International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 05 May 2024, pp: 1027-1045 www.ijaem.net ISSN: 2395-5252

Maintenance Planning Model for a Crew Size under Varying Skills and Job Complexity

Lawal A. S[1] & Kareem B.[2]
[1]Department of Mechanical Engineering, Ekiti State University, Ado Ekiti, Nigeria.
[2]Department of Industrial Engineering, Federal University of Technology, Akure, Nigeria.

Date of Submission: 18-05-2024 Date of Acceptance: 28-05-2024

ABSTRACT
Determining the size of maintenance workforce is an essential element of maintenance planning. It is important for performing maintenance programs perfectly. Although, it is a complex and challenging problem since it involves theconsideration of several important factors. The model developed in this study aims at finding out the optimal size of the maintenance workforce taking into account all of the important factors that affect this size. It is based on determining the needed number of workers with different skill levels and different costs to meet maintenance workload of different grades that is to be performed in a specified planning horizon with minimum cost. A production workshop in Northern part of Nigeria were used as case study where data were collected for appropriate call-in jobs with service personnel clustered into Engineers, Technicians and Craftsmen. The results had varying skills measured in years and cost as the major considerations for evaluating their performance and a software package was developed for quick implementation of this study using visual basic language 6.0. The complications inherent in the problem environment to include a non-random arrival pattern of jobs were incorporated into the software developed. The results showed that the varying crew sizes with different years (skills; 1-2years, 3-4years, 5-6years, 7-8years, 9-10 years) deployed to six equipment units had an optimum cost region obtained through a graph of the maintenance service time cost. With optimum cost of ₦1900 daily within 3-6 years for the multi skilled crews.

I. INTRODUCTION

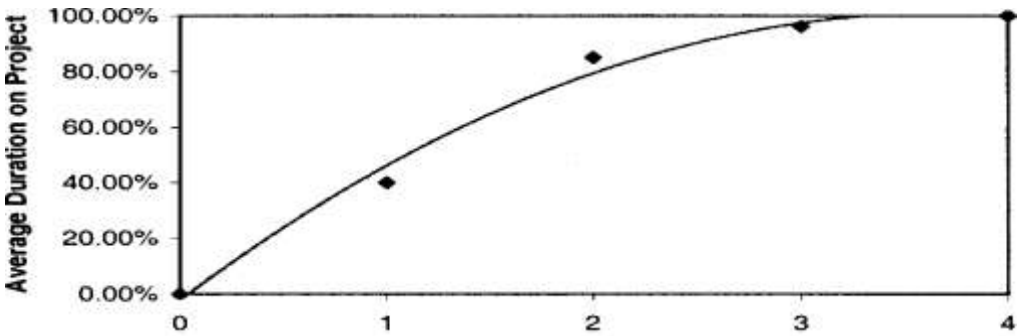
Maintenance planning is the combination of all technical and associated administrative actions intended to retain an item, or restore it to a state in which it can perform its required function (Ozaki,1996). Many companies think of maintenance in terms of repair and replacement only. Today, this form of intervention is no longer acceptable because maintenance is more than a “fix it when it breaks” and planning its activities remains the backbone for a successful and profitable company especially, when these activities require several strata’s of manpower (Villalobos, 1997).Relatively maintenance has been studied in diver’s context, among these methods are the Zero-based budgeting (Haase et al, 1999) procedures based on work factor analysis(Lardner, 1999), techniques based on methods time measurement-MTM (Shewchucket al, 2001) linear programming techniques which is based on cost (Kareem,2005) all these techniques developed proved the importance of manpower planning.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 (Kareem and Aderoba, 2004). However, extension is still in progress with other strategies of planning manpower resources during maintenance activities. Good planning means proper determination of the maintenance resources that are needed to meet the maintenance workload to be performed during the planning horizon (Ashayeriet al,2006). Good maintenance planning can be extended to deal with determination of: Skills of maintenance workers; Exact number of maintenance workers of various crafts, Types of

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 05 May 2024, pp: 1027-1045 www.ijaem.net ISSN: 2395-5252

maintenance equipment and tools, Exact number of maintenance equipment and tools, Specifications of spare parts and materials, Overtime capacity, (Ashayeri ,1996; Daffuaa, 1999; Smith, 2004; Lardner, 1998). The most complex element among all of these essential elements of planning is the determination of the exact number of maintenance workers of various crafts for efficient maintenance. This is because it involves meeting maintenance schedules with different grade of complexity by the use of workers of different skills. Generally, as the size of the maintenance activities increases many maintenance shops also face the problem of short employment duration, frequent layoffs, and periods of unemployment because of the fluctuations experienced in the maintenance planning (Business Round Table,1997).Duffua (2009) have indicated that this trend will not soon change and Belky (2006) reported how difficult and time consuming it took Knitting department to perform an experiment that estimated its optimum repair crew size. This understanding has revealed subtle relationships which have important bearing on the interaction of varying skills for this research.Thus, it is necessary to consider strategies to determine the useful manpower skills in a Maintenance firm to counter the negative effects of this trend.

II. LITERATURE REVIEW

Several models were suggested for manpower staffing without tackling all the features of its problem. Hertz (2009) considered staffing at average demand levels without consideration of workforce skills whereas Larsen (2007) included the problem of varying workload without dealing with workforce capabilities. Paz and Leigh (1994) considered difference in skills between workers and travel time to go to the failure location without taking into account a fluctuating failure pattern. Hegazy (1999) took into account the distribution of failures over the space but not over the time. Some other works on maintenance staff planning found as related literature used a discrete state markovian or semi markovian model which are then optimised through classical methods such as dynamic programming or policy iteration. Markovian model requires identification of discrete states and transition probabilities between states (Koole, 2008). This requirement is quite difficult to fulfil in practice,on the other hand Duffuaa and Andijani (1999), consider that the application of computer simulation to these, provides a better and more viable alternative analysis. This is because of the difficulty of the markovian models in capturing the complexities of maintenance, uncertainty of parameters in arrivals, sequencing, job contents and availability of resources(Jordan et al, 2004). Additional literature was reviewed in the areas of construction, operations research, and human resources management. The objective was to gather information on previous work in multi skilled workforce and assignment optimization. Multi skilled staffs are currently being used in the facility maintenance of Companies such as, Motorola in some of their plants. Documented benefits include increased productivity, lower personnel costs, increased quality, and increased worker satisfaction (Williamson, 1994). Brusco et al (1996) also studied the staffing of a multi skilled workforce with varying levels of productivity using the operations of a paper mill facility as a model. The research was conducted using an integer goal-programming model, which was tested by collecting data from the maintenance operations at the paper mill. Different breadths and depths were measured to test the trade-offs between these two factors. This study concluded that the breadth of cross-training had a tremendous effect on the required workforce size and is more important than the depth of cross-training.Campbell (1999) developed an optimization chart (Figure 2.1) for allocating cross-trained workers in a multi-department service environment. Worker capabilities were described by parameters that range from 0 to 1, with fractional values representing workers who are less than fully qualified. Results showed that the benefits of cross-utilization can be substantial, and in many cases a small degree of cross training or breadth can capture most of the benefits.



Value of skills

Figure 2.1: Source; Campbell (1999)

Bechtold (1988) studied a tractable set of integer programming models of a mix of full- and part-time employees in a multiple-objective, multiple-location environment. The first three models developed analyze trade-offs between idle time, the number of employees required to work at multiple "locations", and the size of the total labour pool. The flexibility of this approach is illustrated by a series of modifications made to the constraints that change the objective function and permit the use of preference weights to influence the solutions

2.1 Maintenance Jobs planning

Job simulation is an essential element for effective maintenance management as a number of tasks may have to be performed in a maintenance job pool within an allotted time.

