When utilizing the Linear Programming Solver, LPX format, the user has two input models to choose from: algebraic and tabular.

aiii) Model Solver

Use the LiPs>> Solver model menu to start the solution procedure. There are two modes in the model solver: basic and advanced. LiPs gives a detailed solution procedure as a sequence of simplex tables in the basic mode (which is good for learning the simplex approach). The result of each iteration includes: a corresponding simplex table, a variable to be made basic, and a variable from the basic set, etc. The computer solution's format mimics the method of manually solving the problem. LiPS presents a series of strategies for solving large-scale problems in advance model: a branch-and-bound technique for MILP based on LU-decomposition, a modified primal and dual simplex method based on LU-decomposition.

aiv) Sensitivity Analysis

Sensitivity analysis is a set of effective computing approaches for studying the dynamic behavior of the optimal solution as a result of changing the model's parameters. Lips offers the following sensitivity analysis services:

i. Changes in the right-hand sides of the restrictions are examined.
ii. Changes in the objective function's coefficients are examined.
iii. Changes in the technology matrix's column are examined.
iv. Changes in the technology matrix's row are examined.

b) Linear Programming Modelling

There are three essential components to the Linear Programming model:

a) To be determined are the decision variables.
b) Optimisation objective (goal or aim).
c) There are some constraints that must be met.

bi) Assumptions

Some assumptions are proposed below for the sake of simplicity:

i. All products have a ready market.
ii. The same standard operating procedure applies to all plant locations.
iii. There is sufficient manpower (talented and knowledgeable) available.
iv. A well-functioning transportation system is in place.
v. Estimating demand is possible.
vi. Constraints
vii. Capacity restriction on production in every period.
viii. Inventory balance at production facility.
ix. Inventory balance at depot.
x. Total demand for each item at customer location.
xi. Total budget.

bii) Model Development

Component formulation

Profit = Sales Revenue – Total cost

$$Sales\ revenue = \sum_{111}^{IKT}\sum\sum\sum S_{ij}\,X_{jikt} \tag{3.1}$$

Total Cost = production cost + inventory cost + distribution cost.

$$Production\ cost = \sum_{111}^{JIT}\sum\sum\sum c_{jit}\,Q_{jit} \tag{3.2}$$

Inventory cost = average sum of starting inventory and ending inventory cost

$$= 0.5h_{jk}\sum_{111}^{JKT}\sum\sum\sum INV_{jkt}\,INV_{jkt} \tag{3.3}$$

$$Distribution\ cost = \sum_{111}^{JIKT}\sum\sum\sum V_{jit}\,X_{jikt} \tag{3.4}$$

Objective function

Maximize:

$$\text{Profit} = \sum\sum\sum\sum S_{jikt}\,x_{jikt} - \sum\sum\sum C_{jit}\,Q_{jit} - 0.5h_{jkt}\sum\sum\sum(INV_{jit} + INV_{jit}) - \sum\sum\sum\sum V_{jit}\,X_{jikt} \qquad 3.5$$

Constraints to satisfy;

Subject to:

Period capacity restriction on production

$$\sum\sum\sum W_{jit}\,Q_{jit} \le T_{1,}\ for\ all\ i\ and\ t$$

Production facility inventory balance

$$\sum\sum\sum\sum(I_{jit}\,jjikt) + Q_{jit} - X \le A_i$$

Depot inventory balance

$$\sum\sum\sum\sum X_{jit}\left(\sum\sum\sum INV_{jkt} - \sum\sum\sum INV_{jkt}\right) = \sum\sum\sum D_{jkt}$$

Production-demand balance

$$\sum\sum\sum Q_{jit} + \sum\sum\sum I_{jit} \le \sum\sum\sum D_{jkt}$$

Budgetary constraint

$$\sum\sum\sum C_{jit}\, Q_{jit} - \sum\sum\sum 0.5\, h_{jkt}\big(INV_1 + INV_{jKt}\big) -$$
$$\sum\sum\sum V_{jikt}\, X_{jikt} \ \leq\ B_u$$

$$\sum\sum\sum C_{jit}\, Q_{jit} - \sum\sum\sum 0.5\, h_{jkt}\big(INV_{jkt} + INV_{jKt}\big) -$$

$$\sum\sum\sum V_{jikt}\, X_{jikt} \ \leq\ B_1$$

$+ 14\, INV_{17} + 13\, INV_{18} + 13.5\, INV_{19} + 13.5 INV_{19} + 15\, INV_{21} + 15\, INV_{22} + 14\, INV_{23} + 14 INV_{24} + 13 INV_{24} \geq$ 2900000000 (3.10b)

