Development of an Activity-Based Job Costing Model on the Lathe Machine Using Maintainability Concept

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Abstract

Equipment maintainability is liable to change with change in technology, personnel skill and environment. Therefore, the cost of using such equipment for production activities will be affected depending on the level of skill of the maintenance personnel and technology involved. Hence, maintainability of production facility has a role to play in arriving at a realistic cost of operating it. However, activity-based costing that has been widely used for job costing has failed to include maintainability cost into the job costing procedure. The study developed an activity-based job costing model on lathe with the inclusion of maintainability scenario. First, activity-based costing method was used in estimating costs of job handling, machining, cutting tool, and material. Second, maintainability of the lathe machine was assessed based on its conceptual and hierarchical configuration. The lathe's components' maintenance accessibility at a

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predetermined level of personnel skill was routed and time of maintenance was estimated for every branch. The hourly maintainability cost was estimated utilizing failure probabilities of lathe's components based on exponential distribution. The total cost of job operated on lathe machine was estimated by summing up the maintainability cost with other activity-based cost elements. The result obtained when the model was tested with jobs of cast iron and mild steel material, using similar cutting tools, showed that there was no significant difference between traditional activity-based costing method and the new approach (less than 5%). However, it was evident that the cost difference may be substantial for a complex job that takes several hours to accomplish.

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1   Introduction

Machine tools industries in Nigeria are facing a lot of setback because of improper maintenance of these machine tools [1]. Traditionally in machine tools industry maintenance is carried out when it is very obvious that equipment would be broken down [2]. The delay in the maintenance in most cases is associated with inadequacy of funds [3]; however, maintenance can be carried out with the available meagre funds if a proper maintenance strategy is put in place [4]-[8]. Another problem that has not been taken care of is the problem of the maintainability of the machine tools itself, which many of the machine tools professionals in developing countries have neglected. The assessment of machine tools maintainability will allow machine tools engineers to know strategies and plans that are best in maintaining each component of machine tools before its actual failure; this will also assist in arriving at a justifiable estimate of cost of job on such a machine tool. Nowadays there a lot of developments in machine tools industries due to technological breakthrough. These gradual developments have made the cost of procuring H-tech machine tools (such as NC and CNC) different,

depending on the level of sensitivity required of them. Variation in sensitivity of machine tools will definitely affects maintainability of them. In many developing countries such as Nigeria, machine tool shops are going into taking loans from financial institution to buy automated machine tools such as Numerical control (NC) and Computer Aided Numerical control (CNC) without carrying out a critical investigation on its maintainability. Therefore there is need for a framework that will determine the maintainability of these machine tools so that appropriate decision will be taken in area of application of them to a particular operation. In this sense, the cost of operation of a particular job to be processed on them will be properly estimated for the customers. The customers also will have a choice based on their capability, in term of cost, on the type of machine tools they want the operators to use for their jobs based on the precision requirements. The exiting models and software on machine tools maintenance are deficient in areas of introduction of variability in sensitivity of machine tools, precision of finished jobs in relation to the maintainability of machine tools [9]-[14]. Also, there is no evidence of inclusion of variability in maintainability of machine tools in determining the cost of producing an item on the machine [15]-[20]. This study provides a model that incorporates the deficiencies of the past, relevant works in literature.

2   Method of Approach

Characterization of lathe machine was done which accounted for how much effort was needed to carryout preventive and breakdown maintenance activities on its identified components. The motion and time study analysis was carried out on job and activities involved in the maintenance of lathe machine tools. Various factors that determined the costing of job on lathe machine were identified. These factors were Job handling cost, maintenance cost, machining cost, tool cost, and cost of raw material per job. Theoretical relationships among the identified factors including maintainability cost were mathematically formulated.

3   Mathematical Model Formulation

The total cost of machining on a Lathe machine at any given time includes the following: job handling cost; maintainability cost; machining cost; tool cost; and cost of raw material per job. Total cost of machining is the sum of these cost elements. Job handling cost refers to all cost incurred that includes; loading cost, unloading cost, tool reset cost and set up cost per unit time. Loading cost is the cost that is involved in fastening the material to be machined on the jaw per time, setting the tail stock, adjusting the centre, removing and setting the drill, and any other accessories required for the job. Unloading cost implies any financial implication at dismantling the job after completion of machining process per unit time. Tool reset cost this refers to the cost incurred at resetting tools per unit time. Set up cost per unit time refers to initial cost incurred in mounting the job on the lathe machine.

