Linear Programming Model for Production Cost Minimization at a Chips Plant of a FMCG Company

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Abstract. Companies in the FMCG sector need to set up procedures that maximize revenue while lowering expenses. Manufacturing of chips type products requires good resource planning and large investments encompassing raw materials, technology, infrastructure, and human resources. This paper proposes a methodology which aim is to minimize production cost by taking different factors into consideration. The first section describes the methodology to solve the model also identifies and describes the variables required for modelling. The second section describes a linear programming model which is formulated to minimize the total production related costs. Finally, at last section the model is applied to a real FMCG food manufacturing company producing satisfied results in terms of total cost reduction by 33.56% and an improved production plan also highlighting the significance of important factors like line capacity and operational restrictions and offers a thorough solution for resource allocation and production planning. The purpose of this paper is to help FMCG food manufacturing companies address complicated production planning challenges through the use of mathematical programming models, which will ultimately lead to better resource allocation and profitability.

Keywords: Linear programming · Chips · Production · Cost reduction · Production planning

1 Introduction

In Bangladesh’s fast-growing snack food sector, the demand for chips and other savory snacks has surged, driven by evolving consumer preferences. The snack food market in Bangladesh grew at a 13.98% compound annual growth rate (CAGR) between 2015 and 2019, from $740 million to $1.25 billion USD. Significant market shares are held by sectors like potato chips, indicating a large demand for packaged snacks in the nation. Bangladesh's per capita consumption of snack foods is still lower than the Asia-Pacific average, despite this development, suggesting that there is still room for market expansion.

This study aims to address the need for efficient production planning and cost control in chips manufacturing, a prominent segment of the snack food market. The high cost of labor, raw materials, and production infrastructure forces FMCG companies to use cutting-edge cost-cutting strategies. The linear programming (LP) approach presented in this study is intended to match production restrictions and consumer demand while lowering production costs in a chips facility. By using this model in a real-world scenario in an FMCG company in Bangladesh, we show how LP optimization can simplify production planning and result in significant cost reductions. By using this method, the study gives businesses in Bangladesh's snack food industry a useful tool that helps them make better use of their resources and keep prices competitive in the face of expanding market opportunities.

2 Literature Review

In a FMCG industry, aggregate planning is a strategic approach to optimizing production and resource allocation by aligning manufacturing output with anticipated demand over a specific time frame. plays a crucial role in optimizing production efficiency and minimizing costs, as evidenced by Heizer and Render (2015). So cost minimization or optimization is very important in aggregate planning. Production cost optimization plays significant role in production planning.

Linear Programming (LP) is one of the most widely used and well-known techniques in operations research (H. Tannady, 2017) and supply chain analytics. It provides a mathematical approach for resource allocation aimed at maximizing profits, minimizing costs or achieving both goals simultaneously. LP is often applied to optimize variables within a system. In practice, LP quantifies relationships between variables by expressing them as linear mathematical equations. This approach helps allocate scarce resources to meet specific objectives (S. Nahmias, 2007). Linear programming works by formulating an objective function, which typically represents the cost or profit function to be optimized (either minimized or maximized). The function is subject to a set of constraints that represent resource limitations, such as material availability, labor hours, production capacity, and budget. The result provides the optimal solution that meets the specified objectives while adhering to the constraints (W. Sabardi,2023). This case study found optimal costs using POM-QM software in a cashew chips enterprise, total production cost of Rp. 252,670,000, total inventory cost of Rp. 1,200,000 and total annual production cost of Rp. 253,870,000. Again in another case study, LP was applied at a rice crops product manufacturer in Colombia resulting achieving an 11% reduction in total production costs, with specific cost savings of 68% in storage and 44% in shift programming, thus demonstrating LP's effectiveness in cost control and resource management (J. R. Coronado-Hernández,2021). In another study, it suggests a linear programming model that minimizes feeding expenses for the herds that produce milk by determining the best planting schedule based on the distribution of food or diets at a dairy farm. (A. Bellingeri, A. Gallo,2020). In another study, LP was applied to Shree Lakshmi Craft, determining that to minimize production costs of cartons, the company should produce 300,000 monocartons and 60,000 mastercartons per month, resulting in a monthly cost reduction to Rs. 5,600,100 (A. Sharma, Dr. A. Jandhyala, 2023)

