Applying Linear Programming Method to Aggregate Production Planning: A Case Study on Rajshahi Sugar Mill

Jannatul Ferdous Mim, Sharna Sarker and Khairun Nahar
Department of Industrial & Production Engineering
Rajshahi University of Engineering & Technology
Rajshahi 6204, Bangladesh
mim1605008@gmail.com, swarna1605014@gmail.com, shapla05.ipe@gmail.com

Abstract

Sugar is produced by crushing sugarcanes at the Rajshahi Sugar Mill where sugar is produced throughout a certain period of the year, But the number of factory workers remains the same consistency throughout the year, which adds a large amount of cost to the production cost. The problem has been solved by using Aggregate Production Planning. Aggregate production planning (APP) is working for the determination of optimum production and workforce levels for each period over a planning stage. The motive of this study is to optimize the production cost by determining the workforce levels and inventory level for each period as well as to compare the optimized cost with their previous one. Data were collected directly from the Rajshahi Sugar Mill authority and afterward, a Linear Programming Model has been formulated by these datasets. Thereafter an optimum value was determined by using LINGO software. Finally, we compared the previous cost with the optimized cost, where the cost has been diminished by about 4%.

Keywords
Production Cost, Optimization, Aggregate Planning, Linear Programming and Sugar Mill.

1. Introduction
Sugarcane is the main raw material for sugar production, and the land of Rajshahi is suitable for sugarcane production. Sugarcane is produced in large quantities in Rajshahi, due to which sugarcane is a readily accessible material in the area, based on which a sugar mill has sprung up here. The sugar mill has been playing an important role in the national income of the country since 1965-66 (Rajshahi Sugar Mills Limited 2022).

Suitable strategies ought to be adopted to maximize the profits of these sugar mills. Consequently, aggregate planning is important to meet the customer demand as well as maximizing profit by identifying the exact workforce level and inventory that helps the company.

One of the most vital aspects of operations management is aggregate production planning. It is an intermediate planning method that is used to ascertain essential resource capacity that a company will need so that they can meet the expected demand(J 2022). Aggregate planning assists in finding the balance between organizational priorities, financial goals, and the company's overall strategic objective. Where demand is not matching with the production, the aggregate planning balance both by pricing, order management, promotion, and new demand creation. Aggregate plans are also used to set the stage for future short-term planning, such as production scheduling, sequencing, and loading. In actual it is very closely related to the budgeting of a company. The majority of budgets are focused on aggregate output, staff, inventory, and ordering levels. This has a two-to-twelve-month time horizon; in some circumstances, it can go up to eighteen months (Panneerselvam 2012).

1.1 Problem Statement
Rajshahi sugar mill mainly produces sugar by crushing sugarcane. Sugarcane is the main raw material for sugar production which is harvested only at certain times of the year. Since the production system of this sugar mill is running at a certain season, production is stopped at other times. But the number of workers in this factory is almost the same in every season. As a result, the production cost goes up a lot which causes a huge loss to the sugar mill.

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Besides, sugar is mainly produced only during the sugarcane season. However, there is more or less demand for sugar throughout the year. Therefore, a proper inventory system is required to ensure that the sugar produced in a particular season is available throughout the year.

1.2 Objectives

- Optimization of production cost by determining the workforce levels and inventory level for each period.
- Comparing the optimized cost with their previous one.

2. Literature Review

Since we want to work on Aggregate Production Planning of Rajshahi Sugar Mill, we have reviewed some papers related to Aggregate Planning and tried to understand how the problem has been solved. Some literature reviews related to this are discussed below:

Paiva and Morabito (2008) published an article named " An optimization model for the aggregate production planning of a Brazilian sugar and ethanol milling company" in which they designed a mixed-integer programming model to form an opinion about aggregate production planning. The study's main aim is to assist the organization's authority in assessing the volume of sugarcane that will be crushed, as well as to select which processes will be used to produce sugar and also the selection of suppliers of sugarcane and strategies for the inventory of final product. They have been successful in meeting their objectives.

Talapatra et al. (2015) developed an aggregate planning model based on linear programming named “Aggregate Planning problem solving using linear programming method” in. They specifically focused on three workforce criteria: a changing workforce, a fixed workforce, and a fixed and changing workforce combined. The author successfully attained their target which was to optimize the total cost. They had used TORA software to find the optimum result.

Arumugham et al. (2017) published a journal named “Solving Aggregate Planning Problem Using LINGO”. They mainly focused on labor, subcontracting and inventory.

Another article named “Applying linear programming model to aggregate production planning of coated peanut products” was published by (Rohmah et al. 2018). The study's main purpose was to determine the overall production level for each grade of coated peanut product in order to satisfy consumer demand while keeping production costs low. They were concentrated on production capacity and inventory.