For Q_{jit} : Quantity of product „j‟ produced at plant „i‟ in period „t‟

MAXIMIZE PROFIT

$980\, Q_1 + 980\, Q_2 + 980\, Q_3 \quad + 980\, Q_4$

SUBJECT TO

$4.32\, Q_1 + 4.32\, Q_2$	$\leq$	6264000
$2.4\, Q_3 + 2.4\, Q_4$	$\leq$	6264000
$Q_1 + Q_2$	$\leq$	100000
$Q_3 + Q_4$	$\leq$	150000
$Q_1 + Q_3$	$\leq$	400000
$Q_2 + Q_4$	$\leq$	1290000
$Q_1 + Q_3$	$\leq$	290000
$Q_2 + Q_4$	$\leq$	940000
$Q_1 + Q_3$	$\leq$	240000
$Q_2 + Q_4$	$\leq$	790000
$Q_1 + Q_3$	$\leq$	540000
$Q_2 + Q_4$	$\leq$	1750000
Q_1, Q_2, Q_3, Q_4	$\geq$ 0	

For INV_{jkt} : Inventory of product „j‟ at depot „k‟ in period „t‟

MAXIMIZE PROFIT

$13.5\, INV_1 + 14.5\, INV_2 + 15\, INV_3 + 15\, INV_4 + 14\, INV_5 + 13\, INV_6$

SUBJECT TO

$0.5\, INV_1 = 75500$

$0.5\, INV_2 = 125500$

$0.5\, INV_3 = 199000$

$0.5\, INV_4 = 250000$

$0.5\, INV_5 = 400000$

$0.5\, INV_6 = 640000$

$INV_1, INV_2, INV_3, INV_4, INV_5, INV_6 \geq 0$

The values of the variables: $X_1, X_2, X_3, X_4, X_5, X_6 \ldots X_{48}, Q_1, Q_2, Q_3, Q_4 \ldots Q_{16}$
$INV_1, INV_2, INV_3, INV_4, INV_5, INV_6 \ldots INV_{24}$, are computed as given in appendix C.

The variables can further be separated into their individual component parts as given by the model developed in chapter three.

Thus, The above-mentioned model is employed, with parameters substituted based on available data, and the Linear Programming Solver Software is used to run the model and solve the problem.

III. PERFORMANCE EVALUATION

For ease of identification and Simplification, the variables used are redefined as follows

Table 1: Quantity of product "j" produced at plant "i" in period "t" in year 2013.

Q_{jit}	J	I	T
Q_1	1	1	1
Q_2	2	1	1
Q_3	1	2	1

Where,
Q_1 is quantity of product 1 made at plant 1 in period 1,
Q_2 is quantity of product 2 made at plant 1 in period 1,
Q_3 is quantity of product 1 made at plant 2 in period 1.
Product 1 is "Coke" while Product 2 is "Fanta"
(See Table A.1 in Appendix A for details)
X_{jikt} is quantity of product„"j" produced at plant„"I" distributed to depot k inperiod "t"eg,
X_1 is quantity of product 1 produced at plant 1 distributed to depot 1 in period 1.(See Table B.2 in Appendix B for details)

I_{jikt} is inventory of product"j" at depot "k" in period "t" e.g. $I_1$is inventory of product 1 at depot 1 in period 1. (See Table B.3 in Appendix B for details)

Table 2: Demand for product "j" at depot "k" in period "t" (quarters), D_{jkt} (unit) in year 2013.