These types of optimization can also be done with with other methods like MILP, as in a case study, suggests a mixed integer linear programming model with the primary goal of reducing production times while accounting for the ideal number of workstations. Using a lean manufacturing methodology and time study methodologies to gather data for the model, the objective was to reduce costs and boost production capacity of a truck assembly line at an Indonesian automaker (J. Yudhatama, I. M. Hakim, 2020). Again in another study, suggests a mixed-integer linear programming (MILP) model for optimizing the cost of heating, ventilation, and air conditioning (HVAC) systems in buildings. By modeling equipment like chillers and boilers as generators and using discrete variables for on/off states, it addresses equipment load, energy storage, and time-varying utility costs. Real-time solutions achieve optimality within 1%, enabling rapid adaptation to changing conditions and optimizing occupant comfort at reduced costs. (M. J. Risbeck et al, 2017)

3 Methodology

The proposed methodology seeks to reduce production costs at an FMCG company's chip manufacturing plant. This approach involves three stages. Firstly, the production related problem is identified and precisely described, with an emphasis on the particular production difficulties and financial considerations that the facility faces. To evaluate the context, pinpoint important cost factors, and determine the variables required for the modeling procedure, a thorough analysis is carried out. Secondly, a Linear Programming model is developed to minimize the total production cost. By optimizing both fixed and variable production costs, the goal is to increase the plant's productivity and efficiency. To do this, the LP issue is solved using specialist tools, such as python programming pulp modelling framework which enables the maximum or minimization of inputs to produce an ideal solution. Finally, the model is fed with the company's industrial data to perform simulations and produce useful outcomes. This data includes historical demand, production capacities, and cost structures. This stage makes it possible to put the model into practice and makes it a repeatable instrument for continuous cost optimization and production scheduling (See Fig. 1).

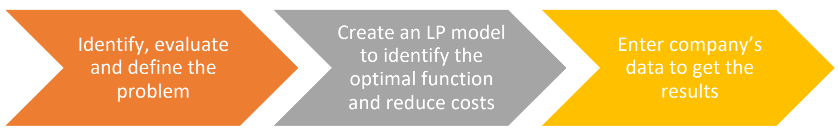

Fig.1. Diagram of the methodological process.

4. The variables, objective function, model and the problem with mathematical formulation

Suppose in a food manufacturing factory, there are s SKUs. These SKUs are produced in l line. Each line has a different variable cost structure and a maximum capacity. Also there is fixed cost is associated with every line. The manufacturing factory can only operate certain number of n (where n < l) lines at a maximum per day. We want determine the quantity of each SKU we can make at each line per day in order to minimize total production cost while meeting demand and adhering to line capacity by linear programming.

4.1 The Decision Variables

In this case of linear programming model of minimizing production cost are of three types:

Q_{sl} = Quantity of SKU s produced on Line l per day

y_l = 1 if Line l is used, 0 otherwise

Z_{sl} = 1 if SKU s is produced on Line l, 0 otherwise

4.2 Objective Function

The total cost associated with production is denoted by Z which is composed of variable cost and fixed. we have to minimize Z:

Min $Z = \sum_{s=1}^{m}(\sum_{l=1}^{m} C_{sl} . Q_{sl}) + \sum_{l=1}^{m} F_l . y_l$ Where s = 1,2,3,….,m and l = 1,2,3,…….,m

Here,

C_{sl} = Variable cost per metric ton for SKU s on Line l

F_l = Fixed cost associated with operating Line l

4.3 The Constraints

Constraints are the conditions that compel the necessary capacity and demand to be met. In this case of linear programming model of production cost minimization, there are 7 types of constraints:

Demand Constraints

$\sum_{l=1}^{m} Q_{sl} \geq \frac{D_s}{25}$, $\forall s \in$ {SKU-1, SKU-2, SKU-3,……SKU-m}

Capacity Constraints

$Q_{sl} \leq P_{sl} . Z_{sl}$, $\forall s \in$ {SKU-1, SKU-2, SKU-3,……SKU-m}, $\forall l \in$ {1,2,3,………,m}

Line Use Constraints

$\sum_{s=1}^{m} Q_{sl} - \mathrm{M} . y_l \leq 0$, $\forall l \in$ {1,2,3,………,m}

Operational Constraint (maximum n lines per day) Constraints

$$\sum_{l=1}^{m} y_l \leq \mathrm{n}$$

x SKU per Line Constraints

$\sum_{S=1}^{m} Z_{sl} \leq x$, $\forall l \in$ {1,2,3,………,m}

Non-Negativity Constraints

$Q_{sl} \geq 0$, $\forall s \in$ {SKU-1, SKU-2, SKU-3,……SKU-m}, $\forall l \in$ {1,2,3,………,m}

Binary Constraints

y_l , $Z_{sl} \in$ {0,1} , $\forall l \in$ {1,2,3,………,m} , $\forall s \in$ {SKU-1, SKU-2, SKU-3,……SKU-m}

Where

P_{sl} = Maximum daily production capacity for SKU s on Line l

D_s = Monthly demand for SKU s

P_{sl} = Maximum daily production capacity for SKU s on Line l

M = A large number, such as the maximum production capacity P_{sl}

5 Validation of the Mathematical Model

5.1 Case Study Company

This FMCG food manufacturing company based in Bangladesh, operating within the food and beverage industry. The company is recognized for its production of a wide range of consumer goods, including dairy products, spices, and edible oils. With a strong foothold in the Bangladeshi market, this company is well-positioned for significant growth due to the high demand for quality food products in the region. The company's strategic location in Bangladesh allows it to capitalize on efficient supply chains and distribution networks, ensuring timely delivery to both domestic and international markets. In this paper, a production cost minimization problem of chips plant of this company's factory is solved by linear programming.

5.2 Problem Formulation

In the chips plant of mentioned company, there are currently running 3 chips SKU: Pillow BBQ, Stix BBQ, Wavy BBQ. These three SKUs are produced in three Line. They are- Line-1, Line-2, Line-3. Each line has a different variable & Fixed cost structure:

Variable Production Related Cost (BDT) per MT of Each SKUs			
Line/SKUs	**Pillow BBQ**	**Stix BBQ**	**Wavy BBQ**
Line-1	2340.91	1754.68	2783.78
Line-2	1523.64	1457.39	2394.29
Line-3	2340.91	1754.68	2783.78

Fixed Cost (BDT) Associated per Line	
Line-1	102375
Line-2	204750
Line-3	102375

These SKUs also have a maximum production capacity. The Demand of each SKUs are:

Each SKUs per day capacity in MT (2 shift) Line Wise			
Line/SKUs	**Pillow BBQ**	**Stix BBQ**	**Wavy BBQ**
Line-1	4.4	5.87	3.7
Line-2	11	11.5	7
Line-3	4.4	5.87	3.7

Demand of SKUs per Month	
SKUs	**MT**
Pillow BBQ	153
Stix BBQ	50
Wavy BBQ	50

The chips plant can only operate two lines at a maximum per day. Each line can produce only 2 SKU per day. Also the fixed cost only applies if the lines produces any chips SKU. The company's working days are 25 days per month and also each shift of day = 8hrs.

We want determine the quantity of each SKU we can make at each line per day in order to minimize total production cost while meeting demand and adhering to line capacity by linear programming.