Let,

$$\text{Job handling Cost} = C_h T_h \tag{1}$$

where,

C_h = cost of handling per unit time

T_h = Total handling time

Maintainability cost per unit time refers to all costs incurred to ensure timely operational performance of the lathe machine. This included; cost of repair, cost of dismantling and cost of assemblage per unit time

Let,

$C_m t_m$ – Maintainability cost

C_m – maintenance cost

t_m – time to maintain

t^r – time to repair

t^d – time to dismantle

t^a – time to assemble

Taking into consideration the hierarchical arrangement of the lathe machine's components [7] (Fig. 1) as analysed as follows
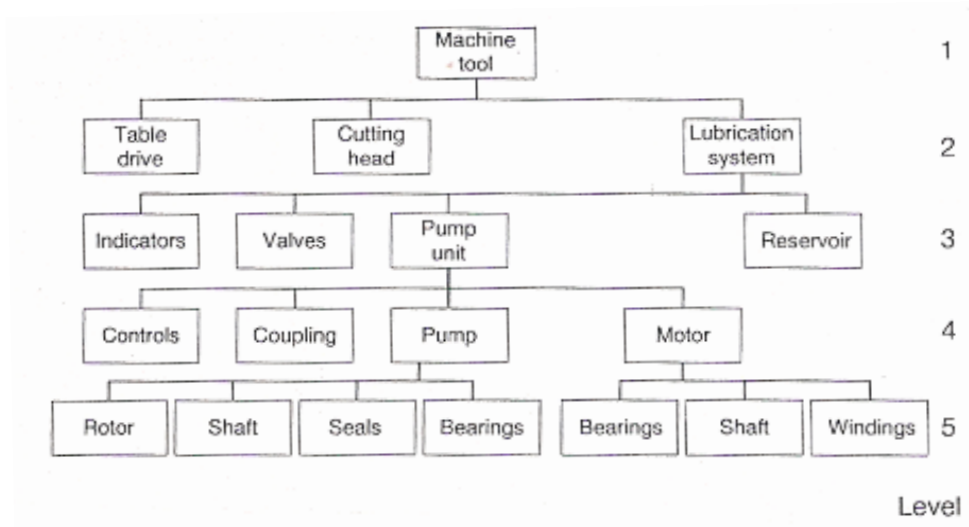

Figure 1.   Assembly hierarchy for a lathe machine tool

Stage 1-2

$$T_{mi} = \sum_{i=1}^{n} (t_i^r + t_i^d + t_i^a) \tag{2}$$

where $i = 1, 2, \ldots, n$, $i =$ counter for components

Stage 2-3

$$T_{mij} = \sum_{i=1}^{n} \sum_{j=1}^{n} (t_{ij}^r + t_{ij}^d + t_{ij}^a) \tag{3}$$

Stage 3-4

$$T_{mijk} = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} (t_{ijk}^r + t_{ijk}^d + t_{ijk}^a) \tag{4}$$

Stage 4-5

$$T_{mijkl} = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} (t_{ijkl}^r + t_{ijkl}^d + t_{ijkl}^a) \tag{5}$$

Total maintenance time, (t_m)

$$t_m = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} (t_{ijkl}^{\ r} + t_{ijkl}^{\ d} + t_{ijkl}^{\ a}) \tag{6}$$

Let assume that failure rate, λ, is constant for all lathe's components and followed negative exponential distribution. Then, failure rate is expressed as

$$\lambda = \frac{1}{MTFB} \qquad (7)$$

where,

MTBF- Mean Time Between Failures

Then, probability of a component's failure, $P_r(t)$

$$P_r(t) = 1 - R(t) \qquad (8)$$

The corresponding reliability, $R(t)$ of a component is expressed as

$$R(t) = e^{-\lambda t} \qquad (9)$$

Criticality of component's failure called maintainability, $P(C_r)$ is improvised as

$$P(C_r) = e - \frac{t_r}{tr^{\bar{x}}} \qquad (10)$$

where,

$tr^{\bar{x}}$ = Mean MTTR, Mean Time To Repair

t_r = overall time along the critical path, which may be maximum, mean, critical and minimum.

With total cost of maintenance per unit time, C_m which is the sum of costs of repair, dismantling and assemblage, then the maintainability cost per unit time, C^m is given as,

$$C^m = P_r(t).P(C_r)C_m \qquad (11)$$

Parameters are as defined before.