Recently, many researchers have worked on several complex maintenance problem using different techniques like Branch and Bound (Yu, 2003), meta-heuristic methods (Wang, 2005; Qi, 2004) mixed integer linear programming (Haase, 1999) constraint programming (Goldberg, 2004) simulation methods (Ugochukwu 2011).It is not easy to compare these different approaches due to the lack of a common benchmark set for the computational challenge. The recent capabilities of simulation modelling, namely optimization modelling is adopted in many environments that may engender the application of one or more responses due to complexity of the problem structure and a simulated approach along this perspective was adopted for this research while disintegrating the master schedule of the fault's arrival into time–phased; daily, hourly activities. The general, rules of schedules which should be used regardless of the job phase are;

- First come, first serve (FCFC). In thisrule, work orders are done in the order of arrival
- Shortest processing time: in this rule work orders are run in the inverse order to the time required to process them.
- Due Date; Earliest due date first, the jobs with earliest due date first are prioritised for processing

2.2 Maintenance Crew Planning

Recently the Business Roundtable (BRT, 2007) recognized that crew scheduling has also been discovered useful for maintenance planning on tasks in industries. Conversely its uniqueness has recently attracted three approaches (Li, 1995) these are:

i. Numerical flexibility approach; refers to the ability of employers to adjust the numbers of individuals working, and/or the number of hours worked by the employees, in response to changing needs. This may include the use of short-term temporary contracts.

In the application of numerical flexibility to maintenance problems, one possible strategy is to use both half-time and full-time workers at the same time; another possible strategy is to use a different number of workers in a crew in different time slots, this is related to variations in the number of hours worked in response to changing demand. This latter is adopted in this research

ii. Wages approach; also called financial flexibility, is related to the capacity of the remuneration system to respond to differing performance levels and changing labour demand/supply. Within the human resource management context, this type of flexibility includes performance-related-pay and, in some sectors, special arrangements that will facilitate the recruitment and retention of specialized staff. The salary structure is confidential in most industries; therefore, this research study did not directly apply a wage strategy. Instead, a cost sensitive analysis to demonstrate the influence of the different salary

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 05 May 2024, pp: 1027-1045 www.ijaem.net ISSN: 2395-5252

structures on the maintenance plan and crew size was used.

iii. Functional approach; is related to an employer's ability to redeploy workers for different tasks, according to changing organizational needs. In such a situation, workers may be required to demonstrate a wider range of competencies, so they can move from task to task. Functional flexibility is not a preferable strategy for solving maintenance problem in this study, because the strict system limits any multi tasks capabilities required.

2.3 Maintenance Costing

Maintenance costs have significant consequences in the short and long term for matters such as resources (i.e., budget) allocation, technological choices, managerial and organizational procedures, etc. At this level of selection, it is only necessary to define the cost to adopt for each maintenance project, by entering into the details of the manpower cost,

Cost estimation is a reasonable approach to executing a work, which according to George (1990) should be optimistic or pessimistic. Aderoba (1997) referred to it as the prediction of the cost of product before its actual manufacture, which if under estimated will result to loss for the company and if overestimated will result to loss of contracts or customer's good will. In order to have an estimate close to the actual cost as much as possible. Aderoba (1997) opined that there is a need to employ suitable cost estimation method. There are different types and methods of approach to cost estimation, to include traditional cost accounting (TCA) direct cost (DC) and activity-based costing (ABC). Among these methods ABC has been considered to be relevant and suitable for this research study. In ABC analysis, costs are pooled together based on activities involved.

2.4 Maintenance Indicators

Maintenance planning employs various approaches to measure effectiveness of the maintenance function. Often indices are used to manage and control maintenance. These indices show trends by using past data as a reference point. Usually, a maintenance organization employs various indices to measure maintenance effectiveness, as there is no single index that can accurately reflect the overall plan of the maintenance activity.
The values of all these indices are plotted periodically to
show trends.

2.4.1 Total Maintenance Cost index
This index relates the total maintenance cost to the total investment in plant and equipment
(Chase, 1981). This is defined as follows:

$$TP_i = \frac{TMC}{TIPE} \quad (2.2)$$

Where; TP_i = total maintenance cost to the total investment in plant and equipment index parameter,
TMC = Total Maintenance Cost
TIPE =total investment in plant and equipment.

2.4.2 Control of Maintenance Activity
This is a useful index to control maintenance activity within a maintenance organization
(Dhillon, 1991) and is defined by

$$CM_i = \frac{TTPM}{TTEM} \quad (2.3)$$

Were; CM_i = index parameter,
TTPM = total time spent in performing preventive maintenance,
TTEP = total time spent for the entire maintenance function.

2.4.3 Maintenance Budget Plan
This index can be used to measure the accuracy of the maintenance budget plan (Stoneham 1998) and is expressed by

$$MB_p = \frac{TAMC}{TBMC} \quad (2.4)$$

Where; MB_p = accuracy of the maintenance budget plan index parameter,
TAMC = total actual maintenance cost,
TBMC = total budgeted maintenance cost.
In this case, large variances indicate the need for immediate attention.

2.4.4 Maintenance Overhead Control
This is a useful index for maintenance overhead control (Dhillon, 1991) and is expressed by

$$MO_C = \frac{TMAC}{TMC} \quad (2.5)$$

Where; MO_C = maintenance overhead control index parameter,
TMAC = total maintenance administration cost.
TMC = Total machine cost

2.4.5 Scheduling Work
This index is useful in scheduling work (Dhillon, 1991) and is expressed as follows:

$$WS = \frac{PJCED}{TPJ} \quad (2.6)$$

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 05 May 2024, pp: 1027-1045 www.ijaem.net ISSN: 2395-5252

where
WS = scheduling work index parameter,
PJCED = total number of planned jobs completed by established due dates,
TPJ = total number of planned jobs.

2.4.6 Material Control

This index is useful in material control area (Dhillon, 1991) and is defined by

$$MC_a = \frac{TPJAM}{TPJ} \quad (2.7)$$

where
MC_a = material control index parameter,
TPJAM = total number of planned jobs awaiting material.
TPJ = total number of planned jobs.

2.4.7 Maintenance Effectiveness

This index can be used to measure maintenance effectiveness (Jordan, 1990) and is defined by

$$M_{eff} = \frac{MHEUJ}{TMMH} \quad (2.8)$$

where
M_{eff} = maintenance effectiveness index parameter,
MHEUJ = man-hours of emergency and unscheduled jobs,
TMMH = total maintenance man-hours worked.

2.4.8 Maintenance Effectiveness

This index can also be used to measure maintenance effectiveness (Dhillon, 1991) and is expressed by

$$MM_{eff} = \frac{DTCB}{TDT} \quad (2.9)$$

where
MM_{eff}= maintenance effectiveness index parameter,
DTCB=downtime caused by breakdowns,
TDT=total downtime.

2.4.9 Inspection Effectiveness

This is an important index used to measure inspection effectiveness (Jordan, 1990)and is defined by

$$I_{eff} = \frac{NJI}{TIC} \quad (2.10)$$

where
I_{eff} = inspection effectiveness index parameter,
NJI =number of jobs resulting from inspections,
TIC =total number of inspections completed.

2.4.10 Material and Labour Costs

This index relates material and labour costs (Dhillon, 1991)and is expressed by

$$ML_c = \frac{TMLC}{TMMC} \quad (2.11)$$

where
ML_c = material and labour costs index parameter,
TMLC =total maintenance labour cost,
TMMC =total maintenance materials cost.

2.4.11 Maintenance Cost and Manufacturing Cost

This index ratio relates maintenance cost to manufacturing cost (Niebel, 1994);

$$MM_{cc} = \frac{TMC}{TMFC} \quad (2.12)$$

Where; MM_{cc} = maintenance cost to manufacturing cost index parameter,
TMFC =total manufacturing cost.
TMC = total maintenance cost

2.4.12 Maintenance Cost and Man-hours

This index relates maintenance cost to man-hours worked (Dhillon, 1991) and is expressed by

$$MH_{mc} = \frac{TMC}{TNMW} \quad (2.13)$$

Where;MH_{mc}= maintenance cost to man-hours index parameter,
TNMW =total number of man-hours worked.
TMC = total maintenance cost

2.4.13 Cost Reductions

This is a useful index to monitor progress in cost reduction efforts (Westerkamp, 1997) and is defined by

$$PC_r = \frac{PMMSJ}{MCPP} \quad (2.14)$$

Where; PC_r = Cost reductionsindex parameter,
PMMSJ =percentage of maintenance man-hours spent on scheduled jobs,
MCPP =maintenance cost per unit of production.

