Production Schedule Using Integer Linear Programming for Tasty Menu Bakery Yola, Adamawa State of Nigeria

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ABSTRACT

For the Tasty Menu Bakery in Yola, Adamawa State, this study used integer linear programming to determine the production plan. Data on the ingredients required to make each of the five types of bread were gathered. Additionally, data on each type of bread's unit selling price and production cost was gathered.

Maximization of profit is the objective function, and there are 18 specified restrictions. The issue was run via the Production/Operation Management Quantitative Method (POMQM) software as an integer linear programming issue. The solution to the original puzzle indicates that just 529 loaves of sliced bread should be made each day in order to make a profit of up to N53,164.50. Sensitivity analysis was performed, and the objective function was modified. The analysis's findings indicate that there are 280 loaves of roll bread and 117 loaves of sliced bread. To make a daily profit of N55,087, 111 loaves of fruit bread, 10 loaves of coconut bread, and 10 loaves of milk bread must be made. The fact that all of the bakery's customers will be satisfied and a higher profit will be made in comparison to the result of the original problem, however, demonstrates that the sensitivity analysis's result is preferable.

Based on the sensitivity results, the study suggests that Tasty Menu Bakery, Yola implement the linear programming model to cut down on resource and time waste. Additionally, it suggests that a market research study be conducted for the bakery in order to increase product sales.

(Keywords: linear programming model, sensitivity analysis, production planning, production schedule, profit analysis)

INTRODUCTION

Every production company's major goal is to turn a profit in order to keep the business afloat. To achieve this goal, a variety of elements need to be considered. These include, among other things, meeting client requests and providing goods and services on schedule. To accomplish these, the business should have the necessary technological know-how and capable management to adopt the most recent managerial techniques and the required technology.

To provide clear guidance on how the manufacturing process should be carried out, it is advisable for a corporation to create a production plan based on scientific methodologies. All these actions are purposeful initiatives to reduce production costs and increase revenue for the business.

One of the most crucial tasks in manufacturing companies is production planning. A production plan is usually created by many manufacturing companies before the start of each fiscal year. The production plan specifies both the quantity of commodities to be produced and the demand for each period of the financial year. Depending on the company's products, the production plan may be carried out every week, every month, every quarter, or even every year.

Production scheduling is the process of allocating the production's resources through time in a way that best satisfies many requirements, including those for quality, delivery date, demand, and supply. An ideal production schedule is one that effectively distributes resources over time to best meet certain criteria (i.e., the plan that assigns the ideal level of production resources required to supply a particular demand at the lowest possible cost) (Amponsah, Ofosu, and Opoku-Sarkodie, 2011).

Making a strategy to please clients while making a fair profit is a step in the production planning process (Lopez and Roubellat, 2008). Production scheduling issues, machine capacity planning issues, storage and freight scheduling issues are all examples of production issues.

In order to stay competitive, management is encouraged by fierce rivalry to create innovative production and supply processes (Abernathy, 1995). One major concern is the distribution of limited production resources among conflicting demands, which is a common issue when dealing with several complicated man-made systems (Cassandras, 1993).

Scheduling models and planning models differ from one another in a variety of ways, according to Kreipl and Pinedo (2004). First, scheduling models are typically created for a single stage (facility) and optimize over a short-term horizon, whereas planning models frequently span numerous stages and optimum over a medium term horizon. Second, planning models employ more generalized data whereas scheduling models employ more specific data. Thirdly, while the objective to be minimized in a schedule model is typically a function of the completion times of the jobs, the unit in which this is measured is frequently in time unit, the objective to be minimized in a planning model is typically a total cost objective, and the unit in which this is measured is a monetary unit. Although these two types of models differ fundamentally, they frequently need to be integrated into a single framework, share information, and interact closely with one another.

LINEAR PROGRAMMING (LP)

A mathematical method called LP deals with the distribution of scarce resources. When a factor (such as labor or machine hours) is constrained, it is a process to maximize the value of the aim (for instance, maximum profit or minimum cost).

a. The issue must be able to be expressed in numerical terms.

b. There must be a linear relationship between every element contributing to the issue.

c. The issue must allow the user to select one or more alternate courses of action.

d. The element in question must be subject to one or more constraints. These might be resource limitations.

