IMPACT: International Journal of Research in Engineering & Technology (IMPACT: IJRET)
ISSN(E): 2321-8843; ISSN(P): 2347-4599
Vol. 3, Issue 10, Oct 2015, 43-54

DEVELOPMENT OF DYNAMIC STRATEGY OF ESTIMATING COST OF JOBS ON LATHE WITH VARYING COMPLEXITY

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ABSTRACT

This paper parametrically examined the strategy of estimating cost of jobs produced on lathe machine with consideration for varying the complexity of jobs. Holistic assessment of the associated cost of production of jobs on a lathe was adopted taking into considerations the lathe, the workshop-environment and the machinist remuneration. The cost estimation approach utilizes machine hour rate assessment together with a multiple linear regression model for predicting the release time of jobs. The product of machine hour rate and the estimated release time gives cost of jobs produced on lathe. This method gives adequate room for evaluation of a piece and as well as mass produced jobs on the lathe. It further captures some of the salient cost elements such as overhead cost, repair and maintenance on lathe, cost of working space on the lathe, repair and maintenance of lathe floor space and insurance cost on lathe machine that are usually not included among the production factors on lathe machines.

KEYWORDS: Lathe, Cost of Job, Production, Machine Hour Rate, Release Time, Complexity of Job, Overhead, Repair, Maintenance

INTRODUCTION

Cost estimation is imperative to all manufacturing or production industry so as to assess or establish profitability of jobs or to determine the most economical process, tooling or material for making a particular job. This could be accomplished by developing mathematical algorithm or parametric equation or cost estimation model to account for the cost elements associated with the production of jobs on lathe machine. It will assist in long term financial planning and to prepare cost estimates for jobs to be produced on lathe machines. Costing is critical towards efficient management or running of any enterprise and it gives most useful information for the preparation of financial accounts. Estimation of cost associated with machining or production of jobs on lathe is also critical in production or metal workshop. However, there is a need for understanding the scope, the different perspectives, and essential factors inherent in job production on lathe.

Cost estimation is pre-calculation, which involves the prediction of costs before actual production (Cheung, 2008). The methods for pre-calculation are mainly initiated from the field of engineering science, while the post-calculation methods have arisen from business administration concerns (Layer et al, 2002). Within manufacturing, cost estimation is the procedure of approximating the cost of manufacturing a product before all stages of the product development cycle have been executed based on the information available or that can be collected at the stage of the product development cycle (ten Brinke, 2002). Cost estimation has to provide a high degree of accuracy due to the small margins between cost and selling price in a competitive market. The cost estimates have also to be generated as quickly as possible because quotations have to be offered to potential customers in a short time period. The methods of cost estimation should also be applicable when the product and the production are complex (Layer et al, 2002). Production cost is one of the most widely used performance measures in machining performance studies. In manufacturing techniques, metal cutting is one of the most important processes (Sundara, 2010).

Job complexity in job production on lathe means the number of operation or processes involved in the production of a given job on lathe. A simple job with limited number of operations will have little machining time when compared to a complex job with multiple numbers of operations (T. I. Ogedengbe et al, 2013) (O. O. Ojo et al, 2012). The challenging and competitive global market demands the manufacturing industries for high quality products with low cost (Sundara, 2010). As a result, a strategy for the estimation of cost of job produced on lathe machine under varying complexity is vital to check for release times as well as the associated cost of production.

METHOD

Costing of jobs produced on lathe machine is a dynamic process due to variation in the nature of jobs that can be produced on lathe. A more practical approach involving the determination of machine hour rate of lathe and estimation of release time undertaken in the production of jobs was adopted in estimating lathe production cost.

The methods employed for this research include:

- Modeling of release time of jobs produced on lathe
- Validation of model
- Parametric determination of lathe machine hour rate
- Estimation of lathe production cost

RESULTS AND DISCUSSIONS

The results obtained are explained in a stepwise manner in this section; the methodology adopted for the research and the obtained findings were carefully highlighted.

