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Optimal product quantity linear programming model for profit maximization in plastic small medium manufacturing firms

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Abstract

Planning production and maximizing profits can be difficult tasks for small and medium-sized manufacturing businesses (SMEs). Owing to their difficulties implementing the newest and most advanced Industry 4.0 technologies, small and medium-sized enterprises (SMEs) generally depend more on expert guidance. Thus this study focuses on the development of a Linear programming model for determining the optimum quantities of product in order to maximize profit profits in manufacturing Small medium enterprises. Data spanning over a period of forty five months was obtained from a manufacturing small and medium-sized enterprise. An optimization was developed in the study to determine the optimal product quantity for profit maximization. Based on the developed model and its optimization, it was determined that the optimal production quantity for the plastic factory to be 12000cups resulting in a maximum profit of ₦456000. This optimization approach provides valuable insights for the plastic factory's production planning.

Keywords: Linear programming; Linear optimization; Manufacturing SME; Optimal product quantity; Plastic industry

1. Introduction

Product and service providers are under tremendous pressure to improve and modernize their processes and procedures due to increased global competition and corporate growth (Chukwutoo and Nkemakonam, 2018). Manufacturing small medium enterprises (SMEs) must now establish industrial strategies in order to compete effectively, as the industry is seeing exponential growth in competition due to customers' increasing demands and the increasing unpredictability of supply (Chikwendu et al., 2020; Igbokwe and Godwin, 2021; N. Igbokwe and Mba, 2019).

Production planning and profit maximization is often a challenging prospect for manufacturing small medium enterprises (SMEs).

Due to their challenges in adopting the newest and most sophisticated Industry 4.0 technologies, small and medium-sized firms (SMEs) typically rely more on professional advice (Skėrė et al., 2023). The majority of manufacturing firms aim to maximize profits or decrease costs with limited resources, despite the fact that management issues are always changing. For this reason, manufacturing organizations must manufacture the correct amount of product and fulfill anticipated demand in order to maximize profit.

Production planning can be defined as a method of anticipating each step in the drawn-out production process, taking them at the appropriate time and degree, and attempting to finish activities with the highest possible level of efficiency (Alexopoulos et al., 2022). Due to their reliance on a variety of raw materials and complex manufacturing processes, small and medium-size enterprises in the plastics industry need to plan and optimize their operations carefully in order to maximize output, minimize waste, and assure streamlined operations. These are primarily mass-production, made-

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to-stock businesses. In practice, they base their production level on anticipated demand. Optimizing production quantities to maximize profit is a fundamental problem for various manufacturing firm. Understanding the complex interplay between production costs, selling prices, and demand becomes crucial for achieving sustainable success. Thus this study focuses on the development of a Linear programming model for determining the optimum quantities of product in order to maximize profit profits in manufacturing Small medium enterprises. The integration of this model ensures adaptability to changing market conditions, thereby contributing to the overall competitiveness and sustainability of the enterprise.

2. Methodology

The first phase of the research will involve collecting and analyzing data from the Nnamdi Azikiwe University Plastic Factory. The case study is a medium-sized plastic manufacturing company that operates a one injection molding machine that produces plastic cups. The factory operates from 8am to 5pm every weekday, since the company is a made-to-stock company; production is based on forecasted demand.

The data were gathered through direct observation of the production processes, interview with some key personnel of the factory. The observation of the production processes was carried out so as to understand the stages of production from raw-material to finished product. Historical data over the period of forty five months were also obtained, this data includes production data, resource availability, processing and setup times, product information, machine capacity and sales data.

2.1. Development of Linear Programming Model

In this study Linear Programming (LP) technique is used in the production planning of plastic cups production on a single injection molding machine. The aim here is to develop a plan that will give the optimal quantities of these parts. The materials involved in the production of the products is the same as they are, Recycled propylene plastic and Master Batch.

The variables and parameters of the model are as follows:

Decision Variables:

X_1 = Number of cups produced per month

Model Variables and Parameters:

P_T = Total Profit
P_1 = Profit of Unit of X_1
D_1 = Forecasted demand of X_1 per month
IMC_1 = Injection Molding Capacity per Month
T_1 = Total Available Machine Hours
M_a = Total Quantity (Kg) of raw materials available for Recycled Propylene Plastics
M_b = Total Quantity (Kg) of raw materials available for Master Batch
r_a = Required raw material needed to produce X_1
r_b = Required raw material needed to produce X_1
r_c = Required raw material needed to produce X_1
t_1 = Production time required to produced X_1

Objective Function:

$$\text{Max } P_T = P_1 X_1 \ldots\ldots\ldots\ldots(1)$$

Subject to:

$$X_1 \geq D_1 \ldots\ldots\ldots\ldots (2)$$

$$X_1 \leq IMC_1 \ldots\ldots\ldots\ldots\ldots (3)$$

$$r_a X_1 \leq M_a \ldots\ldots\ldots\ldots\ldots (4)$$

$$r_b X_1 \leq M_b \text{ ………………} (5)$$

$$t_1 X_1 \leq T_1 \text{ ……………..} (7)$$

$$X_1 \geq 0 \text{ …………………..} (8)$$

Equation (2) ensures that supply meets demand, this is important to prevent the production fewer cups than the number of cups demanded by customers. Equation (3) prevents exceeding the capacity of the injection molding machine. Equation 4, 5 and 6 are raw material constraints, it ensures that the raw material used do not exceed raw material availability. Equation (7) ensures that the production time is utilized adequately, likely to meet a minimum production time requirement. Equation (8) accounts for the Non-negativity constraints which ensures that the decision variable can't be negative

2.2. Assumptions of the Model

- Machine Setup and Machine Changeover time were overlooked since the study is considering only one product
- It is assumed that cost is a constant, which means it doesn't change based on the number of product units.