2.4.14 Equipment Availability

This index expresses maintenance availability (Niebel, 1994)

$$EA = \frac{H_{ea}}{TH_{rp}} EA \quad (2.15)$$

Where; EA =equipment availability,
H_{ea} =number of hours each unit of equipment is available to run at capacity,
TH_{rp} =total number of hours during the reporting period.

2.4.15 Maintenance Time Control Index

For overall time planning consideration methods such as Program Evaluation and Review Technique

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 05 May 2024, pp: 1027-1045 www.ijaem.net ISSN: 2395-5252

(PERT) to assure effective overall monitoring and control of time uncertainties (liu, 2002)

$$p_t = \frac{\alpha_{op} + 4(\alpha_{mt}) + \alpha_{pt}}{6}$$

α_{op} = optimistic time required for completion of maintenance service,
α_{pt} = pessimistic time required for completion of maintenance service,
α_{mt} = most likely time required for completion

These models were designed so that an acceptable situation could be sought by changing the decision variables. Once this had been found, slight adjustments could be made to test the robustness of the proposed solution

III. METHODOLOGY

In the selected maintenance workshop, the maintenance crew consisting of the formal and informal trained staffs formed the target. They embodied a craft mix dedicated to the maintenance of a ground nut oil production firm in Northern part of Nigeria. The maintenance group is responsible for the repairs of all electrical services, corrective mechanical faults and overhauls. The firm is staffed by different types of workers and for the purposes of this study are grouped into three distinct occupational specialities, Engineers, Technicians and craftsmen. Maintenance crew was monitored for the required service time(s), as they provided relevant data which include size of the crew, operational statistics and cost reports. Maintenance faults occur randomly however, there is a time associated with each task (amount of time it takes to complete the action) and these time definitions are subjective. Therefore, the poisson's distribution for random variable was used to determine the faults arrival distribution.

$$P_n = \frac{AR^n e^{-AR}}{n!} \qquad 3.1$$

Where P_n= probability distribution of the Poisson random variable for arrival rate (AR)
n =number of faults arriving daily 0,1,2, 3,....∞
AR= Arrival rate AR> 0

3.1 Manpower Service time

The concept of service time was also introduced as a target time for the manpower crew to respond to a schedule fault in order to obtain limits of backlog. Different skilled maintenance personnel work at different rate depending on their level of training (skills) on the jobs. Therefore, varying service time is obtained as along different service crews. The index to account for these variations is expressed in equation 3.2 (Dhillon, 1991) (2.16)

$$W_i = \frac{MT}{TST} \times y \qquad 3.2$$

Where;
W_i= ratio of the maintenance service time for manpower skill i
TST = total time scheduled for maintenance service (hours)
MT = tasks time to accomplished maintenance task (hours)
y = utilisation factor

The utilisation factor is to account for rework and non-productive times of the varying skills since a multiskilled team will not always be 100% efficient

3.2 Method of Specifying Costs

Total Maintenance Cost was determined making use of the fact that it is equal to the cost of using maintenancecrews and the cost of waiting of jobs.

$$TMC_{(cs)} = CUMC + CWJ \qquad 3.3$$

CUMC = Cs (Ci)

Where Cs = Crew size
Ci= cost of utilising one member of a crew per day
CUMC = cost of utilising maintenance crew(s)
CWJ= Average cost of job waiting for maintenance

The consequence of service cost rate is critical and will determine the schedule for the final craft skill to engage in the final choice for a maintenance service, since the wrong choice will cost the company more. Equation (3.4) was applied to determine the final maintenance crew

$$w_i \times TMC$$

3.3 Sensitivity Analysis

This is used to determine how different values of the manpower skills in different service time costs will impact a particular maintenance unit under a given set of controlled conditions. This will help predict the outcome of decisions if situation turns out to be different compared to the key prediction The planning model for the varying manpower skills in different service time cost is;

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 05 May 2024, pp: 1027-1045 www.ijaem.net ISSN: 2395-5252

$$Z = \frac{(w \times TMc)_i}{(w \times TMc)_T}$$

subject to:

$Z = P$ = optimality

$Z < P$ = service rate less than required workload

$Z > P$ = service rate more than required workload

$$0 \leq P \leq 1$$

$$Z \leq P \leq 1$$

Where; Z represent the parameter ratio for maintenance manpower plan.

$w \times Mc_i =$ Service time costs for the varying skills engaged within the crew

$w \times Mc_t =$ Total net value of the service time costs for the maintenance crew

3.4 Algorithm

The logical arrangement to show steps by steps on how to determine each of the parameters used to compare the maintenance plans to accompany the desired objectives in formulating the problem

Algorithm.

Step1: input all parameters,

Step 2: set up the maintenance tasks to be performed

Step3: for each of the equipment, generate the task distribution

Step4: set up the manpower requirements

Step5: evaluate the maintenance service time

Step6: specify the various values of active work time

Step7: compute the corresponding values of costs

Step 8: compute the product of each manpowertime and costs

Step 9: compute the varying sums of step 8

Step10 obtain the ratio of varying sums of step 8 and 9

Step 11: evaluate the ratios for the fitness of the workers for the task

Step12: Obtain performance index

Step 13 Select the best alternative

Step 14: print result

Step 15: stop

3.5 Software Development

A software tool has been developed using Visual Basic programme 6.0 that implements automatically the algorithm described in this section.

3.5.1 Software Output Samples

The process of generation of random numbers for fault arrival was conducted and transformed into the appropriate random variables for the service time.

Figure 3.2, Figure 3.3 and Figure 3.4 are the input dialogue box for keying the input parameters.