Integer Programming

Each decision variable, slack variable, and/or surplus variable in linear programming is allowed to take any discrete or fractional value. However, there are some real-world issues where the choice variables' fractional values are irrelevant. Three types of linear integer programming issues can be identified:

i. Pure (all) integer programming issues, in which all of the decision variables can only take on integer values.

ii. Mixed integer programming issues, in which certain decision variables, but not all, are constrained to integer values.

iii. Zero-one integer programming issues, in which all variables used to make decisions can only have integer values of 0 or 1.

Method of Solving Integer Linear Programming Problem

Cutting Plane Algorithm: Gomory cutting plane algorithm starts by solving the continuous LP. Problem. From the optimum LP. Table is selected a row, called the source row, for which the basic variable is non-integer. The desired cut is then constructed from the fractional components of the coefficients of the source row. For this reason, it is referred to as the fractional cut.

Steps of Gomory's All Integer Programming Algorithm: An iterative procedure for the solution of an all integer programming problem by Gomory's cutting plane method can be summarized in the following steps.

Step 1: Initialization formulate the standard integer LP problem. If there are any non-integer coefficients in the constraint equations, convert them into integer coefficients. Solve the problem by the simple method, ignoring the integer valve requirement of the variables.

Step 2: Test the Optimality.

(a). Examine the optimal solution. If all basic variables (i.e., $x_{Bi} = b_i \geq 0$) have integer values, then the integer optimal solution has been obtained and the procedure is terminated.

(b). If one or more basic variables with integer value requirement have non-integer solution values, then go to Step 3

Step 3: Generate cutting plane choose a row r corresponding to a variable x r that has the largest fractional value and follow the procedure to develop a 'cut' (a Gomory constraint) as explained in Equation:

$$-f_r = S_g - \sum f_{rj} x_j \quad \textbf{(1)}$$

where $0 \leq f_r \leq 1$ and $0 < f_r < 1$

If there are more than one variables with the same largest fraction, then choose the one that has the smallest profit/unit coefficient in the objective function of maximization LP problem or the largest cost/unit coefficient in the objective function of minimization LP problem.

Step 4: Obtain the new solution Add this additional constraint (cut) generated in step 3 to the bottom of the optimal simplex table. Find a new optimal solution by using the dual simplex method, i.e. choose a variable that is to be entered into the new solution having the smallest ratio: $\left\{ \left(c_{j-z_j} \right) / y_{ij};\ y \leq 0 \right\}$ and return to step 2. The process is repeated until all basic variables with integer value requirement assume non-negative integer values.

Branch and Bound Algorithm: Branch and bound algorithms is the most widely used method for solving pure as well as mixed integer problems in practice. Most commercial computer codes use this method for solving LP Problems. In this method also, the problem is first solved as a continuous L.P problem ignoring the integrality condition. If the solution is infeasible or unbounded, then the given LP also has an infeasible or unbounded solution. If the solution satisfies the integer restrictions, the optimal integer solution has been obtained. If in the optimal solution some variable, say x_j is not an integer, then:

$$x < x_j < x_j + 1x \quad \textbf{(2)}$$

Where x_j and $x_j + 1$ are consecutive non-negative integers.

It follows that any feasible integer value between of x must satisfy one of the two conditions, namely:

$$x_i \leq x_j \text{ or } x_j \geq x_j + 1. \quad \textbf{(3)}$$

Since variable has no integer value between x_j and x_{j+1}.These two conditions are mutually exclusive and when applied separately to the continuous LP problem, form two different subproblems (also called nodes). Thus, the original problem is 'branched' or 'partitioned' into two subproblems. Geometrically it means that the branching process eliminates that portion of the feasible region that contains no feasible integer solution.

Steps for using Branch and Bound Algorithm

Step 1: Initialization consider the following all integer programming problem.

$$\left.\begin{array}{l} \text{Maximize } Z = c_1x_1 + c_1x_2 + \ldots + c_nx_n \\ \text{Subject to the constraints} \\ \quad a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n = b_1 \\ \quad a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n = b_2 \\ \quad \vdots \\ \quad a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n = b_m \\ \quad x \geq 0 \text{ and non-negative intigers} \end{array}\right\} \quad \textbf{(4)}$$

Obtain the optimal solution of the given LP problem ignoring integer restriction on the variables.