Period, t (Quarter)	Depot, k	Product, j 1	Product, j 2
	1	75,500	250,000
1	2	125,500	400,000
	3	199,000	640,000
Total		400,000	1,290,000
	1	50,000	205,000
2	2	100,000	300,000
	3	140,000	435,000
Total		340,000	1,040,000
	1	40,000	105,000
3	2	75,000	260,000
	3	125,000	425,000
Total		290,000	890,000
	1	100,000	385,000
4	2	180,000	560,000
	3	260,000	805,000
Total		**440,000**	**1,650,000**

Starting inventory of product "j" at plant "I" in period "t" = 1, assumed to be zero, Similarly, starting inventory of product "j" at depot "k" in period "t" = 1, assumed to be zero.

Table 3: Unit production time, "W_{ji}" (seconds) of product in year 2013.

Plant, i	Product, j 1	2
1	4.32	4.32
2	2.4	2.4

Maximum available time at each plant: Plant 1 = 20hrs
Therefore, the maximum available time (in seconds) in each period or quarter (1 period = a quarter = 3 months)
60mins/1hr x 60secs/1min x 20hrs/1day x 20days/1mnth x 3mnths/1 period
4,320,000 seconds/quarter

Similarly,
Plant 2 = 20hrs
Therefore, the maximum available time (in seconds) in each period or quarter
(1 period = a quarter = 3 months)
60mins/1hr x 60secs/1min x 20hrs/1day x 20days/1mnth x 3mnths/1 period
4,320,000 seconds/quarter

Table 4: Total unit cost of producing product "j" at plant "I", (₦ /unit) in year 2013.

Plant, "I"	**Production Cost of**	**"j" (₦ /unit)**
	1	2
1	830	830
2	830	830

Table 5: Selling price per unit of product "j" at depot "k" (₦ /unit) in year

Product, 'j'		**Depot, 'k'**	
	1	2	3
1	980	980	980
2	980	980	980

Selling price per unit product (crate) = ₦1,210 (50cl) Selling price per bottle (liquid Content Only) = ₦70 (50cl)
Selling price per unit product (crate) = ₦980 (35cl) Selling price per bottle (liquid Content Only) = ₦50 (35cl)

Table 6: Distribution cost per unit of product, (₦ /unit) in year 2013.

Plant, 'i'		**Depot, 'k'**	
	1	2	3
1	7	9.5	11
2	11	9	6

Table 7: Inventory holding cost at each depot, ₦ /unit (assumed constant Over a long range) in year 2013.

Depot, 'k'		**Product, 'j'**
	1	2
1	13.5	15
2	14.5	14

3	15	13

Maximum storage capacity at warehouse: Plant 1 = 100,000 units
Plant 2 = 150,000 units
Substituting all the parameters above into the model developed in chapter three (3): Objective Function to Optimize:

MAXIMIZE
$+ 14\,INV_{17} + 13\,INV_{18} + 13.5\,INV_{19} +$
$+ 15\,INV_{21} + 15\,INV_{22} + 14\,INV_{23} +$
≥ 2900000000 (4.5b)
The variables can further be separated into their individual component parts as given by the model developed in chapter three.
For X_{jikt} : Quantity of product „j‟ from plant „i‟ supplied to depot „k‟ in period „t‟

For Q_{jit} : Quantity of product „j‟ produced at plant „i‟ in period „t‟

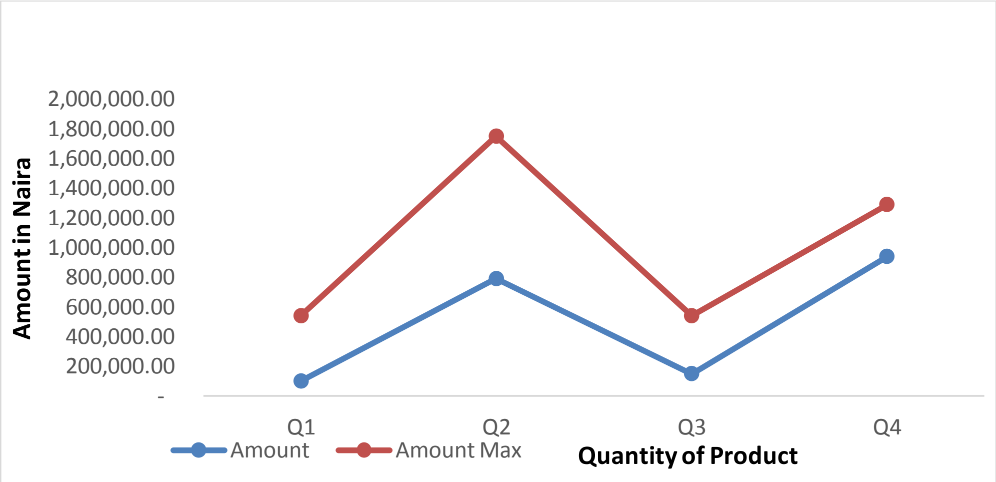

Figure 1: Quantity/ Amount Maximization Distribution

For INV_{jkt} : Inventory of product "j" at depot "k" in period "t"