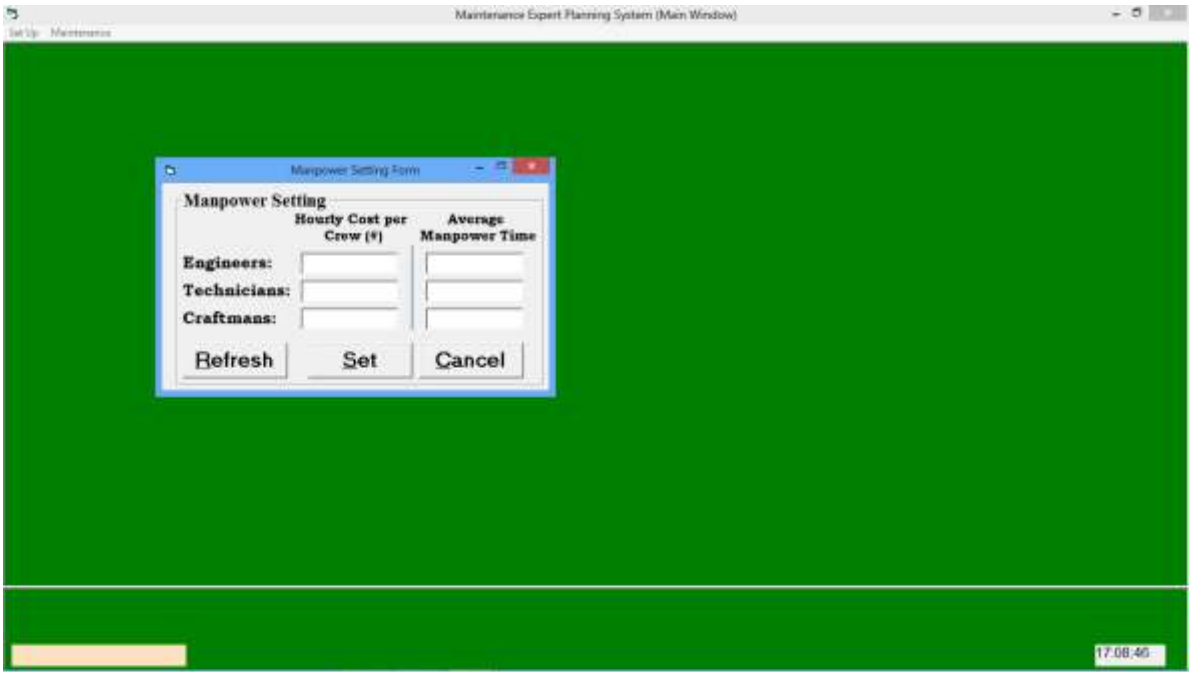


Figure 3.2 MaintenanceCrew input data column

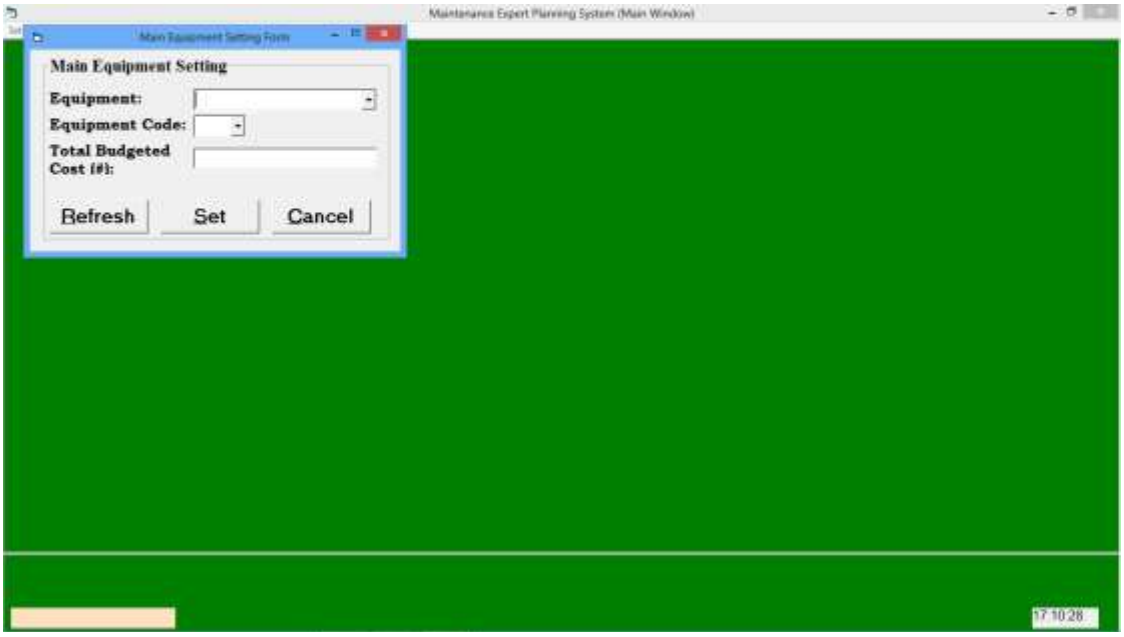


Figure 3.3: Maintenance equipment data column

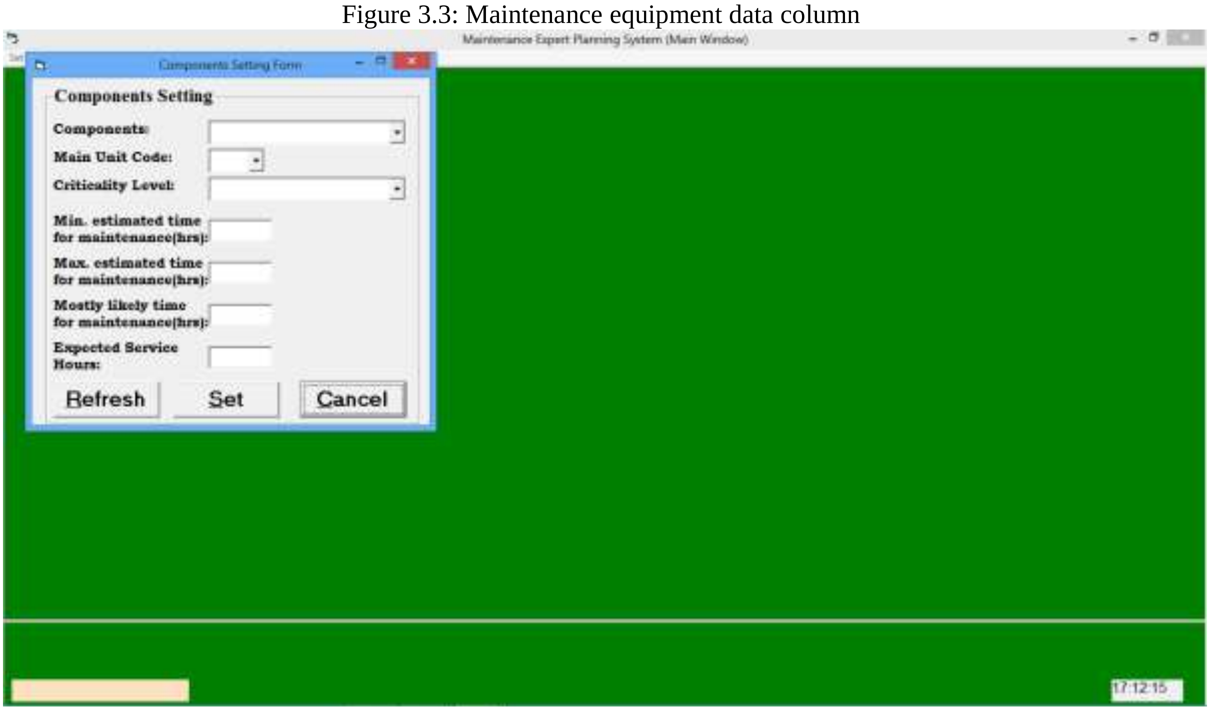


Figure 3.4 Input unit to estimate varying maintenance time

In carrying out the analysis of the imputed data, the application of the review technique for programme evaluation which calls for three-timeestimates was used to create a balance for the servicing times obtained from questionnaires.

3.5.2 Arrivals of Maintenance Jobs

The nature of the work is temporary in that it is envisaged that all cases will occur within the next eight weeks after that the routine work will be largely handled by computer. Six machines are largely been used for operation with a fleet of equipment within each unit. An eight weeks period of maintenance call in activity was observed and reviewed. The incidence of machine parts fault was recorded by a one-hour interval for each day during an eight-hour operation. Data obtained for eight weeks suggested no apparent trend was present in the number of faults arriving daily. However, when call in faults were aggregated by the hour it was obvious that the arrival rate of faults could not be assumed stationary. Therefore, a frequency of arrival rate of jobs was constructed for each of the eight intervals

Table 3.1 Average arrival of faults per machine/day

Times(hrs) / Equipment	1	2	3	4	5	6	7	8	Cumulative jobs on each machine/day	hours available for service/ day
Groundnut toaster	1		1		1		1	1	5	2.26
Crusher		1	1	1		1			4	3
Oil Filter	1	1	1	1			1		5	3
Boiler			1	1	1	1			4	2
Pumping machine		1	1	1					3	1
Stripping tank						1	1		2	2
Cumulative number of faults/hours	2	3	5	4	3	3	2	1		

Source; Survey (2014)

Although the fault arrival rate was described by a random process for the purposes of computer analysis, faults arrival was assumed to be non-homogeneous configuration (That is, call in jobs would be randomly distributed across each interval to reflect a singular mean arrival)

Table 3.2 Equipment Codes and Penalty costs

Equipment	Codes for Units	Penalty costs for excess Down time Per hour (₦)
Groundnut toaster	A	400
Crusher	B	300
Oil Filter	C	250
Boiler	D	500
Pumping machine	E	300

Stripping tank	F	200

Source: Survey (2015)
(NB** these cost were based on the estimates from the past records)