Machining cost is defined as the cost of using the machine per unit time, that is, the cost of operating the machine called machine hour rate (MHR), cost of labour and cost of accessories. For the turning of a unit length of metal rod on lathe [21],

$$T_a = \frac{l}{f\,N} \qquad (12)$$

where,

T_a = time of machining

f = feed in mm per revolution

N = spindle in revolution (rpm)

V = cutting speed in m/min

Cutting speed V and N are related thus [4], [21],

$$V = \frac{\prod DN}{1000} \qquad (13)$$

where, D = diameter at job in mm

Machining cost = $C_a T_a$ \qquad (14)

Tool cost is the cost required for the purchase of cutting tools per unit time of use. F.W Taylor, introduced the well known relationship between the cutting speed and tool life as [5], [21-23],

$$VT^n = C \qquad (15)$$

where,

V = cutting speed m/min

T = tool life

C = a constant which is numerically equal to cutting speed that gives a tool life of 1 minutes

n = an index which is as follows

0.1 to 0.15 for high speed steel tools

0.2 to 0.4 for tungsten carbide tools

0.4 to 0.6 for ceramic tools

0.2 to 0.25 for carbide tools

Hence,

$$T = n\sqrt{c/v} \qquad (16)$$

$$\text{Tool cost} = \frac{CcTc}{T} \qquad (17)$$

where,

$Tc =$ Time of operation

$Cc =$ Cost of reconditioning per time

$T =$ tool life

Cost of raw materials per job is the actual cost for the purchase of raw material used in the fabrication of the job.

Let cost of raw material per job = C_P

$$C_P = C_v T_v$$

where,

C_v = Cost per weight

T_v = Total weight of material used for job

Hence, the general equation for determining cost on lathe machine (C)

$$C = C_h T_h + C_a T_a + C_v T_v + \frac{T_c C_c}{T} + C^m \tag{18}$$

where,

C = Total cost of production (₦), ₦, symbol of Nigerian currency

C_h = Job handling cost per unit time (₦ / min),

T_h = Total handling time (min),

C_a = Machining cost time per unit time (₦ / min),

T_a = Total machining time (min),

C_v = Cost per Kg. of material (₦/ Kg.)

T_v = Total mass of material per job (Kg.),

T_c = Time of cut (min),

C_c = Cost per tool (₦),

T = Tool life (min),

In order to include provision for negotiation in pricing the criticality factor was introduced which occurred in four stages; maximum, mean, critical and minimum which was explained before.

3   Model Testing/Validation

Data were collected on the mean time between failure (MTTF) and mean time of repair (MTTR) of a typical lathe machine tool, using work study principle, based on the hierarchical arrangement of components (Figure 1, Table 1).

Table 1: Estimating mean time, between failure and to repair

Maintenance cost (₦)	Lathe's components		MTBF (YRS)	MTTR (HRS)
			t_{ef}	t_{er}
50,000	Table drive	A	13.8	27.7
100,000	Cutting head	B	10.3	21.7
40,000	Lubrication system	C	8.3	24.3
4,000	Indicators	D	5.7	12.2
10,000	Valves	E	4.8	14.7
25,000	Pump Unit	F	4.8	14.7
5,000	Reservoir	G	4.8	10
2,500	Control	H	3.7	10.5
1,500	Coupling	I	4.8	12.5
15,000	Pump	J	8.3	20
15,000	Motor	K	3.7	20.3
5,000	Rotor	L	14.2	14
30,000	C.shaft	M	8.3	26.3
2,500	Seals	N	4	13
2,500	C.Bearing	O	4.8	10.2
3,000	M.Bearing	P	3.7	12
10,000	M.Shaft	Q	7	12.3
3,000	Windings	R	12.5	14.3

t_{ef} , MTBR, expected Mean Time between Failure,

t_{er} , MTTR, expected Mean Time to Repair.

4   Results and Discussion

The results of MTBF and MTTR are shown in Table 1. the cost of machining without maintainability cost for mild steel and cast iron workpiece using Carbide and high speed steel cutting tools, under two samples (1 and 2) of job configurations are shown in Table 2, while Table 3 show manufacturing cost when maintainability was considered. The activities routing results show that the effect

of maintainability on the lathe machine tools is insignificant because of high reliability nature of its components (Table 1). For, example the table drive can be used for as long period as 14 years without failure. The life of lathe machine could be further prolonged with the implementation of a regular preventive maintenance system. The total cost of machining revealed that sample 1 was produced with lower cost from a cast iron workpiece using carbide tool. In case of mild steel as workpiece, the job was produced with lower cost using HSS tool (Tables 2 and 3). For sample 2 of cast iron lower cost was achieved using carbide tool, while the mild steel having lower production cost using HSS tool (Tables 2 and 3). It was generally showed that it will be cheaper to machine cast iron with carbide tool, and mild steel with HSS.