MAXIMIZE PROFIT

$13.5\,INV_1 + 14.5\,INV_2 + 15\,INV_3 + 15\,INV_4 + 14\,INV_5 \quad + 13\,INV_6$

SUBJECT TO

$0.5\,INV_1 = 75500$

$0.5\,INV_2 = 125500$

$0.5\,INV_3 = 199000$

$0.5\,INV_4 = 250000$

$0.5\,INV_5 = 400000$

$0.5\,INV_6 = 640000$

INV_1 , INV_2 , INV_3 , INV_4 , INV_5 , INV_6 $\geq$ 0
The values of the variables: X_1 ,X_2 , X_3 , X_4 , X_5 , X_6 . . . X_{48} , Q_1 , Q_2 , Q_3 , Q_4 . . . Q_{16}
INV_1, INV_2, INV_3, INV_4, INV_5, INV_6. . . INV_{24}, are computed as given in appendix C.

- **Profit analysis of year 2013 (without Optimization Principle)**

Selling Price per unit product (35cl) = ₦ 980
Average Sales Volume range per day = 24,000 cases per day
Sales Revenue = ₦ 980 X 24,000 X 365 = ₦8,584,800,000
Unit Production time of Products = 8hrs per day
Filler Capacity Cases (35cl) = 1,083 cases per hour
Unit Production Cost per Case (35cl) =₦ 830
Production Cost = ₦ 830 X 1,083 X 8 X 365 = ₦2,624,758,800 Maximum Storage Capacity at the warehouse = 150,000 units Inventory holding Cost at the warehouse per unit product = ₦ 15 Inventory Cost = ₦ 15 X 150,000 X 365 = ₦ 821,250,000 Sales Volume Range per day = 24,000 cases per day Distribution Cost per unit case (35cl)
= ₦ 11Distribution Cost = ₦11 X 24,000 X 365 = ₦96,360,000
Profit = Sales Revenue – Total Cost
Where Total Cost = Production Cost + Inventory Cost + Distribution Cost Profit = Sales Revenue – Production Cost – Inventory Cost – Distribution Cost Profit = ₦ 8,584,800,000 – ₦2,624,758,800 – ₦821,250,000 – ₦96,360,000 Profit = ₦5,042,431,200.00K

- **Profit analysis of year 2013 (with Optimization Principle)**

Profit = Sales Revenue – Total Cost
Where Total Cost = Production Cost + Inventory Cost + Distribution Cost Profit = Sales Revenue – Production Cost – Inventory Cost – Distribution Cost Profit = ₦ 389,148,000 + ₦1,255,010,000 + ₦282,110,000 + ₦914,455,000 + 233,495,000 + ₦ 768,575,000 + ₦ 525,320,000 + ₦ 1,702,440,000 -- 207,500,000 – ₦ 207,500,000 – ₦ 207,500,000 – ₦ 207,500,000 -- 46,988,000 – ₦ 34,310,000 – ₦ 28,485,000 – ₦ 63,880,000
Profit =₦ 5,066,890,000.00K
Where: 389148000, 1255010000, 282110000, 914455000, 233495000, 768575000, 525320000, 1702440000, 207500000, 207500000, 207500000, 207500000, 46988000, 34310000, 28485000, 63880000.
Are the values of the Optimum Solutions generated from the Linear Programming Solver Software.