3.5.3 Utilisation of Crew Size

The varying specialities of Engineers, Technicians and Craftsmen was further subdivided into varying years of experience to mark the varying skills. The engineers were assumed to possess a tertiary degree as an added qualification over technicians and craftsmen. However, it is assumed that all the workers can carry out maintenance jobs in all the units and costs of training changes bi-annually. The costs of the maintenance crew is specified in Table 3.3 and it the intuitive approach adopted was that it is increasing with the years of experience for each speciality

Table 3.3 Costs of utilising maintenance Crew

Maintenance crew	Manpower Skills (years)	daily remuneration (₦)
Engineers	1-2	250
	3-4	700
	5-6	1200
	7-8	1500
	9-10	3500
Technicians	1-2	200
	3-4	500
	5-6	1100
	7-8	1400
	9-10	2800
Craftsmen	1-2	150
	3-4	350
	5-6	1000
	7-8	1200
	9-10	2400

Table 3.4.1 Expected Craft service times

Equipment	Craft Service times (hrs)				
	1-2years	3-4years	5-6years	7-8years	10years
G/nut toaster	12.00	11.23	8.89	6.99	4.92
Crusher	7.00	5.61	4.44	3.49	2.46
Oil Filter	6.50	5.26	4.17	3.28	2.31
Boiler	5.40	2.81	2.22	1.75	1.23
Pumping machine	3.00	2.81	2.22	1.75	1.23
Stripping tank	4.90	4.21	3.33	2.62	1.85

Source: Survey Data(2014)

Table 3.4.2 Expected Technician service times

Equipment	Technician Service times				
	1-2years	3-4years	5-6years	7-8years	10years
G/nut toaster	5.00	5.00	3.00	7.00	0
Crusher	5.00	2.00	3.78	3.0	2.28
Oil Filter	4.69	3.75.	3.26	3.00	2.14
Boiler	2.50	2.00	1.74	1.60	1.14
Pumping machine	2.50	2.00	1.74	1.60	1.14
Stripping tank	3.75	3.00	2.60	2.40	1.71

Source: Survey Data(2014)

Table 3.4.3 Expected Engineers service times

Equipment	Engineers Service times (hrs)				
	1-2years	3-4years	5-6years	7-8years	10years
G/nut toaster	6	7	5	8	0
Crusher	5.33	4.71	3.48	3.2	2.28
Oil Filter	5	4.41	3.26	3	2.14
Boiler	2.67	2.35	1.74	1.6	1.14
Pumping machine	2.67	2.35	1.74	1.6	1.14
Stripping tank	4	3.5	2.61	2.4	1.71

Source: Survey Data (2014)

IV. RESULTS AND DISCUSSION

Varieties of service times were collected and the analysis of variance provides the basis for the F-ratios concerning variations between the maintenance crews for varying skills due to the fluctuations of sampling and hence serves as the basis for significance test. The F- ratios are compared with their corresponding table values for given degrees of freedom at specified level of significance and if it is found that the calculated F-ratio concerning variation between the service times (columns) specified for the varying years (skills) is equal to or greater than its table value then the differences among skills (columns) is considered significant. Similarly, the F-ratio concerning variation between crew specialities (rows) was interpreted.The service times obtained for each speciality on the Ground nut unit is obtained as expressed in tables 4.1

Table 4.1 Maintenance Crew Service time

Time of service by crew speciality		Engr.(hrs)	Tech.(hrs)	Craft. (hrs)
Skills(yrs.)	1-2	6	5	5
	3-4	7	5	4
	5-6	3	3	3
	7-8	8	7	4
	9-10	0	0	0

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 05 May 2024, pp: 1027-1045 www.ijaem.net ISSN: 2395-5252

From ANOVA table(Appendix A) the differences concerning the varying speciality on this unit was insignificant at 5% level as the calculated F-ratio of **4** is less than the table value of 5.14, but the variety differences concerning the skills are significant as the calculated F-ratio of **6** is more than its table value of 4.76

Tables 4.2 Excess Down time for the Ground nut Toaster

Unit	Maximum time specified for service	Crew size	1-2yrs	3-4yrs	5-6yrs	7-8yrs	9-10yrs above
			Time (hrs)	Time (hrs)	Time (hrs)	Time (hrs)	Time (hrs)
G/nut toaster	1.24	Engineer	4.76	5.76	1.76	6.76	0
	1.24	Technicians	3.76	3.76	1.76	5.76	0
	1.24	Craftsman	3.76	2.76	1.76	2.76	0

4.3 Net values of service time costs (cost /time).

Unit	Crew size cluster	1-2yrs	3-4yrs	5-6yrs	7-8yrs	9-10yrs
		Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)
Groundnut Unit	Engineer	1190	4032	2112	10,140	0
	Technicians	752	1880	1936	8064	0
	Craftsman	564	966	1760	3313	0

Thus, recalling the values of the costs specified for the varying skills in table 3.3 the line graph of the effective maintenance crew was obtained based on the costs of utilising maintenance skills and costs of waiting jobs.

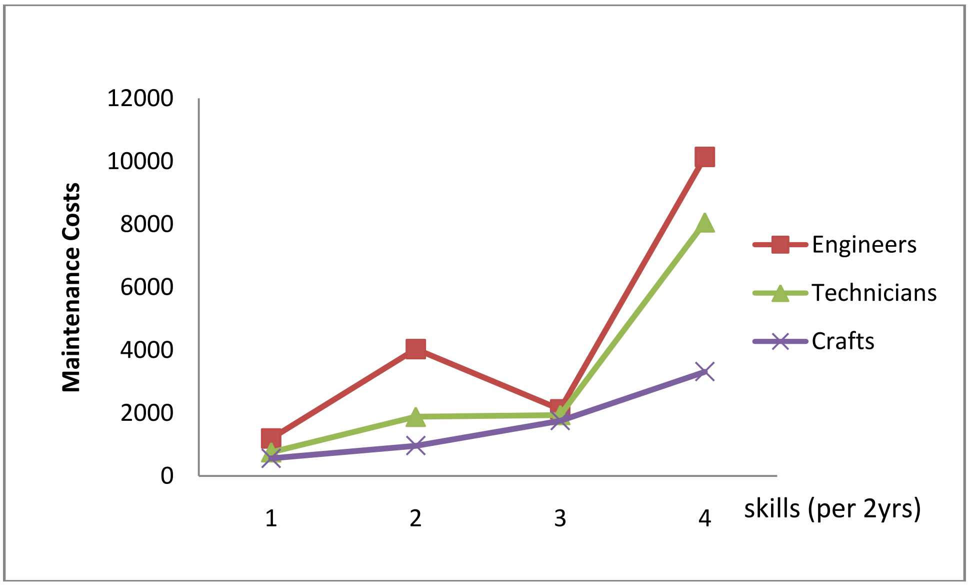


Figure 4.1 Effective maintenance Crew size on the groundnut toaster

For the allocation of varying crew skills on the maintenance jobs of Groundnut toasting unit, the workers on point 3 possessing 5-6 years' experience represent the region of the distribution of skills that leads to the acceptance of the optimum costs since the line graphs is closely converging at this point, with an approximate maintenance cost equilibrium of ₦1900 daily

The behaviour of each service crew is essentially different on each faulty state, say-

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 05 May 2024, pp: 1027-1045 www.ijaem.net ISSN: 2395-5252

different time spent by different skills. A total of five mixed replications was conducted for the three mixes of skills and the values of the major results obtained from the case study are presented for each machine unit

An analysis from the values of the varying work cycle time for the crews and the varying skills time for the completion of each task was compared with the maximum time specified to repair the faults on each machine unit at F- ratio of 5% significance and the values of excess down time was obtained

Table 4.4 Maintenance Crew Service time (Crusher)

Time of service by crew speciality		Engr.(hrs)	Tech.(hrs)	Craft. (hrs)
Skills(yrs)	1-2	5.33	5	7
	3-4	4.71	2	6.61
	5-6	3.48	3.78	4.44
	7-8	3.2	3	3.49
	9-10	2.28	2.28	2.46

