Linear Programming based Effective Maintenance and Manpower Planning Strategy: A Case Study

B. Kareem and A.A. Aderoba

Department of Mechanical Engineering
Federal University of Technology, Akure, Nigeria
E-mail: karbil2002@yahoo.com

Abstract

In this study, maintenance related data of a cocoa processing industry in Akure, Ondo State of Nigeria were collected, classified and analysed statistically. Linear Programming (LP) model was formulated based on the outcomes of the analysed data. The data analysed includes maintenance budget, maintenance cycle, production capacity and waiting time of production facilities in case of failure. Data were analysed based on manpower cost, machine depreciation cost and the spare part cost, which were assumed to be proportion to the number/magnitude of the breakdowns. The generated LP model was solved using software named "the Quantitative System for Business- QSB (Version 3.0). The results of the model showed that four maintenance crews were needed to effectively carryout maintenance jobs in the industry. The sensitivity analysis showed that the results have a wide range of feasibility.

Keywords: Maintenance System, Manpower Planning, LP-model, QSB Software, Sensitivity Analysis.

1. Introduction

Many operation management decisions involving making most effective use of organization resources can be resolved by applying linear programming techniques. Linear programming is a widely used mathematical technique designed to help in planning and decision making relative to the trade-off necessary to allocate resources (Joseph, 1987). In any production firm there are two sub systems, human and technical. The two sub-systems must be balanced and coordinated in order to function effectively (Joseph, 1987). Many studies have been carried out on how to make maintenance and manpower planning effective in a production firm. In previous studies, models adopted to analyze prevailing situation include: simulation model, queue model, utility model and network analysis. In this study, linear programming technique is used to analyze maintenance operations and manpower planning in a production firm used to analyze maintenance operations and manpower planning in a production firm that was used as a case study.

Allan *et-al* (1988) defined maintenance as all activity in keeping equipment in working order. They also pointed out that the amount and type of maintenance applied depends strongly on its cost and safety implication of the system failure. Joseph (1987) said that both passive and active repair times are influenced by factors other than equipment design. He said maintenance philosophy plays an important role in determining overall availability, and defined it as consideration of maintenance procedures, personnel and spare part provision.

Armstrong (1971) said that manpower refers to human resources used in carrying out jobs in any organization. Report of the conference board on manpower planning and evolving system in 1971 further defined manpower planning as a process intended to assure an organization that it will have the proper number of properly qualified and motivated employees in its workforce at some specific future time to carry on the work that would then have to be done. Many scientific approaches have been used to solve the problem of manpower. Among these are the workload method, mathematical programming approach and simulation techniques. In all these approaches the main aim of manpower planning that is pursued are to ensure that the organization: obtains and retains the quantity and quality of manpower it needs; makes the best use of its manpower resources; and is able to anticipate the problems arising from potential surplus or deficit of manpower. In this study linear programming approach is used to determine optimal number manpower that can work effective in maintenance sector subject to manpower cost, spare part cost and depreciation cost of machine. Many of the existing models on manpower planning treated the above constraints separately. The there are scanty work on model that holistically considered the three constraints.

Overview of Linear Programming Model

Linear programming was developed in 1947 by G.B. Dantzig and represents a valuable method in the field of operations research. Linear programming is a mathematical tool for finding solution to a certain class of problem. The word (linear) implies that the relations involved are linear, while the term programming in the context means planning of activities. The objective is to maximize or minimize a single objective function relative to a set of constraints.

A mathematical program is linear, if
$F(x_1, x_2, \ldots, x_n)$ and each
$G(x_1, x_2, \ldots, x_n)$ $(i = 2,3,\ldots,n)$
are linear in each of their argument.

That is,
$F(x_1,x_2,\ldots,x_n) = c_1x_1+c_2x_2+\ldots+c_nx_n$
and
$g(x_1,x_2,\ldots,x_n) = a_{11}x_1+a_{12}x_2+\ldots+d_{in}x_n$
c_i and a_{ij} $(i = 1,2,\ldots..n; \quad j = 1,2,\ldots,n)$ are known constants.

All linear programming problems have the following properties in common: all seek to optimize some quantity. This property is referred to as the objective function. There are constraints, which limit the degree to which the objective can be pursued; and there must be alternatives to choose from. The objectives and constraints in linear programming must be expressed in terms of linear equation or inequalities

However, the following procedures are necessary when formulating Linear Programming (LP) problems: write down decisions variables of the problem; formulate the objective function in terms of decision variables; formulate the other conditions/constraints of the problem to which the optimization process is subjected to, such as resources limitation, market constraints as linear equations in terms of the variables; add non-negativity conditions/ constraints- the considerations that negative values of physical variable in most cases do not have any valid physical interpretation. Summarily, the objective function, the set of constraints and the non-negativity together form the linear programming model of the problem.