3. Results and Discussion

The data collected from the case study were analyzed to determine the optimum product quantities that will maximize profit to the company.

Table 1.0 presents the monthly product quantities and sales for the year 2020 to 2023. It can be seen that the average production units is 15008 and the average sales is 14207 cups, the data shows seasonality and trends.

The data for the profit per unit, selling price, cost price, production time and raw materials are given in Table 1.1. The data for the raw-materials is presented in Table 1.2.

Table 1 Production and Sales Report

Year	Month	Production	Sales
2020	January	10753	10747
	February	10675	4653
	March	0	9488
	April	0	0
	May	0	0
	June	3122	8456
	July	16676	10730
	August	22218	18388
	September	11295	180
	October	14614	11138
	November	14059	6450
	December	9553	9540
2021	January	12948	12172
	February	14868	25482
	March	10237	8632
	April	11917	25885
	May	15608	19990

	June	17259	18306
	July	15377	15025
	August	16590	8860
	September	11882	19104
	October	15380	7219
	November	13813	21557
	December	24867	25619
2022	January	20314	24361
	February	17115	15558
	March	23165	13740
	April	13623	18360
	May	16395	18960
	June	12763	8910
	July	15211	16333
	August	23104	27458
	September	24803	24228
	October	16324	8886
	November	15451	19391
	December	15226	19121
2023	January	17127	12032
	February	17527	12012
	March	15487	23046
	April	18505	19518
	May	22581	16655
	June	13291	336
	July	18222	12643
	August	23499	17844
	September	21916	12301

Table 2 Data on Selling Price, Cost Price, Profit, Time and Machine Capacity

Selling Price per Unit (Naira)	Cost Price per Unit (Naira)	Profit Per Unit (Naira)	Machine Capacity	Production time required for a Unit (Hours)	Total Available Machine (Hours)
168	127	38	27840	0.006	176

Table 3 Data on Raw Materials

Raw Material	Raw Material Usage (kg)	Raw Material Available (kg)
Recycled Propylene Plastic	0.08	1173
Master Batch	0.002	24

3.1. Solution of the Linear Programming Model

The objective function of the model is to maximize profit subject the constraints. Data from Table 1.2 was inputted into the model and solved using Pulp in Python.

Objective Function

$$Max\_Z = P \times X_1 \text{ .... (1)}$$

$$X_1 \geq 5775 \text{ .... (2)}$$

$$X_1 \leq 27840 \text{ .... (3)}$$

$$0.08 \times X_1 \leq 1173 \text{ .... (4)}$$

$$0.002 \times X_1 \leq 24 \text{ .... (5)}$$

$$0.006 \times X_1 \geq 176 \text{ .... (7)}$$

$$X_1 \geq 0 \text{ .... (8)}$$

The programming code used to solve the model is showed in figure 1.0

```
# Define Variables
x1 = pulp.LpVariable("x1",lowBound=0,cat ="Continuous") #Number of Cups
#Objective Function
max_z = pulp.LpProblem("Scopus_Cup_Production",pulp.LpMaximize)

max_z += 38*x1

# Constraints
max_z += x1 >= 5775 # Demand constraint
max_z += 0.08*x1 <= 1173 # Raw material constrain
max_z += 0.002*x1 <= 24  # Raw material constraint
max_z += 0.006*x1 <= 176  # Production time constraint
max_z += x1 <= 27840  # Capacity constraint
```

Figure 1 Solution Model Codes

The original model gave room for inventory by allowing production to exceed demand, the optimum value of cups that should be produced gave 12000cups and a gross profit of ₦456.000 as shown in fig 1.2. When ≥ was changed to ≤ in equation (2) to prevent inventory the optimum value under the constraints shows that the factory should produce exactly the forecasted demand which is 5775 cups which will give a profit of ₦219, 412 as shown in fig 1.3. Since the objective is to find out the number of cups that will yield maximum profit the factory should produce 12000cups as this will give the maximum profit.

```
print(x1.varValue)

12000.0

pulp.value(max_z.objective)

456000.0
```

Figure 2 Solution of the solved model

```
# Define Variables
x1 = pulp.LpVariable("x1",lowBound=0,cat ="Continuous") #Number of Cups
#Objective Function
max_z = pulp.LpProblem("Scopus_Cup_Production",pulp.LpMaximize)

max_z += 38*x1

# Constraints
max_z += x1 <= 5775 # Demand constraint
max_z += 0.08*x1 <= 1173 # Raw material constrain
max_z += 0.002*x1 <= 24  # Raw material constraint
max_z += 0.006*x1 <= 176  # Production time constraint
max_z += x1 <= 27840  # Capacity constraint
```

Figure 3 Sensitivity Analysis

```
print(x1.varValue)

5775.0

pulp.value(max_z.objective)

219450.0
```

Figure 4 Solution of sensitivity analysis

4. Conclusion

Based on the developed model and its optimization, it was determined that the optimal production quantity for the plastic factory to be 12000cups resulting in a maximum profit of ₦456000. This solution adheres to all the specified constraints, including demand, machine capacity and raw materials as limitations.

This optimization approach provides valuable insights for the plastic factory's production planning. By adhering to the recommended production quantity, the factory can maximize its profit while ensuring efficient resource utilization and avoiding potential production shortfalls.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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