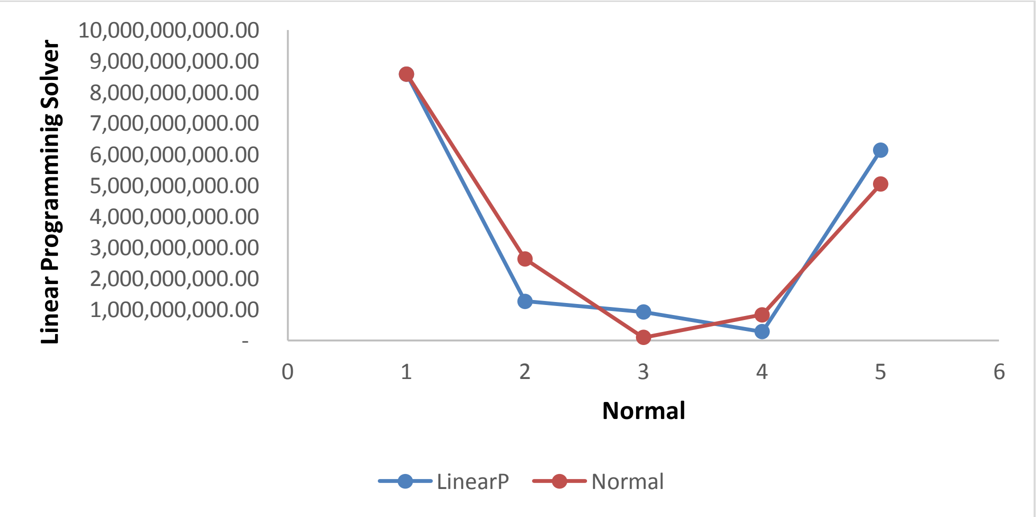

Figure 2: Comparative Analysis between Lips and Normal Process on Profit Maximization

The optimum conclusion provided from the model, based on the data collected, advises that two products, 50Cl Coke and 50Cl Fanta, should be manufactured more. To optimize profit, their production numbers should be higher than other products.
The linear model's conclusion is provided in Appendix C.

IV. CONCLUSION

The NBC's production, inventory, and distribution systems were evaluated, and the potential for employing a Linear Programming model to manage large-scale production, inventory, and distribution challenges was discovered. The decision variables, parameters, and constraints required for constructing a model of the Company's production, inventory, and distribution processes have been solved using Lips' linear programming solver. A linear programming model with eighty-eight (88) variables and fifty-four (54) constraints was fitted and then formulated. The optimal production, inventory, and distribution of NBC items was studied, and the model increased the profit of the company under investigation by around $24,458,800 while also improving the company's production, inventory, and distribution (PID) strategy. The model developed resulted in significant profit margin of about ₦24,458,800 with the optimization principle (a profit margin of ₦5,066,890,000.00K – year 2013) in contrast with the existing profit of ₦5,042,431,200.00K without the optimization principle in year 2013 and a profit increment of ₦42,647,676.26K without the Optimization principle in year 2012. The work's findings suggest that LiPs software (linear programming) may be used to optimize various NBC products, and that it is highly sensitive to modifications while taking into account the limits that limit what is possible. It is therefore highly recommended that the Optimization software should be adopted and used for effective planning and profit maximization.

V. RECOMMENDATION

A possible remedy to linear programming problems is to update model continuously based on plant data. There are many other software packages such as ASPEN PLUS (ASPEN FIMS), HYSIS etc, that can also be used to achieve similar results. Further work can still be done on this project work especially on the review of multi-objective optimization for the decision model and the effects of the addition of new constraints should also be studied. The introduction of a new economic activity (a new variable) should be investigated if it is lucrative (that is, if it increases the optimal value of the objective function).

VI. CONTRIBUTION TO KNOWLEDGE

In the field of business and management, linear programming is a technique for solving complex problems in two main areas: product mix (where the technique may be used when it is difficult to decide how much of each variable to use in order to satisfy certain criteria such as maximizing profits or minimizing costs) and product mix (where the technique may be used when it is difficult to decide how much of each variable to use in order to satisfy certain criteria such as maximizing profits or minimizing costs).

When you have a problem with several resource restrictions, linear programming can help you find the optimum solution. Using this tool to structure the problem and discover a solution is a quick and effective way to maximize things like profit or space while minimizing aspects like cost and waste. As a result, it is critical to apply linear programming in the workplace on a regular basis to ensure that profits are always maximized.

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