(i). If the solution to this LP problem (say LP-A) is infeasible or unbounded, the solution to the given all-integer programming problem is also infeasible or unbounded, as the case may be.

(ii). If the solution satisfies the integer restrictions, the optimal integer solution has been obtained. If one or more basic variables do not satisfy integer requirement, then go to Step 2. Let the optimal value of objective function of LP-A be Z_1. This value provides an initial upper bound on objective function value and is denote by Z_u.

(iii). Find a feasible solution by rounding off each variables value. The value of objective function so obtained is used as a lower bound and is denoted by Z_L.

Step 2: Branching step

(i). Let x_k be one basic variable which does not have an integer value and also has the largest fractional value.

(ii). Branch (or partition) the LP-A into two new LP sub problems (also called nodes) based on integer values of x_k that are immediate above and below its non-integer value. That is, it is partitioned by adding two mutually exclusive constraints:

$x_k \leq [x_k]$ and $x_k \geq [x_k] + 1$

To the original LP problem, Here $[x_k]$ is the integer portion of the current non-integer value of the variable x_k. This obviously is done to exclude the non-integer value of the variables x_k.

The two new LP subproblems are as follows:

LP Subproblem B

$$\left.\begin{aligned} &\text{Max } Z = \textstyle\sum c_j x_j \\ &\text{Subject to} = \textstyle\sum a_j x_j = b_i \\ &\qquad x_k \leq [x_k] \\ &\text{and} \quad x_j \geq 0 \end{aligned}\right\} \quad \textbf{(5)}$$

LP Subproblem C

$$\left.\begin{aligned} &\text{Max } Z = \textstyle\sum c_j x_j \\ &\text{Subject to} = \textstyle\sum a_j x_j = bi \\ &\qquad x_k \geq [x_k] \\ &\text{and} \quad x_j \geq 0 \end{aligned}\right\} \quad \textbf{(6)}$$

Step 3: Bound step Obtain the optimal solution of subproblems B and C. let the optimal value of the objective function of LP-B be Z_2 and that of LP-C be Z_3. The best integer solution value becomes the lower bound on the integer LP problem objective function value (Initial this is the rounded off value). Let the lower bound be denoted by Z_L.

Step 4: Fathoming step Examine the solution of both LP-B and LP-C

(i). If a subproblem yields an infeasible solution, then terminate the branch.

(ii). If a subproblem yields a feasible solution but not an integer solution, then return to step 2.

(iii). If a subproblem yields a feasible integer solution, examine the value of the objective function. If this value is equal to the upper bound, an optimal solution has been reached. But if it not equal to the upper bound but exceeds the lower bound, this value is considered as new upper bound and return to step 2. Finally, if it less than the lower bound, terminate this branch.

Step 5: Termination The procedure of branching and bounding continues until no further sub-problem remains to be examined. At this stage, the integer solution corresponding to the current lower bound is the optimal all-integer programming problem solution.

RESEARCH DESIGN

The design of the study is the plan for how the study will be conducted. It is concerned with what types of information or data will be gathered and through what forms of data-collection technique (Berg, 1995 in Jen, 2007).

Evaluation study research design was adopted for the study. This design was adopted because it involves collection and analysis of data in order to guide decision making (Jen, 2007). He further explained that the overall objectives of evaluation studies have to do with improvement or achieving efficiency by making necessary adjustments and/or modifications.

In this study, data were collected from Tasty Menu production unit through the production manager. The data includes all the materials needed for the production of bread. Also, data were collected from the bakery sales department on the unit cost of production and unit selling price of each product. A visit was made to some sales point of the products.

STUDY AREA

The area of the study is Tasty Menu Bakery Unit, off Army Barracks road, Jimeta, Adamawa State of Nigeria. Adamawa State is located in the North East region of Nigeria. It lies between 7^0 and 11^0 North of the equator and between longitude 11^0 and 14^0 east of the Greenwich Meridian (Adebayo and Tukur, 1999).