2. Methodology Adopted

In pursuing the objective of the study, data were collected, classified, analysed and the linear programming model was formulated based on the data analysed. The department whose data was studied is the maintenance section of a production firm (Cocoa Processing Industry) in Akure, Ondo State of Nigeria, which is responsible for the keeping of the plant and machinery used for cocoa processing in operable condition. The data were collected through the use of questionnaires and oral interview among employees in the maintenance section of the firm. The data that were collected include the following: number and list of all the machines; types of maintenance applied; budget on the maintenance; factors affecting maintenance; present level of manpower planning in maintenance department; maintenance cycle of each of the machines; and the waiting time of each of the machines.

After the collection of the data a close monitoring of the maintenance operations of the production section was done over a period of two weeks to make ensure reliability of the data. The major machines on which scheduled or time based preventive maintenance was carried out include machine one (1) cleaning and destoner, two (2) dryer, three (3) winnower, four (4) reactor, five (5) roaster, six (6) map mill, seven (7) liquor press, eight (8) butter press and nine (9) boiler. The factors affecting the maintenance operation of the firm include understaffing in the maintenance section, mismanagement of budgetary allocation, inadequate tools, equipment and spare part.

The total number of employees in the maintenance section is nineteen, maintenance manager inclusive. The employees are grouped into six crews, each of which has three members. Among the three members, one acts as the supervisor. The budget for the production section of the firm of which the maintenance section is a subsection for the year is as shown in Table 1a. Table 1b shows maintenance cycle, production capacity and average waiting time of each machine.

In the analysis of the data collected, the following assumptions were made: manpower cost associated with the maintenance of each machine per hour is the same for all the machines; depreciation cost associated with each machine is directly proportional to the rate of breakdown of the machine; and spare part cost associated with the maintenance of each machine is directly proportional to the number of hours used during the maintenance of the machine. Based on these assumptions, the data are analyzed as followed.

Total manpower cost for Maintenance Section $= \frac{19}{51} \times 6{,}900{,}000$

$= ₦2{,}570{,}588.24$./Year.

Manpower cost associated with the maintenance of each machine was calculated using

$$\frac{D}{Y} \times \frac{2{,}570{,}588.24}{5760} \text{ per hour.}$$

Where, D is waiting time of the machine during a year and Y is the total waiting time of all the machines in the production section in a year.

Spare part cost for each machine was calculated using

$$\frac{D}{Y} \times \frac{4{,}000{,}000}{5760} \text{ per hour.}$$

Depreciation cost associated with each machine was calculated using

$$\frac{Q}{W} \times \frac{52{,}000{,}000}{5760} \text{ per hour.}$$

Table 1a: Budget for Maintenance Operation

Manpower remuneration for the production section.	₦ 6,900,000:00
Total allocation for spare part for maintenance of the machine.	₦ 4,000,000:00
Total cost for depreciation of the machine.	₦52,000,000:00

Table 1b: Maintenance Cycle, Production Capacity and Waiting Time.

M/C	Maintenance Cycle, (Hrs) (Codes)	Waiting Time (H_1)	Production Capacity (Tons/hr)
1	720 (i)	1	3
2	1384 (ii)	2	2
3	5760 (iii)	2.5	2
4	1800 (iv)	3.33	2
5	2000 (v)	5	2.5
6	720 (vi)	6	1.5
7	2000 (vii)	8	1.5
8	1600 (viii)	1	2.5
9	2000 (ix)	3	1.5

Where W is the total number of repairs of all the machines and Q is the total number of repairs of each machine. From the above relationships the Table 2 is generated. Also from the data collected Table 3 estimates the value of number of repair in a year, maximum number of hours available for repair in a year and the percentage production hour available for each machine.

The objective of the linear program is to determine the crew size that will maximize the effectiveness of maintenance thereby maximizing the effectiveness of the production operation.

The variables used are:

X_1 = Number of crew allocated to machine 1

X_2 = Number of crew allocated to machine 2

X_3 = Number of crew allocated to machine 3

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X_9 = Number of crew allocated to machine 9

The objective is to maximize the percentage production hour available per maintenance cycle of each machine. That is minimize the waiting time of each machine.