Modeling of Release Time of Jobs Produced on Lathe

The difficulties or problems encountered with the existing conventional machining time estimation method were exclusively considered in the formulation of the model. Equation 1 shows a condensed conventional approach for estimating machining time or release time. T is the machining time (in minutes), D is the work piece diameter (mm), L is the length of the machined surface (mm), V is the cutting speed (m/min) and f is the feed rate (mm/rev). Job complexity or number of operations and effect of materials (work piece) on release time of jobs were not taken into consideration in the conventional method of estimating machining time. However, the job specific parameters principal to all lathe jobs include the length of job, job complexity (simple or complex) as well as the depth used in cutting or metal shearing. These parameters were considered in modeling of lathe release time under ranges of spindle speed of 300-550 rev/min and feed rate of 0.068-0.117 mm/rev.

$$T = \frac{\pi DL}{1000Vf} \quad (\text{Omar et al}, 2010) \tag{1}$$

Multiple linear regression method was employed to develop the theoretical model of release time of lathe jobs using experimental data. SPSS 16.0 analytical tool was employed in formulating the multiple linear regressions. Here, the dependent variable was set as the release time of jobs while the independent variables employed in the process of establishment of the model include: length of cut, number of operation and the depth of cut. Equation 2 shows the general form of the model.

$$R_{Tw} = A + BL_c + Cn_p - Dd_c \tag{2}$$

A, B, C, and D are constants to be obtained from the regression analysis while L_c, n_p, and d_c are the initial length machined, number of operations applied and applied depth of cut respectively. A single work piece material was utilized for all the experiment to avoid the influence of materials contribution on release time and the complexity or number of operations of jobs was varied oddly from 3 to 17 operations in order to assess the effect of varying complexity on release time. Nine different jobs were produced for each level of complexity making the total jobs produced for the research to be 81. The jobs produced are studs, plain locators, tensile test specimens, bolts, pulleys, screw locator with handles, sleeves, pin punches, and chuck keys. Table 1 shows the number of operation or complexity of jobs, the average depth of cut, length of cut and as well as the average release time obtained from the machining results.

Table 1: Experimental Data for Cutting with Coolant

No. of Operations	Average Depth of Cut (Mm)	Length of Cut (Mm)	Average Release Time (Min)
3	1.33	210.00	6.30
5	1.62	190.00	4.64
7	0.93	213.00	6.54
9	0.67	288.75	9.19
11	2.20	230.00	7.01
13	1.04	592.00	16.88
15	1.08	531.20	15.88
17	0.82	491.00	15.50
19	0.55	1249.00	36.53

Equation 3 is the model of the release time of cut with the application of cutting fluid at $R^2 = 0.998$.

$$R_{Tw} = 0.414 + 0.027L_c + 0.128n_p - 0.565d_c \tag{3}$$

Adjustment of the model was carried out to accommodate variability in jobs on lathe. This was performed by estimating the ratio of release time to depth of cut, number of operation as well as length of cut as show in table 2. The average ratio of release time and depth of cut in one revolution was estimated. From table 2, the average ratios of release time to each of the job parameters include:

$$\alpha = 0.03\text{min/mm}$$

$$\beta = 1.201\text{min/operation}$$

$$\gamma = 2.509\text{min/mm}$$

α Is average ratio of release time and length of cut (in min/mm), β is average ratio of release and number of operation and γ is average ratio of release time and depth of cut in one revolution.

Table 2: Average Ratios of Release Time to Job Parameters for Wet Cutting

Jobs	No. of Operations	Average Depth of Cut (Mm)	Average Length of Cut (Mm)	Average Release Time (Min)	Ratio of Release Time To Depth Of Cut (Min/Mm)	Ratio of Release Time To Number Of Operation	Ratio of Release Time To Length of Cut (Min/Mm)
1	3	1.33	210.00	6.30	4.737	2.100	0.0300
2	5	1.62	190.00	4.64	2.864	0.928	0.0244
3	7	0.93	213.00	6.54	7.032	0.934	0.0307
4	9	0.67	288.75	9.19	13.716	1.021	0.0318
5	11	2.20	230.00	7.01	3.186	0.637	0.0305
6	13	1.04	592.00	16.88	16.231	1.300	0.0285
7	15	1.80	531.20	15.88	8.822	1.059	0.0299
8	17	0.82	491.00	15.50	18.902	0.912	0.0316
9	19	0.55	1249.00	36.53	66.418	1.923	0.0292
					15.758	1.201	0.0300

The adjusted model of estimating release time is expressed in equations 4 and 5. Where, L_{cn} is additional length of cut, n_{pn} is additional number of operation and d_{cn} is new depth of cut

$$R_{Tw} = 0.414 + 0.027L_c + 0.128n_p - 0.565\,d_c + \left[0.414 + 0.027\alpha(L_c - L_{cn}) + 0.154\left(n_p - n_{pn}\right) - 0.565\gamma(d_c - d_{cn})\right] \quad (4)$$

$$R_{Tw} = 0.414 + 0.027L_c + 0.128n_p - 0.565\,d_c + \left[0.414 + 0.00081(L_c - L_{cn}) + 0.128\beta\left(n_p - n_{pn}\right) - 1.418(d_c - d_{cn})\right] \quad (5)$$

Validation of Model

The model was put to test by comparing and investigating the release time of jobs predicted by the model with the ones measured directly on the lathe. Paired t-test was employed to check for significant difference in the results of the two time estimation methods. This was examined by considering case studies of some jobs that were produced on a lathe machine. Table 3 shows the release time estimated by the model and that measured directly on the lathe machine.