Table 4.5 Excess Down time for the Crushing Unit

Unit	Maximum time specified for service	Crew size	1-2yrs	3-4yrs	5-6yrs	7-8yrs	9-10yrs above
			Time (hrs)	Time (hrs)	Time (hrs)	Time (hrs)	Time (hrs)
G/nut toaster	6	Engineer	2.33	1.71	0.48	0.2	0.0
	6	Technicians	2.0	1.41	0.26	0.0	0.0
	6	Craftsman	4.0	2.61	0.44	0.0	0.0

Table 4.6 Net values of service time costs (cost /time)

Unit	Crew size cluster	1-2yrs	3-4yrs	5-6yrs	7-8yrs	9-10yrs
		Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)
Crusher	Engineer	967.5	1287	1500	2700	3800
	Technicians	834	1300	1300	3000	3100
	Craftsman	1500	1269	1012	1800	2800

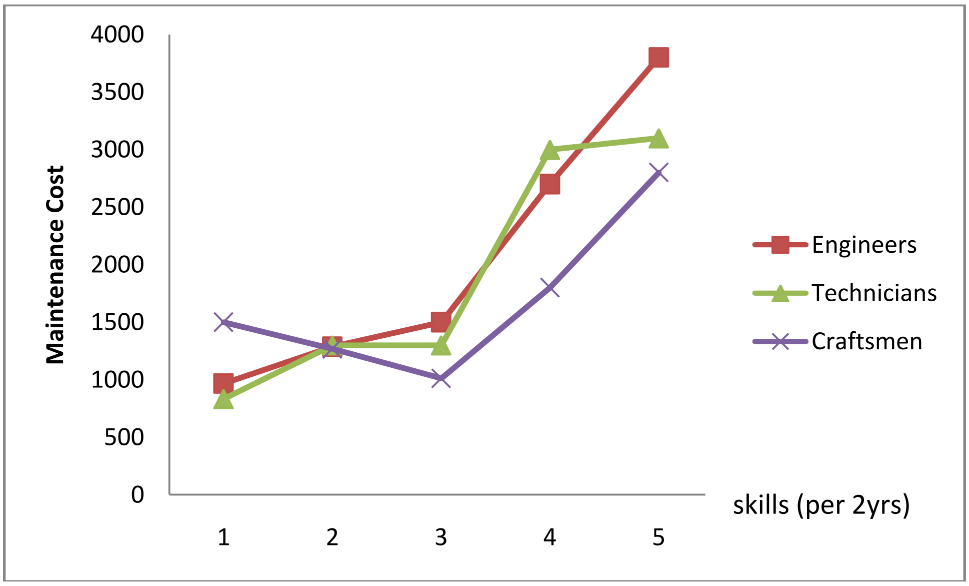


Figure 4.2- Effective Maintenance Crew size on the Crusher

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 05 May 2024, pp: 1027-1045 www.ijaem.net ISSN: 2395-5252

For the allocation of varying crew skills on the maintenance jobs of Groundnut crusher, the workers on point 2 possessing 3-4 years' experience would be required for the varying skills to operate since the graph is closely converging at this point, with an approximate maintenance cost equilibrium of ₦1300 daily

Table 4.7 Excess Down time for the Oil Filtration Unit

Unit	**Maximum time specified for service**	**Crew size**	**1-2yrs**	**3-4yrs**	**5-6yrs**	**7-8yrs**	**9-10yrs above**
			Time (hrs)	**Time (hrs)**	**Time (hrs)**	**Time (hrs)**	**Time (hrs)**
Oil Filter	**3**	**Engineer**	**2**	**1.41**	**0.26**	**0.0**	**0.0**
	3	**Technicians**	**1.69**	**0.75**	**0.25**	**0.0**	**0.0**
	3	**Craftsman**	**3.5**	**2.26**	**1.17**	**0.28**	**0.0**

Table 4.8 Net values of service time costs (cost /time)

Unit	Crew size cluster	1-2yrs	3-4yrs	5-6yrs	7-8yrs	9-10yrs
		Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)
Oil Filter	Engineer	650	1100	1600	2800	3900
	Technicians	600	900	1400	2400	3200
	Craftsman	550	700	1200	1900	2500

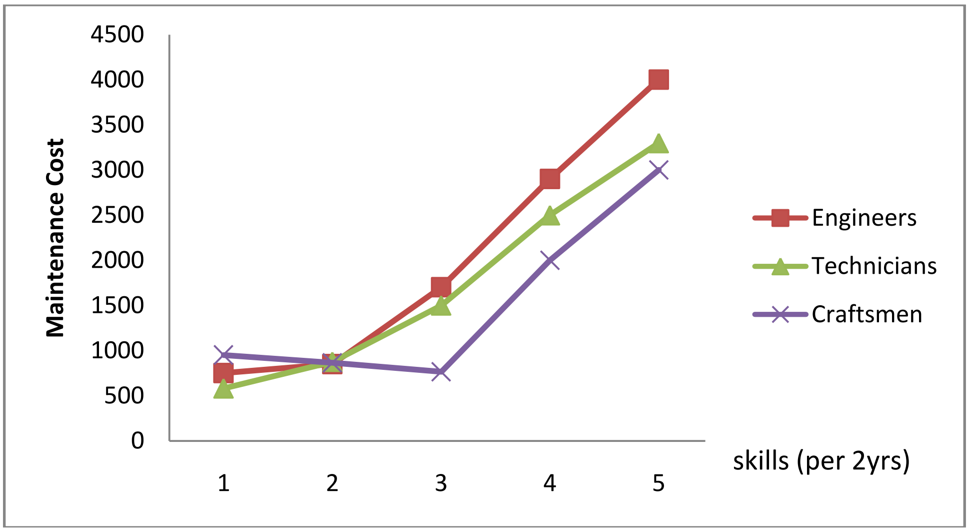


Figure 4.3 Effective maintenance Crew cost for the Filtration Unit

For the allocation of varying crew skills on the maintenance jobs of Filtration unit, the workers on point 2 possessing 3-4 years' experience would be required for the varying skills to operate since the graph is closely converging at this point, with an approximate maintenance cost of ₦900 daily

Table4.9 Excess Down time for the Boiler Unit

Unit	Maximum time specified for service	Crew size	1-2yrs	3-4yrs	5-6yrs	7-8yrs	9-10yrs above
			Time (hrs)	Time (hrs)	Time (hrs)	Time (hrs)	Time (hrs)
Boiler	2	Engineer	0.67	0.35	0.0	0.0	0.0

	2	Technicians	0.5	0.0	0.0	0.0	0.0
	2	Craftsman	3.4	0.81	1.22	0.75	0.23

.

Table 4.10 Net values of service time costs (cost /time)

Unit	Crew size cluster	1-2yrs	3-4yrs	5-6yrs	7-8yrs	9-10yrs
		Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)
Boiler	Engineer	800	1287	612	2700	3800
	Technicians	850	1245	1050	820	2300
	Craftsman	975	978	1236	1800	2800