Both documentation and interview method were used for data collection from Tasty Menu Bakery Yola. The materials needed for the daily production of the five types of bread were collected from the record of the production unit through the production manager. Also, the unit cost of production of each type of bread and the corresponding unit selling price was collected from sales department. Some of the managers of the sales points were interviewed on the supply and demand of the products. Also, some customers were interviewed on their satisfaction of the products.

METHOD OF DATA ANALYSIS

Integer Linear Programming model was formulated to determine the quantity of each type of bread to be produced by Tasty Menu Bakery with available resources in order to maximized profit. Production/Operation Management, Quantitative Method (POMQM) software was used to run the data.The general linear programming problem (or model) with n decision variables and m constraints can be stated in the following form:

$$\left.\begin{array}{l}
\text{Optimize (Max. or Min.) } Z = c_1 x_1 + c_2 x_2 + \ldots\ldots + c_n x_n \\
\text{Subject to the linear constraints, } (\leq, =, \geq) \\
\qquad a_{11}x_1 + a_{12} x_2 + \ldots\ldots + a_{1n} x_n \quad (\leq, =, \geq)\ b_1 \\
\qquad a_{11}x_1 + a_{12} x_2 + \ldots\ldots + a_{1n} x_n \quad (\leq, =, \geq)\ b_2 \\
\qquad \quad \vdots \qquad \vdots \qquad \vdots \qquad \vdots \\
\qquad a_{m1} x_1 + a_{m2} x_2 + \ldots\ldots + a_{mn} x_n \quad (\leq, =, \geq)\ b_m \\
\text{and} \qquad x_1, x_2, \ldots\ldots, x_n \geq 0
\end{array}\right\} \quad \textbf{(7)}$$

The above formulation can also be expressed in a compact form as follows.

$$
\left.\begin{aligned}
&\text{Optimize (Max. or Min.) } Z = \sum c_j x_j && \text{(Objective function)}\\
&\sum a_{ij} x_j \ (\leq, =, \geq)\ b_i;\ i = 1, 2, \ldots, m && \text{(constraints)}\\
\text{and}\quad & x_j \geq 0;\ j = 1, 2, \ldots, n \quad \text{(Non negativity conditions)}
\end{aligned}\right\} \quad \textbf{(8)}
$$

Where the c_j s are coefficients representing the per unit profit (or cost) of the decision variable x_j to the value of objective function. The a_{ij}'s are referred as technological coefficients (or input – output coefficients). These represent the amount of resource, say I consumed per unit of variable (activity). These coefficients x_j can be positive, negative or zero.

The bi represents the total availability of the ith resource. The term of a resource is used in a very general sense to include any numerical value with the right-hand side of a constraint. It is assumed that bi ≥ 0 for all i. however, if any bi < 0, then both sides of constraint I is multiplied by -1 to make bi > 0 and reverse the inequality of the constraint.

In general LP problem, the expression (≤, =, ≥) means that in any specific problem each constraint may take only one of three possible forms:

i. Less than or equal to (≤)

ii. Equal to (=)

iii. Greater than or equal to (≥)

DATA PRESENTATION

The following data were collected from Tasty Menu Bakery Yola, as shown in Tables 1 and 2 below.

Table 1 shows the five types of bread produced by Tasty Menu Bakery Yola. The weight of sliced, fruit, coconut and milk bread are of the same size and weight (750gm), while roll bread is a bit longer and weighs (700gm).

Table 2 shows all the materials needed with the exception of egg, fruit, coconut powder and milk are required for all types of bread. Egg is an additional requirement for roll bread only, fruit is an additional requirement for fruit bread only, and coconut powder is an additional requirement for coconut bread only while milk is an additional requirement for milk bread only.

Table 1: Types of Bread Produced by Tasty Menu Bakery Yola.

Bread type	Unit Cost of production (₦)	Unit selling price (₦)	Profit (₦)
Sliced	219.50	320	100.5
Roll	232.70	320	87.30
Fruit	219.50	320	100.5
Coconut	219.50	320	100.5
Milk	235.60	320	84.40

Table 2: Material Requirement for the Unit production of the Five Types of Bread.