5.3 Decision Variables

Let the following decision variables represent the quantities produced and line usage:

1. Quantities Produced Per Day (in MT):

- QP1: Quantity of Pillow BBQ produced on Line-1 per day
- QP2: Quantity of Pillow BBQ produced on Line-2 per day
- QP3: Quantity of Pillow BBQ produced on Line-3 per day
- QS1: Quantity of Stix BBQ produced on Line-1 per day
- QS2: Quantity of Stix BBQ produced on Line-2 per day
- QS3: Quantity of Stix BBQ produced on Line-3 per day
- QW1: Quantity of Wavy BBQ produced on Line-1 per day
- QW2: Quantity of Wavy BBQ produced on Line-2 per day
- QW3: Quantity of Wavy BBQ produced on Line-3 per day

2. Line Usage Indicators:

- y1: Binary variable indicating if Line-1 is used (1 if used, 0 otherwise)
- y2: Binary variable indicating if Line-2 is used (1 if used, 0 otherwise)
- y3: Binary variable indicating if Line-3 is used (1 if used, 0 otherwise)

3. SKU Production Indicators Per Line:

- zP1: Binary variable indicating if Pillow BBQ is produced on Line-1
- zS1: Binary variable indicating if Stix BBQ is produced on Line-1
- zW1: Binary variable indicating if Wavy BBQ is produced on Line-1
- zP2: Binary variable indicating if Pillow BBQ is produced on Line-2
- zS2: Binary variable indicating if Stix BBQ is produced on Line-2
- zW2: Binary variable indicating if Wavy BBQ is produced on Line-2
- zP3: Binary variable indicating if Pillow BBQ is produced on Line-3
- zS3: Binary variable indicating if Stix BBQ is produced on Line-3
- zW3: Binary variable indicating if Wavy BBQ is produced on Line-3

5.4 Objective Function

The objective is to minimize the total cost, which includes both the variable and fixed costs associated with production:

Minimize $Z = 25 \times (2340.91 \times QP1 + 1523.64 \times QP2 + 2340.91 \times QP3 + 1754.68 \times QS1 + 1457.39 \times QS2 + 1754.68 \times QS3 + 2783.78 \times QW1 + 2394.29 \times QW2 + 2783.78 \times QW3) + 102375 \times y1 + 204750 \times y2 + 102375 \times y3$

5.5 Constraints

1. **Updated Constraints:**

Demand Constraints:

$25(QP1+QP2+QP3) \geq 153$ (Pillow BBQ)

$25(QS1+QS2+QS3) \geq 50$ (Stix BBQ)

$25(QW1+QW2+QW3) \geq 50$ (Wavy BBQ)

Capacity Constraints:

- $QP1 \leq 4.4 \times zP1$
- $QP2 \leq 11 \times zP2$
- $QP3 \leq 4.4 \times zP3QP3$
- $QS1 \leq 5.87 \times zS1$
- $QS2 \leq 11.5 \times zS2$
- $QS3 \leq 5.87 \times zS3QS3$
- $QW1 \leq 3.7 \times zW1$
- $QW2 \leq 7 \times zW2$
- $QW3 \leq 3.7 \times zW3$

Line Usage Constraints:

- $y1 \geq 1/25 \times (QP1+QS1+QW1)$
- $y2 \geq 1/25 \times (QP2+QS2+QW2)$
- $y3 \geq 1/25 \times (QP3+QS3+QW3)$

Operational Constraint:

- $y1+y2+y3 \leq 2$

Two SKU per Line per Day:

- $zP1+zS1+zW1 \leq 2$
- $zP2+zS2+zW2 \leq 2$
- $zP3+zS3+zW3 \leq 2$

Non-negativity Constraints:

- $QP1, QP2, QP3, QS1, QS2, QS3, QW1, QW2, QW3 \geq 0$

Binary Constraints:

- $y1, y2, y3, zP1, zS1, zW1, zP2, zS2, zW2, zP3, zS3, zW3 \in \{0,1\}$

5.6 Implementation and Summary

The linear programming problem for minimizing chips production cost involves 21 decision variables, including 12 binary variables and 20 equations. The problem was solved by python in Jupyter Notebook using pulp modelling framework. The computational process was executed on a mac book pro equipped with an Intel Core i5 1.4 GHz processor and 8 GB of RAM. The computational time required to solve the problem was approximately 0.02 seconds for 58 iteration.