Campo et al. (2018) presented an article which was published named “Linear Programming for Aggregate Production Planning in a Textile Company”. They proposed and implemented an aggregated production planning model to provide optimum medium-term strategies for a textile business, for which a linear programming model was proposed to reduce overall labor and inventory costs.

Djordjevic et al. (2019) developed an aggregate planning model named “A fuzzy linear programming model for aggregated production planning (APP) in the automotive industry”. Their objective was to minimize the total cost consisting of production cost, inventory cost, regular payroll, and overtime. They concentrated on flow time, and the proposed APP model resulted in a decrease in overall content flow time. The authors suggested forecasting consumer demand based on historical data and comparing the fuzzy APP model's output to that of other strategies.

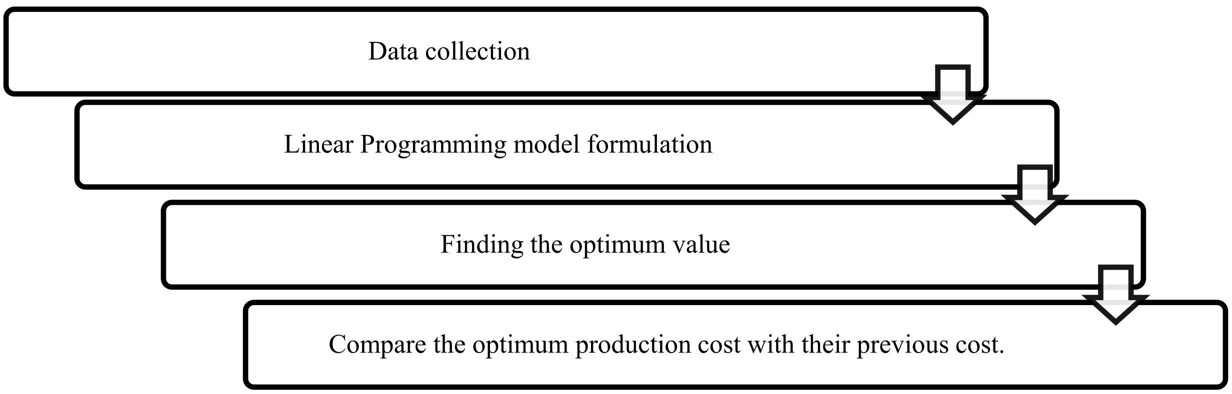
An article titled as "Aggregate production planning: A literature review and future research directions " has been reviewed (Cheraghalikhaniaet al. 2019). In order to accomplish two key goals, this paper evaluates the literature on APP models. Firstly, a structured classification scheme for APP models is suggested. Then reviewing APP models, gaps and trends in the literature have been extracted using three types of analysis: structural, significant issues, and solving methodologies. Finally, structures, significant issues, problem-solving techniques, and general recommendations were highlighted as four distinct categories of considerations for additional research on the APP models.

From our reviewed papers we have seen that authors have identified problems in various production areas, applied various methods including linear programming methods, and solved them through various software. Most of the authors have been able to maximize profit by reducing production costs to meet their objectives. In this case study, we have worked with the problem of Rajshahi Sugar Mill, where we use linear programming method since this method is generally appropriate for this kind of production area. Later we have used a software to determine the optimum production cost which is moderately less than the past cost as the principal objective of our study was to limit the production cost and maximize the profit.

3. Methodology and Model Formulation

3.1 Methodology

The problem stated above was solved by aggregate production planning by following the successive steps.



3.2 Data collection

We went to Rajshahi Sugar Mill, Rajshahi and collected our required data like number of regular and seasonal workers, wages of regular and seasonal workers, overtime wages of different workers, production level, material cost, demand, inventory cost, beginning inventory and maximum inventory level.

3.3 Linear Programming model formulation

We have to formulate the objective function and the constraints for developing a linear programming.
Let,
t = Time period, t=1, 2 … 12.
C= Total production cost
C1= Material cost
C2= Operation cost
C3= Labour costs
C4= Inventory cost
D_t =Approximate demand during period t, t=1, 2…,12.
I_t =Inventory of sugar at the end of period t, t=1, 2…,12.
MD_t =Man-days required to complete the sugar produced during period t=1, 2…, 12.
MDA_t =Man-days available to complete the sugar produced during period t=1, 2…, 12.
P_t =Production of sugar during period t=1, 2…12.
SW_t =Seasonal workers assigned during period t=1, 2…,12.
FW_t =Fixed workers assigned during period t=1, 2…,12.
EI_t = Expenses of Inventory during period t, t= 1, 2, … 12.
EM_t = Expenses of material during period t, t=1, 2…,12.
$EOSW_h$ = Hourly expenses of seasonal workers' overtime worked during a day-off day.
$EOSW_n$= Hourly expenses of seasonal workers' overtime worked during a normal working day.
$EOFW_h$= Hourly expenses of fixed workers' overtime worked during a day-off day.
$EOFW_n$ = Hourly expenses of fixed workers' overtime worked during a normal working day.
ESW =Wage of seasonal worker per period in period t. t=1, 2, … 12.
EO_t = Expenses of operation during period t, t=1, 2…,12.
EFW =Salary of a fixed worker per period.