Material	Sliced Bread	Roll Bread	Fruit Bread	Coconut Bread	Milk Bread	Requirement
Flour	0.472	0.472	0.472	0.472	0.472	250kg
EDC	1.887	1.887	1.887	1.887	1.887	1000g
Preservative	1.415	1.415	1.415	1.415	1.415	750gm
Salt	0.755	0.755	0.755	0.755	0.755	3750gm
Improver	0.943	0.943	0.943	0.943	0.943	500gm
Yeast	2.358	2.358	2.358	2.358	2.358	1250gm
Sugar	0.066	0.066	0.066	0.066	0.066	35kg
Butter	0.009	0.009	0.009	0.009	0.009	5kg
Vegetable oil	0.009	0.009	0.009	0.009	0.009	5Litre
Coloring	0.472	0.472	0.472	0.472	0.472	250gm
Energy	1.949	1.949	1.949	1.949	1.949	1033(#)
Water	0.222	0.222	0.222	0.222	0.222	117.5Litre
Flavor	1.415	1.415	1.415	1.415	1.415	750gm
Nylon	1	1	1	1	1	530pieces
Egg	0	0.189	0	0	0	20pieces
Fruit	0	0	0.009	0	0	1kg
Coconut	0	0	0	0.019	0	2kg
Milk	0	0	0	0	0.019	2kg

FORMULATION OF LINEAR PROGRAMMING MODEL

Definition of Decision Variables

Let x_1 = represent the number of loaves to be produced for sliced bread per daily production.

x_2 = represent the number of loaves to be produced for roll bread per daily production.

x_3 = represent the number of loaves to be produced for fruit bread per daily production.

x_4 = represent the number of loaves to be produced for coconut bread per daily production.

x_5 = represent the number of loaves to be produced for milk bread per daily production.

Z = total profit of the various types of bread per daily production (in Naira).

Objective function

Maximize $Z = 100.5x_1 + 87.3x_2 + 100.2x_3 + 100.5x_4 + 84.4x_5$

Subject to:

$$
\left.
\begin{array}{ll}
\text{Flour} & 0.472x_1 + 0.472x_2 + 0.472x_3 + 0.472x_4 + 0.472x_5 \leq 250 \\
\text{EDC} & 1.887x_1 + 1.887x_2 + 1.887x_3 + 1.887x_4 + 1.887x_5 \leq 1000 \\
\text{Preservative} & 1.415x_1 + 1.415x_2 + 1.415x_3 + 1.415x_4 + 1.415x_5 \leq 750 \\
\text{Salt} & 0.755x_1 + 0.755x_2 + 0.755x_3 + 0.755x_4 + 0.755x_5 \leq 3750 \\
\text{Improver} & 0.943x_1 + 0.943x_2 + 0.943x_3 + 0.943x_4 + 0.943x_5 \leq 500 \\
\text{Yeast} & 2.358x_1 + 2.358x_2 + 2.358x_3 + 2.358x_4 + 2.358x_5 \leq 1250 \\
\text{Sugar} & 0.066x_1 + 0.066x_2 + 0.066x_3 + 0.066x_4 + 0.066x_5 \leq 35 \\
\text{Butter} & 0.009x_1 + 0.009x_2 + 0.009x_3 + 0.009x_4 + 0.009x_5 \leq 5 \\
\text{Vegetable oil} & 0.009x_1 + 0.009x_2 + 0.009x_3 + 0.009x_4 + 0.009x_5 \leq 5 \\
\text{Coloring} & 0.472x_1 + 0.472x_2 + 0.472x_3 + 0.472x_4 + 0.472x_5 \leq 250 \\
\text{Energy} & 1.949x_1 + 1.949x_2 + 1.949x_3 + 1.949x_4 + 1.949x_5 \leq 1033 \\
\text{Water} & 0.222x_1 + 0.222x_2 + 0.222x_3 + 0.222x_4 + 0.222x_5 \leq 117.5 \\
\text{Flavour} & 1.415x_1 + 1.415x_2 + 1.415x_3 + 1.415x_4 + 1.415x_5 \leq 750 \\
\text{Nylon} & x_1 + x_2 + x_3 + x_4 + x_5 \leq 530 \\
\text{Egg} & 0.189x_2 \leq 20 \\
\text{Fruit} & 0.009x_3 \leq 1 \\
\text{Coconut Powder} & 0.019x_4 \leq 2 \\
\text{Milk} & 0.019x_5 \leq 2 \\
 & x_1, x_2, x_3, x, x_5 \geq 0 \text{ and integer}
\end{array}
\right\} \quad \textbf{(9)}
$$

Table 3: Integer Linear Programming Solution for Tasty Menu Bakery Yola, Generated by POMQM Software of the above model (Equation 9).