Table 2: Cost of machining without maintainability cost

		HSS/mild steel	*HSS/cast*	*Carbide/mild steel*	*Carbide/cast*
Sample 1	tr^c	14,448.17	13,588.59	21,260.48	11,834.21
	tr^{max}	14,448.17	13,588.59	21,260.48	11,834.21
	tr^{min}	14,448.17	13,588.59	21,260.48	11,834.21
	tr	14,448.17	13,588.59	21,260.48	11,834.21
Sample 2	tr^c	40,120.42	41,435.48	121,256.34	28,567.51
	tr^{max}	40,120.42	41,435.47	121,256.58	28,567.51
	tr^{min}	40,120.11	41,435.47	121,256.34	28,567.51
	tr	40,119.57	41,435.48	121,256.34	28,567.18

Table 3: Cost of machining with maintainability cost

|		*HSS/mild steel*	*HSS/cast*	*Carbide/mild steel*	*Carbide/cast*
Sample 1	tr^c	14,448.17	13,588.59	21,260.48	11,834.21
	tr^{max}	14,448.17	13,588.59	21,260.48	11,834.21
	tr^{min}	14,448.17	13,588.59	21,260.48	11,834.21
	tr	14,448.17	13,588.59	21,260.48	11,834.21
Sample 2	tr^c	40,120.46	41,435.57	121,256.36	28,567.57
	tr^{max}	40,120.46	41,435.58	121,256.36	28,567.58
	tr^{min}	40,120.19	41,435.69	121,256.39	28,567.65
	tr	40,120.51	41,436.25	121,256.40	28,568.25
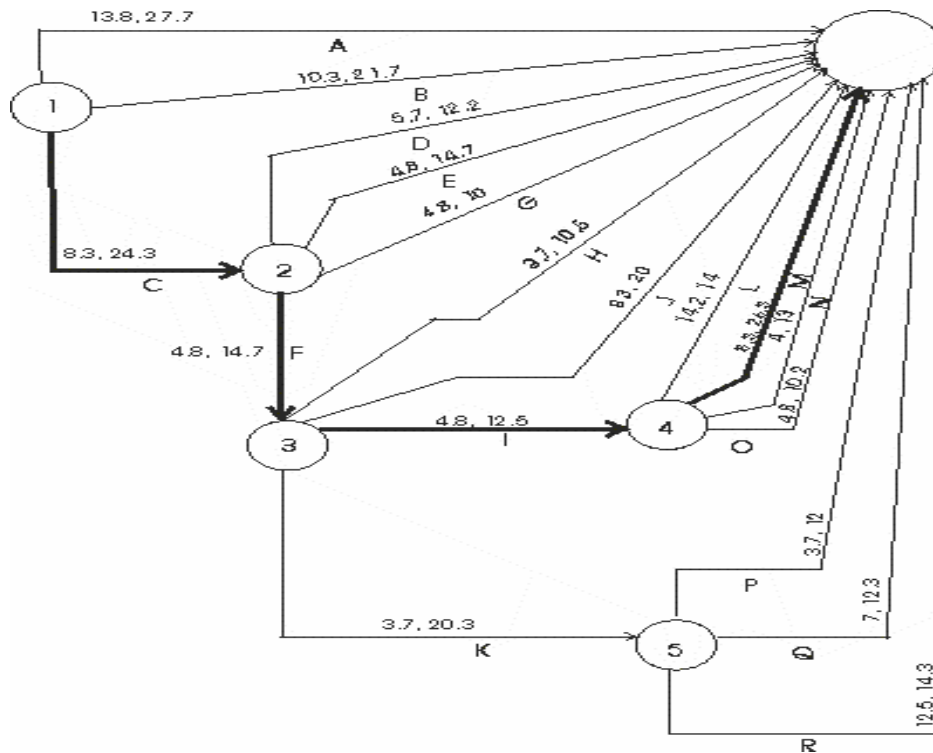
Figure 2. A network routing diagram showing the critical part (C-F-I-M), MTBF, and MTTR tr^c =77.8.

4   Conclusion

The model was successfully used to determine job costing on lathe machine considering maintainability of machine tool (lathe). The result showed that the effect of maintainability concept on such machine tool like lathe is minimal in fact, negligible due to high reliability value of lathe machine (i.e is as high as 0.99). This is only possible while putting in place daily routine and preventive maintenance policies. This is not always the situation for electrical equipments which comes with high value of failure rate. Equipments such as lathe machine of high reliability will attract low cost of maintenance as a result of high maintainability nature MTTR will tend to zero. It is therefore recommended that regular and routine maintenance activities of lathe machine be given utmost priority to ensure minimum production cost which is required for optimal production rate.

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