n_h= Regular working hours in each normal working day.
n_t = Regular working days during period t, t=1, 2…12.
SW_{max} =Maximum number of seasonal workers.
FW_{max} =Maximum number of fixed workers.
FW_{min}=Minimum number of fixed workers.
OSh_t = Seasonal worker's overtime hours during off day in time t=1, 2…,12.
OSn_t = Seasonal worker's overtime hours during normal days in time t=1, 2…,12.
OFh_t = Fixed worker's overtime hours during off day in time t=1, 2…,12.
OFn_t = Fixed workers overtime hours during normal days in time t=1, 2…,12.

Objective Function

$$\text{Min } C= \sum_{t=1}^{12} EMt*Pt+\sum_{t=1}^{12} EOt * Pt + \sum_{t=1}^{12}(EFW * FWt + EOFWn * OFnt + EOFWh * OFht)+\sum_{t=1}^{12}(ESW * SWt + EOSWn * OSnt + EOSWh * OSht) + \sum_{t=1}^{12}(EIt * (It+I_{t-1})/2)$$

Model constraints:

$D_t + I_t = P_t + I_{(t-1)}$ for each t = 1, 2…,12
$FW_{min} \leq FW_t \leq FW_{max}$ for each t = 1, 2....,12
$0 \leq SWt \leq SW_{max}$ for each t = 1, 2....,12
$OFn_t + OSn_t \leq On_{max(t)}$ for each t = 1, 2….12
$OFh_t + OSh_t \leq Oh_{max(t)}$ for each t = 1, 2….12
$On_{max(t)} =O_n\times n_t (FW_t+SW_t)$ for each t = 1, 2….12
$Oh_{max(t)} =Oh\times h_t (FW_t+SW_t)$ for each t = 1, 2….12
$OSh_t <= OFh_t$ for each t = 1, 2 ….12
$MDR_t <= MDA_t$ for each t = 1, 2, ...,12
$MDA_t=(FW_t\times n_t+OFn_t/n_h+OFh_t/n_h) +(SW_t\times n_t+OSn_t/n_h + OSh_t/n_h)$ for each t = 1, 2, ...,12

3.4 Finding the optimum value

Optimized value has been extracted by solving Linear Programming model using lingo software.
From the above calculation it is seen that the production cost will be minimal when all the 292 seasonal workers will be working in regular shifts and overtime. Optimized inventory levels in this planning period are 2673,2673,2673, 2006,2006,2006,1173,1173,1173,506,506 and 506 metric tons respectively.

3.5 Compare the optimum production cost with their previous cost.

Through Excel, we have calculated the optimum production cost and the previous production cost of Rajshahi Sugar Mill, then compared them manually. Table 1 shows the regular production cost of the sugar mill of a year from January to December. After calculating the linear programming stated above, optimized workforce and inventory level has been calculated and the cost is shown in Table 2. Lastly the comparison between the regular total cost and optimized total cost is shown is Table 3.

Table 1. Regular Production Cost Calculation

Time	Material Cost	Operation Cost	Regular Worker Cost	Seasonal Worker Cost	Inventory Cost	Total Cost
JAN	147275000	666666	5491200	6382933	12500	159828299
FEB	0	0	1830400	0	12500	1842900
MAR	0	0	1830400	0	12500	1842900
APR	0	0	1830400	0	12500	1842900
MAY	0	0	1830400	0	12500	1842900
JUNE	0	0	1830400	0	12500	1842900
JULY	0	0	1830400	0	12500	1842900
AUG	0	0	1830400	0	12500	1842900
SEP	0	0	1830400	0	12500	1842900
OCT	0	0	1830400	0	12500	1842900

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NOV	147275000	666666	5491200	6382933	12500	159828299
DEC	147275000	666666	5491200	6382933	12500	159828299
					Total cost	494228097

Table 2. Optimum Production Cost Calculation

Time	Material Cost	Operation Cost	Regular Worker Cost	Seasonal Worker Cost	Inventory Cost	Total Cost
JAN	147275000	666666	0	10278400	12500	158232566
FEB	0	0	0	0	12500	12500
MAR	0	0	0	0	12500	12500
APR	0	0	0	0	12500	12500
MAY	0	0	0	0	12500	12500
JUNE	0	0	0	0	12500	12500
JULY	0	0	0	0	12500	12500
AUG	0	0	0	0	12500	12500
SEP	0	0	0	0	12500	12500
OCT	0	0	0	0	12500	12500
NOV	147275000	666666	0	10278400	12500	158232566
FEB	147275000	666666	0	10278400	12500	158232566
					Total cost	474810198