Variable	Type	Value
x_1	Integer	529
x_2	Integer	0
x_3	Integer	0
x_4	Integer	0
x_5	Integer	0
Solution Value		53,164.5

Sensitivity Analysis

The study of how sensitive the best solution to an LP problem is to discrete variations (Changes) in its parameters is known as sensitivity analysis. The ideal solution to the specific LP problem can alter significantly or not at all depending on how sensitive the solution is to these differences. The range of LP model parameters that can vary without having an impact on the existing optimal solution is thus determined through sensitivity analysis. According to the results, the study advised changing each product's unit profit to see the changes it would bring about. It indicates that just the objective function has changed. That is when the profit contribution of:

Sliced bread (x_1) has been changed from 100.5 to 80.5

Roll bread (x_2) has been changed from 87.3 to 107.3

Fruit bread (x_3) has been changed from 100.2 to 120.5

Coconut bread (x_4) has been changed from 100.5 to 120.5

Milk bread (x_5) has been changed from 84.4 to 104.4

This resulted in:

Maximize Z = 80.5 x_1 +107.3 x_2+ 120.5 x_3+ 120.5 x_4+ 104.4 x_5

The objective function is then run against the constraints of Equation 9. The following results were obtained as shown in Table 4.

DISCUSSION OF RESULTS

From Table 4 (result of the original problem) shows that value of the objective function is ₦ 53,164.5 while the value of the five variables $x_1, \ldots, x_5$ are 529, 0, 0, 0 and 0, respectively.

These indicate that only x_1 variable contributed meaningfully to improve the value the objective function. The integer linear programming model showed that it is economical Tasty Menu Bakery Yola, to concentrate on the production of sliced bread only. The total production of 529 loaves of sliced bread should be produce daily. This will generate the Bakery an optimum profit of ₦53,164.50 daily based on the cost of raw materials only.

Table 4 (result of the sensitivity analysis) shows that the value of the objective function is ₦55,087 while the value of five variables $x_1, \ldots, x_5$ are 117, 280, 111, 10 and 10 respectively. This indicated that 117 loaves of sliced bread, 280 loaves of roll bread, 111 loaves of fruit bread, 10 loaves of coconut bread and 10 loaves of milk bread should be produced daily to generate a total profit of ₦55,087. This result shows that it is economical for Tasty Menu Bakery to produce all the five types of bread daily.

Table 4: Integer Linear Programming Solution with Regards to the Change in Objective Function.

Variable	Type	Value
x_1	Integer	117
x_2	Integer	280
x_3	Integer	111
x_4	Integer	10
x_5	Integer	10
Solution Value		55,087

Comparing the sensitivity analysis result with the result of the original problem, it shows that more profit will be generated (increment of ₦1,922.50 daily) when the result of the sensitivity analysis is implemented and all the five types bread will be produced daily. In other words, the bakery will satisfy all its customers by producing all the five types of bread.

SUMMARY

The objective of the study was to determine the optimal production schedule for Tasty Menu Bakery Unit taken into consideration the raw materials needed for the daily production of the five types of bread. The problem was formulated as linear programming problem and QM software was used to solve the problem. Result was generated for the original problem and for a sensitivity analysis where changes were made only at the objective function of the original problem.

CONCLUSION

The study has successfully determined the number of breads to be produced daily in order to maximize profit at Tasty Menu Bakery Yola. The sensitivity result showed that 117 loaves of sliced bread, 280 loaves of roll bread, 111 loaves of fruit bread, 10 loaves of coconut bread and 10 loaves of milk bread should be produced daily to make a maximum profit of ₦55,087.00.

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