The objective function is written as:

$$\text{Maximize } Z = 0.998X_1 + 0.998X_2 + 0.999X_3 + 0.998X_4 + 0.997X_5 + 0.994X_6 + 0.996X_7 + 0.999X_8 + 0.998X_9$$

Subject to:

Constraint on manpower cost associated with the maintenance of each machine

$$13.49X_1 + 15.74X_2 + 5.62X_3 + 17.90X_4 + 28.1X_5 + 53.96X_6 + 44.97X_7 + 6.75X_8 + 16.86X_9 \leq 347.22.$$

Constraint on spare part cost associated with the maintenance of each machine.

$$20.99X_1 + 24.5X_2 + 8.75X_3 + 27.99X_4 + 43.73X_5 + 83.96X_6 + 69.96X_7 + 10.5X_8 + 26.24X_9 \leq 850.69.$$

Constraint on depreciation cost associated with the maintenance of each machine.

$$826.97X_1 + 432.4X_2 + 137.83X_3 + 344.57X_4 + 344.57X_5 + 826.97X_6 + 344.57X_7 + 413.49X_8 + 344.57X_9 \leq 9027.78.$$

Table 2: Maintenance Cost Analysis.

Machine	1	2	3	4	5	6	7	8	9	Max. Available cost/hr.
Manpower cost/hr.	13.49	15.74	5.62	17.90	28.10	53.96	44.97	6.75	16.86	347.22
Spare part cost/hr.	20.99	24.50	8.75	27.99	43.73	83.96	69.96	10.50	26.24	850.69
Depre-ciation cost/hr	826.97	432.40	137.83	344.57	334.57	826.94	344.57	413.49	344.57	9027.78

Table 3: Production and Maintenance Hour Analyses

Machine S/N	Number of repairs in a year	Max. hrs. available for repair in a year	% Production hrs. Available/ production cycle.
1	12	12	99.8
2	4	14	99.8
3	2	5	99.9
4	5	16	99.8
5	5	25	99.7
6	12	48	99.4
7	5	40	99.6
8	6	6	99.9
9	5	15	99.8

Constraints on the maximum hour available for maintenance in each maintenance cycle, $X_1 \leq 1$, $X_2 \leq 2$, $X_3 \leq 2.5$, $X_4 \leq 3.33$, $X_5 \leq 5$, $X_6 \leq 4$, $X_7 \leq 8$, $X_8 \leq 1$, $X_9 \leq 3$

Non-negativity, $X_1 \geq 0$, $X_2 \geq 0$, $X_3 \geq 0$, … $X_9 \geq 0$

The general linear program is of the form.

$$\text{Max. } Z^* = 0.998X_1 + 0.998X_2 + 0.999X_3 + 0.998X_4 + 0.997X_5 + 0.994X_6 + 0.996X_7 + 0.999X_8 + 0.998X_9$$

Subject to:

$$13.49X_1 + 15.74X_2 + 5.62X_3 + 17.90X_4 + 28.1X_5 + 53.96X_6 + 44.97X_7 + 6.75X_8 + 0.998X_9 \leq 347.22$$

$$20.99X_1 + 24.5X_2 + 8.75X_3 + 27.99X_4 + 43.73X_5 + 83.96X_6 + 69.96X_7 + 10.5X_8 + 26.24X_9 \leq 850.69.$$

$$826.97X_1 + 432.4X_2 + 137.83X_3 + 344.57X_4 + 344.57X_5 + 826.97X_6 + 344.57X_7 + 413.49X_8 + 344.57X_9 \leq 9027.78.$$

$$X_1 \leq 1, X_2 \leq 2, X_3 \leq 2.5, X_4 \leq 3.33, X_5 \leq 5, X_6 \leq 4, X_7 \leq 8, X_8 \leq 1, X_9 \leq 3$$

$$X_1, X_2, X_3, X_4, \ldots, X_9 \geq 0$$

The linear program model generated was solved using software called the Quantitative System for Business, QSB (version 3.0). The main advantage of this software is that it does not only generate the result, but also does the sensitivity analysis of the optimal solutions.

4. Results and Discussion

Solving the linear programming model with QSB software, the optimal results with its objective function co-efficients sensitivity analysis including opportunity cost are given in Table 5. From Table 4, which shows the frequency of machine breakdown, Table 6 is developed to indicate how maintenance crew must be allocated based on the results obtained from the optimal solution of the linear programming model developed (Table 5). During the first maintenance cycle, only machines machine number one and six broke-down and only one crew is needed to perform the maintenance job in each of these machines. Invariably, only two crews are needed in this maintenance period. Also during the second maintenance cycle, machines one, two and six broke-down and the number of maintenance crew needed to perform the maintenance job on machine, m/c one is one, on machine number two is two and on machine number six is one. Invariably, four maintenance crews are needed to effectively carry out the maintenance job during this maintenance cycle. Following the trend of this Table, it can be seen that the cycle that having the highest number of machine breakdown (peak maintenance period) and also requiring the highest number of maintenance crews is cycle period six (vi). At this cycle eight machines broke-down and twenty-crews will be needed to carry out peak maintenance jobs, instead of maximum of six crews available in the section. This indicates a shortage of 14 crews during the peak maintenance period.