Table 3. Comparison between Regular and Optimum Production Cost

Type of cost	**Total cost**	**Reduced cost**
Regular cost	494228097	3.93 %
Optimum cost	474810198	

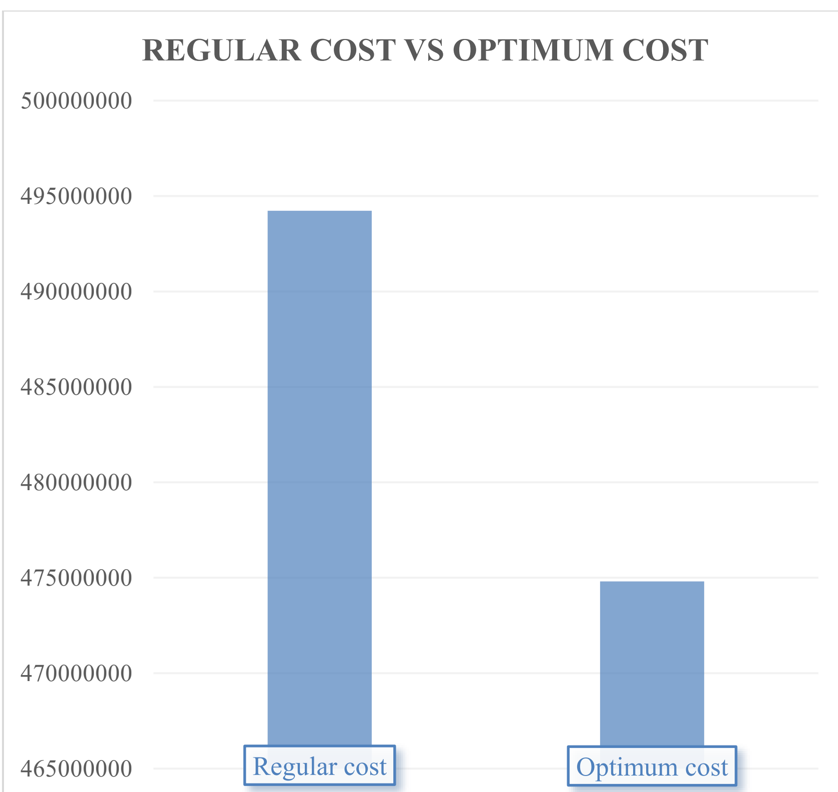

Figure 1.Regular cost vs Optimum cost

Figure 1 illustrates the reduction of cost of the optimal situation. The reduction of cost mainly happened in inventory and workforce cost.The value of the optimized production cost is reduced by 3.93% from the previous production cost.

4. Results and Conclusions

4.1 Result

In the study, the number of workers, as well as the inventory level, are optimized. It can be seen that, when only seasonal workers work from the November to January period, the amount of production cost is the optimum at this time for this sugar mill. During the production period, the optimum inventory in January is 2673 metric tons, and periodically 2006, 2006, 2006, 1173, 1173, 1173, 506, 506, 506, 2673, and 2673 metric tons. The optimum cost is calculated which is reduced and is 3.93% less than the previous production cost.

4.2 Conclusion

In this case study, aggregate production planning has been applied to Rajshahi Sugar Mill by using the linear programming method. The motive of the study was to determine the optimum production cost by extracting optimum inventory and workforce. To find out the optimum value and calculate the production cost Lingo software and Excel has been used respectively. The results of this study have confirmed that using the above method reduces the production cost of Rajshahi Sugar Mill by 3.93%, which confirms that the objective has been achieved.

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Biographies

Jannatul Ferdous Mim is an alumni of Rajshahi University of Engineering and Technology, Bangladesh. Her research interest includes waste management, aggregate production planning, supply chain management, quality control ect. She is currently working with several non-profit organizations. Jannatul has attended several workshops and seminars according to her research interest.

Sharna Sarker has recently graduated from Rajshahi University of Engineering & Technology, Bangladesh. Her major of BSc (Engineering) degree was Industrial and Production Engineering. Waste management, quality control, supply chain management, mathematics is some of the fields that reflect her research interest. Sharna has attended various workshops and seminars according to her interest. Currently she is working with some youth led organizations.

Khairun Nahar is an Assistant Professor of Industrial & Production Engineering at Rajshahi University of Engineering & Technology. Her main research interests are in CAD/CAM, quality control, operations research, measurements & instrumentation, engineering economy & multiple criteria decision analysis.

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