Table 3: Case Studies on Wet Produced Jobs

Jobs	No. of Operations	Average Depth of Cut (Mm)	Average Length of Cut (Mm)	Measured Average Release Time (Min)	Release Time Obtained From Model (Min)
Stud	3	1.33	210.00	6.30	5.717
Plain Locator	5	1.62	190.00	4.64	5.269
Tensile Test Specimen	7	0.93	213.00	6.54	6.536
Bolt	9	0.67	288.75	9.19	8.984
Pulley	11	2.20	230.00	7.01	6.789
Screw Locator with Handle	13	1.04	592.00	16.88	17.474
Sleeve	15	1.80	531.20	15.88	15.659
Pin Punch	17	0.82	491.00	15.50	15.384

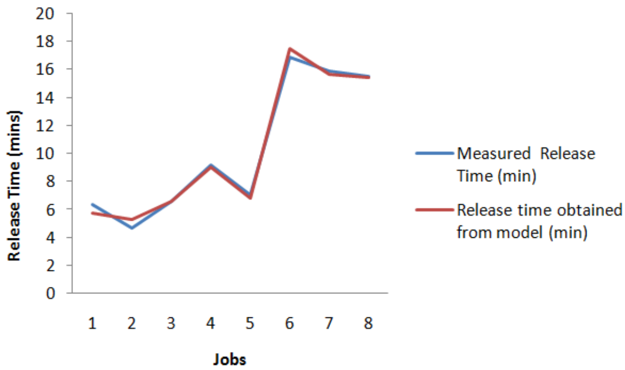

Figure 1: Case Studies of Measured and Modeled Release Time of Wet Produced Jobs

The graphical representation of the two sets of release time is shown in figure 1 The differences in the release times are very small but further investigation needs to be performed to validate if there is significant difference in the results. Tables 4-6 the paired sample statistics, correlation and test of measure and modeled release times respectively. These tables confirmed there is no significant difference in the two release times.

Table 4: Paired Samples Statistics of Measured and Modeled Release Times For Wet Cut

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	R_{mod}	10.2425	8	5.00964	1.77118
	R_{mes}	10.2265	8	5.07839	1.79548

Table 5: Paired Samples Correlations of Measured and Modeled Release Times For Wet Cut

		N	Correlation	Sig.
Pair 1	R_{mod} & R_{mes}	8	0.997	0.000

Table 6: Paired Samples Test of Measured and Modeled Release Times For Wet Cut

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence interval of the difference				
					Lower	Upper			
Pair 1	R_{mod} & R_{mes}	0.016	0.421	0.149	-0.334	0.368	0.11	7	0.9

Parametric Determination of Lathe Machine Hour Rate

Cost accrues as production cost on lathe machine ranges from purchase price of work piece materials, electricity and water charges, coolant and cutting tool prices, maintenance charges to machinist's charges. The various parameters believed to have paramount contributions to the machine hour rate or unit cost determination of any lathe job production were carefully analyzed. The cost input factors or parameters considered to be significant include: electrical power consumption for machining, cost of lubricant or coolant required for wet machining, machinist cost for a typical job or charge rate of a machinist, tooling cost and cost of material or work piece required for production.

The machine hour rate consists of the rates of the associated cost elements of production on a lathe machine. It can be represented as the unit cost of machining which can be effectively derived by dividing incurred cost of production by the whole production units. Since, the whole cost of production needs to be determined, it is better estimated by calculating individual cost rates associated with machining operation. Thus, lathe machine hour rate can be expressed as shown in equation 6. Where, i is counter for machine hour rate elements which range from 1 to n; and C_i is cost element hour rate cost for element i

$$MHR = \sum_{i=1}^{n} C_i \qquad (6)$$

C_i Includes the tooling cost, coolant cost, direct machinist's cost, utility or electricity cost, and the other general cost elements the parametric estimations of each of these cost elements are discussed below.