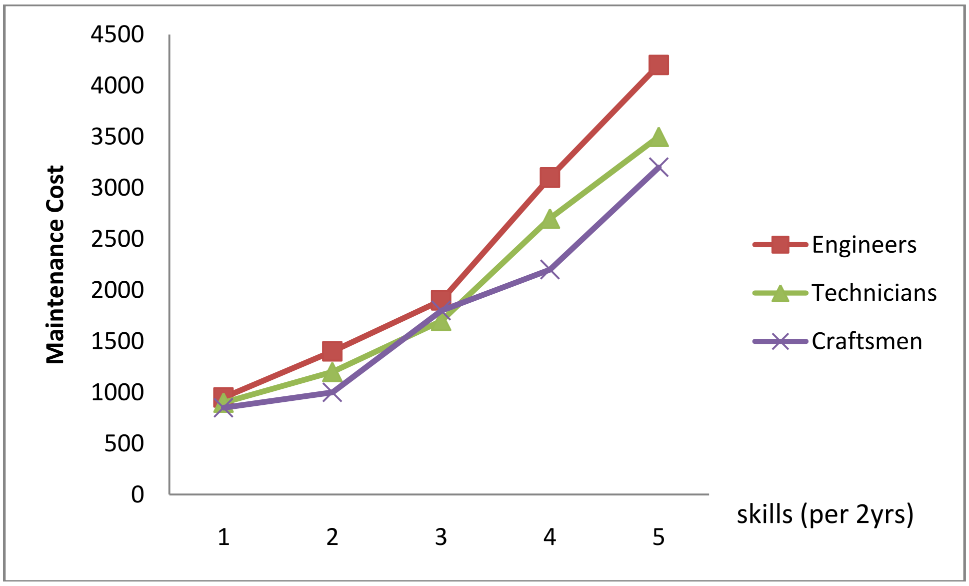


Figure 4.4 Effective maintenance Crew cost for the Boiler unit

For the allocation of varying crew skills on the maintenance jobs of Boiler unit, the workers on point 1 possessing 1-2 years' experience would be required for the varying skills to operate since the graph is closely converging at this point, with an approximate maintenance cost equilibrium of ₦850 daily

Table4.11 Excess Down time for the Pumping Unit

Unit	Maximum time specified for service	Crew size	1-2yrs	3-4yrs	5-6yrs	7-8yrs	9-10yrs above
			Time (hrs)	Time (hrs)	Time (hrs)	Time (hrs)	Time (hrs)
Pumping Machine	1	Engineer	1.67	1.35	0.74	0.0	0.0
	1	Technicians	1.5	1	0.75	0.6	0.0
	1	Craftsman	2	0.81	1.22	0.75	0.0

Table 4.12 Net values of service time costs (cost /time)

Unit	Crew size cluster	1-2yrs	3-4yrs	5-6yrs	7-8yrs	9-10yrs
		Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)	Time costs (₦ hrs)
Pumping	Engineer	950	1400	1900	3100	4200

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 05 May 2024, pp: 1027-1045 www.ijaem.net ISSN: 2395-5252

machine	Technicians	900	1200	1700	2700	3500
	Craftsman	850	1000	1800	2200	3200

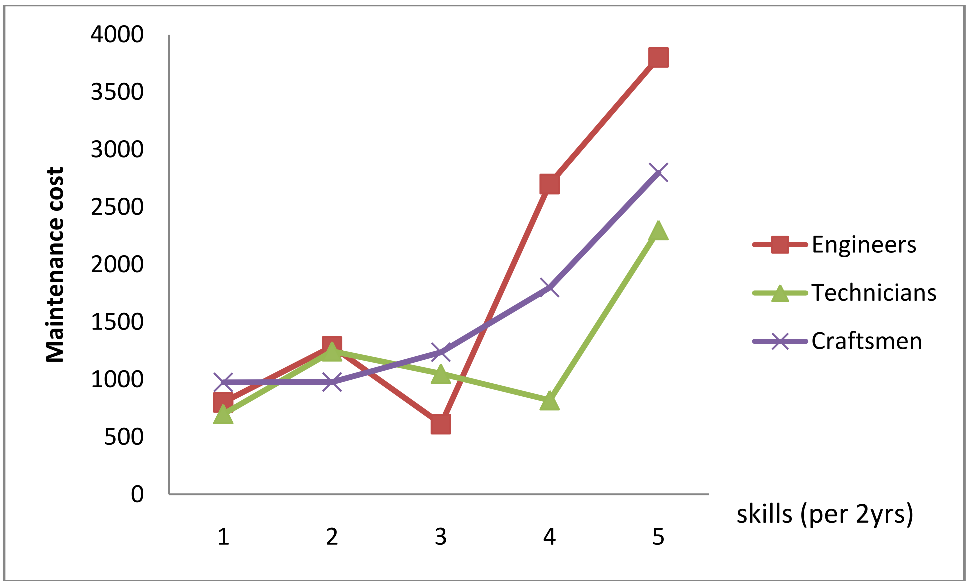


Figure 4.5 Effective maintenance Crew cost for the Pumping Unit

The differences concerning the varying speciality on this unit was insignificant at 5% level as the calculated F-ratiois less than the table value of 5.14, but the variety differences concerning the skills are also insignificant as the calculated F-ratio of less than its table value of 4.76. therefore, Allocation of varying crew skills on the maintenance jobs of pumping unit could not be obtained since there was no converging point for the three skills.

The resulting balance in terms of excess job waiting service ratios and maintenance crew costs per skill was represented fig 4.6 The goal is to match the current maintenance manpower costs with the penalty costs of waiting jobs

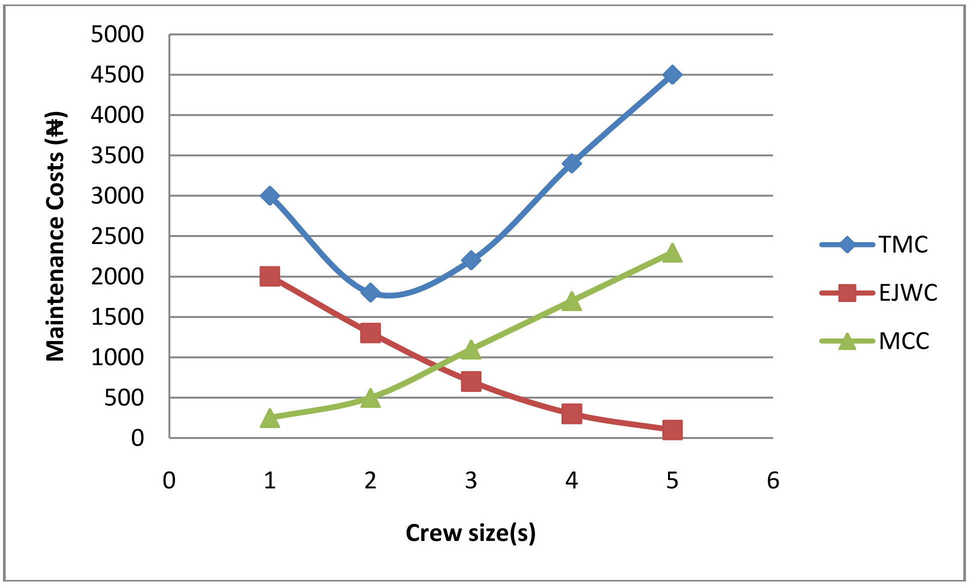


Fig 4.6 Determination of Most effective crew size

TMC= total maintenance cost
MCC= average cost of utilising crews
EJWC= excess job wait cost

The trend of the maintenance plan for crews is the graph of Figure 4.6 the differences concerning the varying speciality on this unit was significant at 5% level as the calculated F-ratio of **5.26** is greater than the table value of 5.14, but the variety differences concerning the skills are significant as the calculated F-ratio of **3.19** is less its table value of 4.76. Therefore as the number of crew skill increases (years of Service) the cost curve of waiting jobs tends to reduce geometrically while the average cost of maintenance for utilising crew increased linearly. The total maintenance cost initially reduces geometrically until it reaches a point then it changed its course and starts to increase thereafter forming a curve with minimum value. Hence the corresponding crew size at that approximate minimum value of TMC is the most effective crew size in this case it is two corresponding to skills within the range of 2-3years exposure on jobs

V. CONCLUSION

The overall trend results indicated that, there was a significance along the varying skills at 5% for the service times on the equipment(Bi-annually). Comparative evaluation of models' graph showed that the maintenance crew best value stage from 2 to 3 skills while the average values of the work years ranged between 3-6years. The implication of this results is that workers in a maintenance crew can best be allocated to maintenance jobs regardless of their trainings when they possessbetween three to six years since the costs values of graphsconverge within these points. The ultimate success of maintenance firms greatly relies on experience, for persons who have had practical experience performing maintenance jobs. The model provides maintenance manager with useful information to make a trade-off between crews during maintenance operation. From the research findings, the first specific objective was met with the generation of comprehensive functional requirement to formulate an equation model to estimate the crew size required for varying job complexities. The second specific objective was met by development of a computer software package for quick implementation, algorithm was also formulated which serve as a guide for coding the system. The third specific objective was also met by testing the model with data in order to validate the efficiency of this model in assigning a multi skilled crew on maintenance jobs.