Summary (Appendix 1) of results of variables and values:

QP1 = 0.0, QP2 = 6.12, QP3 = 0.0, QS1 = 2.0, QS2 = 0.0, QS3 = 0.0, QW1 = 0.0, QW2 = 2.0, QW3 = 0.0, y1 = 1.0, y2 = 1.0, y3 = 0.0, zP1 = 0.0, zP2 = 1.0, zP3 = 1.0, zS1 = 1.0, zS2 = 0.0, zS3 = 0.0, zW1 = 0.0, zW2 = 1.0, zW3 = 1.0

Minimum total production cost = 25 × (2340.91× 0.0 + 1523.64 × 6.12 + 2340.91× 0.0 + 1754.68 × 2.0 + 1457.39 × 0.0 +1754.68 × 0.0 + 2783.78 × 0.0 + 2394.29× 2.0 + 2783.78 × 0.0) + 102375 × 1.0 +204750 × 1.0 + 102375 × 0.0 = 747690.42

Summary of the solution:

1. Production Strategy:

- Pillow BBQ: Produced only on Line-2 with a daily quantity of 6.12 MT.

- Stix BBQ: Produced only on Line-1 with a daily quantity of 2.0 MT.

- Wavy BBQ**: Produced only on Line-2 with a daily quantity of 2.0 MT.

2. Line Usage: Line-1 and Line-2 are both used for production. Line-3 is not used.

3. SKU Production: Line-1 is used to produce Stix BBQ. Line-2 is used to produce both Pillow BBQ and Wavy BBQ. No production on Line-3.

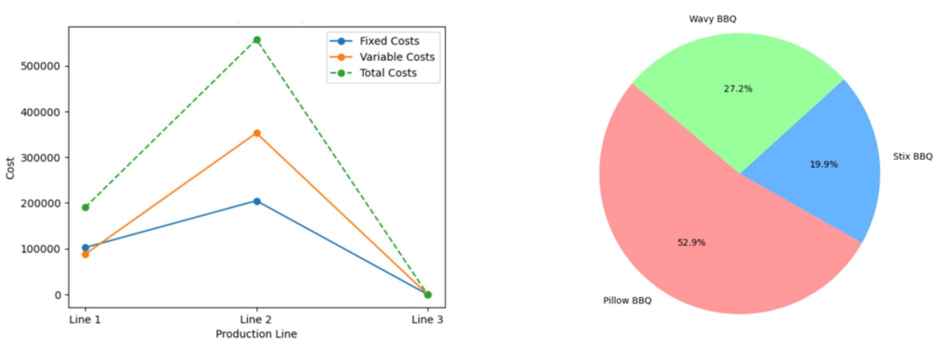

Fig2: Cost Component by Line and Cost Distribution by SKUs

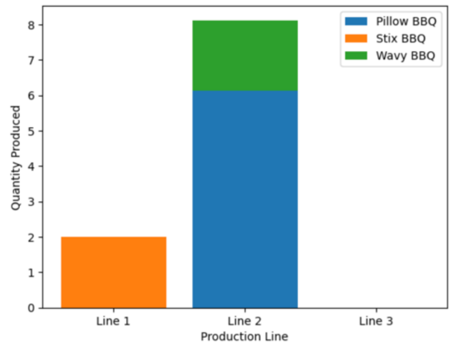

Fig3: Stacked Production Quantities by Line

6 Comparison of the Proposed Model to the Current Planning System

In the chips plant, the fixed cost is summation of three cost quantity:

Fixed Cost = Product Wastage Cost + Operator Salary + Servicing Cost

At current state,

Fixed cost of every month = 121875 + 8 * 29000 + 15000

= 368875

Variable cost of every month= 756500 (combined of labor cost and electricity cost)

Total current production related cost = 1125375

From the linear programming model optimum solution,

Fixed cost of every month = 307375

Variable cost of every month = 440315.42

Total minimum production related cost according to model = 747690.42

The model reduces the total production cost by 33.56% (Fig4) compared to current state of the chips plant. The fixed cost reduces by 16.67%(Fig4). The model successfully reduces a significant amount in the variable cost. The model reduces the variable cost by 41.80%(Fig4) compared to current state of the plant.

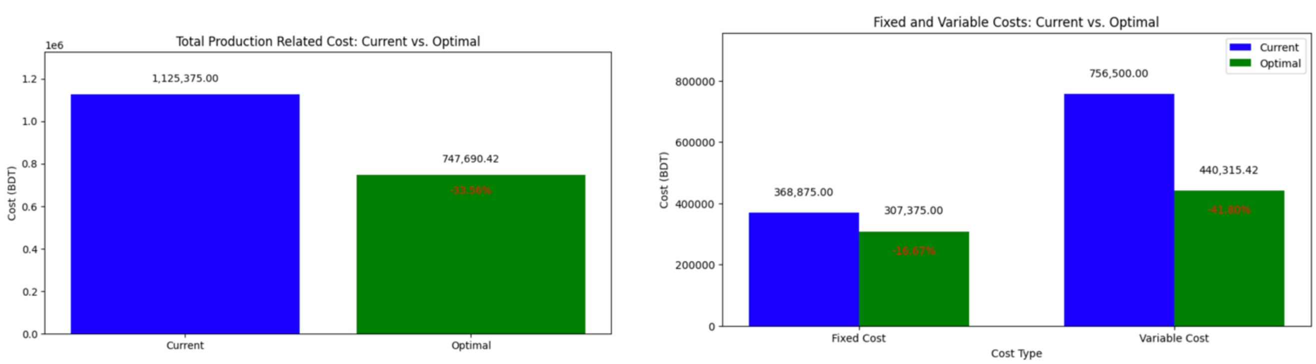

Fig4: Comparison of Costs: Current vs Optimal

7 Sensitivity Analysis

A sensitivity analysis was carried out to determine how the variations of some parameters affect total production costs, storage costs, setup cost, and the optimized total cost. This analysis is carried out by making variations by 10,-10,50,-50, −25, +25 and 25% ,50% in the values of the parameters such as in this model sensitivity analysis was done by changing three parameters: changes in the demand of Pillow BBQ SKU, changing the capacity of Pillow BBQ SKU, changing the cost of Wavy BBQ of Line-2.The sensitivity analysis has been done on the linear programing model using pulp modelling framework of python language in Jupyter Notebook. At first case, changes in the demand of Pillow BBQ was done which proportional rise effect on total production cost (Appendix-2). For 10MT increase in Pillow BBQ demand increases the total production cost by 2%. At second case, sensitivity analysis was done by changing the capacity of Pillow BBQ which has no effect on total cost and SKUs production quantity. At third case, cost of Wavy BBQ of Line-2 was changed. For Wavy BBQ increase of cost 50 BDT increases the total production cost by 0.34% (Appendix-2).

8 Conclusion

The paper considered a real problem of linear programming model in detail by taking an example in a Bangladeshi FMCG food manufacturing company. By mathematical model we can solve many real company's programs in optimal manner, also we can make many informal decisions from them. This tool has many merits such as improving use of resources, reducing costs, optimal solutions, a basis for decision making and many more. The study in this paper shows how to improve production planning based on demand, also helps to get economical benefits which improves business profitability and proper utilization of resources. The model reduces overall production cost by 33.56%. The model is feasible and optimal under the revised constraints. The solution suggests a cost-effective production strategy given the current constraints and demand requirements.