Table 4: Frequency of Machine Breakdown per Cycle

Machine	i	ii	iii	iv	v	vi	vii	viii	ix	x	xi	xii
1	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
2		✔		✔		✔		✔		✔		✔
3								✔				
4			✔			✔			✔			✔
5			✔			✔			✔			✔
6	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
7			✔			✔			✔			✔
8			✔			✔			✔			✔
9			✔			✔			✔			✔

Table 5: Sensitivity Analysis of the Optimal Results

Variable (Optimal crew)	Minimum	Original	Maximum
X_1 (1)	0.2988	0.998	Infinity
X_2 (2)	0.3486	0.998	Infinity
X_3 (3)	0.1245	0.999	Infinity
X_4 (4)	0.3934	0.998	Infinity
X_5 (5)	0.6225	0.997	Infinity
X_6 (0)	Infinity	0.994	1.1952
X_7 (3)	0.8283	0.996	1.5952
X_8 (1)	0.1494	0.999	Infinity
X_9 (3)	0.3735	0.998	Infinity

Table 6: Optimal Allocation of Crews to Machines

Machine	Maintenance Cycle											
	i	ii	iii	iv	v	vi	vii	viii	ix	x	xi	xii
1	1	1	1	1	1	1	1	1	1	1	1	1
2	-	2	-	2	-	2	-	2	-	2	-	2
3	-	-	-	-	-	-	-	3	-	-	-	-
4	-	-	4	-	-	4	-	-	4	-	-	4
5	-	-	5	-	-	5	-	-	5	-	-	5
6	1	1	1	1	1	1	1	1	1	1	1	1
7	-	-	3	-	-	3	-	-	3	-	-	3
8	-	-	1	-	-	1	-	-	1	-	-	1
9	-	-	3	-	-	3	-	-	3	-	-	3

From this, it can be seen that the number of crews needed to solve the maintenance problem that may arise at any point in time as derived from the optimal result without the defective machines undergoing any unnecessary delay is twenty. From the optimal results, Table 7 was gotten which shows the old and optimal waiting times. From Table 8, it can be seen that there is no significant change in production capacity per maintenance cycle of Machine number one, since there is no change in the waiting time of the machine, but in machine number two, there is a change in the production capacity, which is equivalent to the production capacity per gain (reduction) in waiting time of the machine. The same condition applies to the change in production capacity per maintenance cycle of all the remaining machines. It can be seen also that the change in production capacity per gain (reduction) in waiting time of machines is negligible when compared with the original (old) production capacity per maintenance cycle of the machines.

Table 7: The Old and Optimal Waiting Times of Repair Jobs

Machine	Waiting Time (in min.)	
	Old	Optimal
1	60	60
2	120	60
3	150	50
4	200	50
5	300	60
6	240	240
7	430	160
8	60	60
9	180	60

Table 8: Production Capacity (in tons) per Maintenance Cycle

Machine	Production Capacity (in tons) per Maintenance Cycle	
	Old	Optimal
1	2160	2160
2	2768	2771
3	11520	11523
4	3600	3604
5	5000	5005
6	1080	1080
7	3000	3003
8	4000	4000
9	3000	3003

4. Conclusion

Through the application of linear programming techniques to the analysis of the manpower planning in maintenance, the following findings were made: the minimum number of maintenance crew needed to solve the maintenance problem that may arise at any point in time, in order to maximize the effectiveness of the system is twenty (20); with the availability of this number of crew, there will be an appreciable reduction in the waiting time of machines during maintenance as shown in Table 7; the change in production capacity per maintenance cycle is not appreciable even with the use of the optimal number of crew (Table 8). These findings can be used to predict the system operation and no doubt served as a very useful tool for future planning.

Since the twenty maintenance crews needed for peak maintenance period could be idle at less maintenance periods, some of them could be transferred to work in production section to promote efficiency and reduce overall cost of production. To be able to achieve this objective maintenance crew must be multi-skilled in nature. These people should be trained and used as supplement whenever there is excess production workload, but when there is excess maintenance workload they continue with maintenance work. This is to avoid the cost of keeping idle maintenance crew(s). For maintenance to be effective there is need for experienced and skilled personnel. Therefore, further work should look at skill vis-à-vis specified work to be done. Improvement should be made in the documentation of maintenance data to allow easy analysis of the maintenance section in the future.

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