REFERENCE

[1]. Aderoba A.A. (1997), A generalised cost estimation model for job shops, International journal of production economics Vol.53, pp257-263.
[2]. Alsyouf I (2009). "Maintenance Practices in Swedish Industries: Survey Results," International Journal of Production Economics, Vol. 121, No. 1,, pp. 212-223.
[3]. Ashayeri .A, Teelen .A and Selen .W,(2006) "A Production and Maintenance Planning Model for the Process Industry," International Journal of Production Research, Vol. 34, No. 12, pp. 3311-3326.
[4]. Bechtold, Stephen E.(1988), Implicit Optimal and Heuristic Labour Staffing in a Multiobjective, Multilocation Environment, Decision Sciences, Vol. 19, No. 2,
[5]. Belky E.G. (2006) operations Research Introduction McGraw- hill.U.S.A.
[6]. Brusco, M. and Johns, T.(1996) Staffing a Multi-skilled workforce with varying levels of productivity: An analysis of cross-training policies. Proc., 27th Annual Meeting of the Decision SciencesInstitute, Orlando, FL.
[7]. Burleson, Rebecca C (1997), An Analysis of Multiskilled Labour Strategies in Construction, Dissertation, The University of Texas
[8]. Business Roundtable BRT (1997). Confronting the Skilled Construction Workforce Shortage. Washington DC.,.
[9]. Carley, Lynn Ann. (1999) Worker's Attitudes Toward and Experiences with Multiskilling. M.S. Thesis, University of Texas at Austin, Austin, TX.
[10]. Chase, R.B. and Aquilano, N.J. (1981), Production and Operations Research: A Life Cycle
[11]. Approach, Richard D. Irwin, Homewood, Illinois,.
[12]. Campbell Gerard, (1999) Cross-Utilization of Workers Whose Capabilities Differ, Management Science p 722-732.
[13]. DuffuaaS, Raouf A, and Campbell .J, (2009) "Planning and Control of Maintenance Systems: Modeling and Analy-sis," John Wiley & Sons, New York.

[14]. Dhillon, B.S., (1991) Engineering Management, Technomic Publishing Co., Lancaster,
[15]. Pennsylvania,
[16]. Dillon J.E. and Kontogiorgis, S. (1999). US Airways Optimizes the Scheduling of Reserve Flight Crews. Interfaces, Vol. 29, pp. 123–131.
[17]. Goldberg, J.B., (2004). Operations Research Models for the Deployment of Emergency Services Vehicles. EMS Management Journal. 1(1), 20-39.
[18]. Gomar, J. (1999) Assignment and Allocation Optimization of a Partially Multiskilled Workforce, M.S. Thesis, University of Texas at Austin
[19]. Haase, K., Latteier, J. and Schirmer, A. (1999). Course Planning at Lufthansa Technical Training: Constructing More Profitable Schedules. Interfaces, Vol. 29, pp.95–109.
[20]. Hegazy, Tarek. (1999)Optimization of Resource Allocation and Leveling using Genetic Algorithms, ASCE Journal of Construction Engineering and Management, Vol. 125, No. 3
[21]. Jordan, J.K., (1990)Maintenance Management, American Water Works Association, Denver,Colorado
[22]. Jordan, W.C., Inman, R.R., Blumenfeld, D.E., (2004). Chained Cross-Training of workers for robust performance. IIE Transactions, 36(10), 953 – 967
[23]. Kareem, B., and Aderoba, A.A., (2004). “Application of Linear Programming Model to Manpower Planning”, Proceedings of the 2004 NationalInternational Journal of The Computer, the Internet and Management Vol.16. N.o.2 (May-August, 2008) pp 26 - 34 33
[24]. Kareem, B., (2005). “A Review of Strategies for Manpower Planning in a Depressed Economy”, J. of Sci. and Tech. Res., 4: pp. 33-36.
[25]. Kinnie, N and Staughton, R (1994) The Problem of Implementing Manufacturing Strategy. In New Wave Manufacturing Strategies, J Storey (eds)..PCP Ltd, London.
[26]. Kirwan, B and Ainsworth, L (1992) A guide to task analysis. Taylor and Francis,Basingstoke.
[27]. Koole, G., Pot, A., Bhulai, S., (2008). A Simple Staffing Method for Multi-skill Call Centers. Manufacturing & Service Operations Management. 10 (3), 421-428.
[28]. Larsen, A., Madsen, O.B.G., Solomon M.M. (2007). Classification of Dynamic Vehicle Routing Systems. Operations Research, 38, 19-40.
[29]. Lardner, R (1999) Safety Implications of Self-Managed Teams. Report prepared for HSE and BP Oil Grangemouth Refinery Ltd.
[30]. Li, Shirong,(1995) New Approach for Optimization of Overall Construction Schedule,ASCE Journal of Construction Engineering and Management, Vol. 122, No. 1.
[31]. Liu, Z. (2002). Object Oriented Software Development with UML. International Institute of SoftwareEngineering, The United Nations University.
[32]. Niebel, B.W. (1994), Engineering Maintenance Management, Marcel Dekker, New York,
[33]. Ozaki, M (1996) Labour relations and work organization in industrialized countries.
[34]. International Labour Review. Jan-Feb, 135, 1, 37
[35]. Paz, N. M., and Leigh, W. (1994). Maintenance Scheduling: Issues, Results and Research Needs. International Journal of Operations & Production Management, 14 (8), 47-69.
[36]. Qi, X., Bard, J.F. and Yu, G. (2004). Class Sheduling for Pilot Training. Operations Research, Vol. 52, pp.148–162.
[37]. Rodriguez, A. (1998) Planning and Scheduling a Multiskilled Workforce. M.S. Thesis, University of Texas at Austin, Austin, TX.
[38]. Shewchuck, J. P. & Chang T. C. (2001). An Approach to Object Oriented Discrete Event Simulation of Manufacturing Systems. “Proceedings of Winter Simulation Conference” Pages (302-311) Phoenix Arizona,USA.
[39]. Stoneham, D. (1998), The Maintenance Management and Technology Handbook, Elsevier
[40]. Science, Oxford,.
[41]. Stanley, A. (1997) Benefits, Impediments, and Limitations to Multi-skilling in Construction. M.S. Thesis, University of Texas at Austin, Austin, TX.

[42]. Ugochukw C.O (2011) simulation model of multiple queuing parameters: Computer and information science journal.
[43]. Villalobos, J. (1997) Implementation of Multiskilling in the Construction Industry. M.S. Thesis, University of Texas at Austin, Austin, TX.,.
[44]. Wang, J. (2005). A Review of Operations Research in Workforce Planning and Potential Modelling of Military Training. DSTO Systems Science Laboratory. Retrieved, Nov. 17, 2014, from http://dspace.dsto.defence.gov.au/dspace/ handle/1947/3940.
[45]. Westerkamp, T.A., (1997) Maintenance Manager's Standard Manual, Prentice Hall, Paramus, New Jersey,.
[46]. Wright, M (1996) Business re-engineering and health and safety management: case studies.
[47]. 125/1996, HSE Books
[48]. Williamson, Robert M. (1994), Developing a Multi-Skill Maintenance Workforce, Strategic Work Systems Company, Mill Spring, NC,
[49]. Williamson, Robert M.,(1992) Optimum Performance Through Multi-Skill Maintenance, AIPE Facilities,
[50]. Yu, G. Pachon, J. and Thengvall, B. (2003). Optimization-based Integrated Manpower Management for Airlines. Operations Research in Space and Air, Kluwer Academic Publishers, Boston, pp. 407–434.