In future other projects can be taken into consideration in order to give a more comprehensive view of the production process and reduce additional product costs like distribution costs and distribution programming etc.

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Appendix 1

Optimal Solution of this linear programming model in Jupyter Notebook:

```
Result - Optimal solution found

Objective value:                747690.42000000
Enumerated nodes:               0
Total iterations:               58
Time (CPU seconds):             0.02
Time (Wallclock seconds):       0.02

Option for printingOptions changed from normal to all
Total time (CPU seconds):       0.02   (Wallclock seconds):       0.02

Status: Optimal
QP1 = 0.0
QP2 = 6.12
QP3 = 0.0
QS1 = 2.0
QS2 = 0.0
QS3 = 0.0
QW1 = 0.0
QW2 = 2.0
QW3 = 0.0
y1 = 1.0
y2 = 1.0
y3 = 0.0
zP1 = 0.0
zP2 = 1.0
zP3 = 1.0
zS1 = 1.0
zS2 = 0.0
zS3 = 0.0
zW1 = 0.0
zW2 = 1.0
zW3 = 1.0
Total Cost = $ 747690.42
```

Appendix 2

Sensitivity Analysis:

1. Changing the Demand of Pillow BBQ:

Demand of Pillow BBQ/ Variables	Z	QP1	QP2	QP3	QS1	QS2	QS3	QW1	QW2	QW3	y1	y2	y3	ZP1	ZP2	ZP3	ZS1	ZS2	ZS3	ZW1	ZW2	ZW3
153 MT	747690.42	0	6.12	0	2	0	0	0	2	0	1	1	0	0	1	1	1	0	0	0	1	1
150 MT	743119.5	0	6	0	0	0	2	0	2	0	0	1	1	0	1	1	0	0	1	0	1	0
160 MT	758355.9	0	6.4	0	2	0	0	0	2	0	1	1	0	0	1	1	1	0	1	0	1	0

2. Changing Capacity of Pillow BBQ of Line-2:

Capacity of Line-2 Pillow BBQ/ Variables	Z	QP1	QP2	QP3	QS1	QS2	QS3	QW1	QW2	QW3	y1	y2	y3	ZP1	ZP2	ZP3	ZS1	ZS2	ZS3	ZW1	ZW2	ZW3
10 MT	747690.42	0	6.12	0	2	0	0	0	2	0	1	1	0	0	1	1	1	0	0	0	1	1
11 MT	747690.42	0	6.12	0	2	0	0	0	2	0	1	1	0	0	1	1	1	0	1	0	1	0
12 MT	747690.42	0	6.12	0	2	0	0	0	2	0	1	1	0	0	1	1	1	0	0	0	1	0
13 MT	747690.42	0	6.12	0	0	0	2	0	2	0	0	1	1	0	1	0	0	0	1	0	1	0
14 MT	747690.42	0	6.12	0	0	0	2	0	2	0	0	1	1	0	1	0	0	0	1	0	1	0

3. Changing the Cost of Wavy BBQ of Line-2:

Cost of Line-2 Wavy BBQ/ Variables	Z	QP1	QP2	QP3	QS1	QS2	QS3	QW1	QW2	QW3	y1	y2	y3	ZP1	ZP2	ZP3	ZS1	ZS2	ZS3	ZW1	ZW2	ZW3
2300/MT	742975.92	0	6.12	0	0	0	2	0	2	0	0	1	1	0	1	0	0	0	1	0	1	0
2350/MT	745475.92	0	6.12	0	0	0	2	0	2	0	0	1	1	0	1	0	0	0	1	0	1	0
2400/MT	747975.92	0	6.12	0	0	0	2	0	2	0	0	1	1	0	1	0	0	0	1	0	1	0
2450/MT	750475.92	0	6.12	0	0	0	2	0	2	0	0	1	1	0	1	0	0	0	1	0	1	0