Cost Estimation of Tooling Material

The type or nature of cutting tool also determines the tooling cost on lathe machine. In machining, tooling cost can be expressed as the expenses incurred by a manufacturer in the acquisition of cutting tools as well as expenses accrued during fabrication or machining of jobs such as cost of reconditioning or regrinding of tools. Operating hours and labour productivity are essential in estimating the tooling cost of jobs on lathe machine. The cost of the single point cutting tool also goes into cost of machining on lathe machine. There are various types of cutting tool and they have different price tags.

A straight line method of estimating tooling cost on lathe machine was be adopted as shown in equation 7. Where,N_{tc}, T_{lif} and T_c are the net tool cost in naira, estimated tool life in minutes and tool cost per hour respectively. Equation 8 shows the breakdown of the net tool cost. P_p is purchase price of the cutting tool and C_{rec} is cost of reconditioning of a tool per hour.

$$T_c = \frac{N_{tc}}{T_{lif}} \tag{7}$$

$$N_{tc} = P_p + C_{rec} \tag{8}$$

In estimating tool life, according to F.W Taylor's equation for tool life expectancy which gives the relationship between the cutting speed and tool life, as shown in the empirical formula of equation 9. V is the cutting speed and C is a constant which is numerically equal to cutting speed that gives a tool life of 1 minute. However, for turning or steel cutting at feed of 0.01 inch/rev and depth of 0.1 inch, the values of C for different tool materials are given as 20m/min for plain carbon tool steel; 70m/min for high speed steel tool; 500m/min for cemented carbide tool; 600m/min for cermet tool; 700m/min for coated carbide tool; and 3000m/min for ceramic tool (Kareem et al, 2011).

Also, n is an index which can either be one of the followings but it depends on material of the tool: 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; and 0.2 to 0.25 for carbide tools (Kareem et al, 2011)

$$V(T_{lif})^n = C \tag{9}$$

However, the tool life in equation 9 is in minutes; when converted into hours and made the subjected of the formula for substitution into equation 7, the resulting relationship gives equation 10. This expression is required for estimating the tooling cost per hour on lathe machine.

$$T_c = [P_p + C_{rec}]\frac{60}{\sqrt[n]{C/V}} \text{ in cost per hour} \tag{10}$$

Cost Estimation of Coolant

If coolant or lubricant is to be utilized in machining, the cost of the coolant needs to be added to the overall cost of production since; it is also part of production item for wet machining. Since, coolant or lubricant used on a lathe machine undergoes a cyclic process of utilization. A particular volume of lubricant can be used for as many times as possible. The cutting fluid employed in cutting usually over time becomes not useful because of chips or particles in it and some percentage of the fluid gets evaporated during usage as well.

According to Manual Lathe Equipment Maintenance Description (IRI-MS01-EMD) (2004), coolant should be changed periodically at four to six weeks intervals to prevent bacteria build-up in the system. This means that the useful life time of cutting fluids is between four to six weeks.

Then, the average coolant change interval will be 5 weeks. The cost of application of a typical lubricant per hour for a machine tool put into maximum utility is expressed in equation 11. Where, C_L is cost of lubrication per hour, V_{lub} is number of gallons/litre required to be mixed with water to fill the lubricant tank and U_{lub} is unit cost of lubricant per gallon/litre.

However, if five working days in a week and seven possible working hours of utilizing a typical lathe machine tool without allowances for breaks, the coolant change interval becomes 175 hours. Equation 11 will then become equation 12.

$$C_L = \frac{V_{lub} U_{lub}}{O_{ser}} \quad (11)$$

$$C_L = \frac{V_{lub} U_{lub}}{175} \quad (12)$$

Cost Estimation of Direct Machinist/Labour Cost

Direct machinist or labour cost is the total amount of uninterrupted labour required to machine a job. Here, it does not take account of the breaks that the machinist generally require from work, e.g. for rest, eating, and other bodily functions. Therefore, pure labour hours would be reckoned with in the process of estimating the cost of lathe jobs. The advantage of the man-hour concept is that it can be used to estimate the impact of machinist changes on the amount of time required for a machined job. Equation 13 shows the direct machinist cost per hour. L_c, M_A and M_{Wh} machinist cost per hour, monthly allowance and monthly working hours respectively.

In a month, there are twenty (20) working days and a day has a maximum of seven (7) working hours on the lathe machine; according to the Mechanical Engineering Workshop's work hour of the Federal University of Technology Akure. On the basic of this, the labour/machinist cost per hour in equation 13 will be transformed to equation 14.

$$L_c = \frac{M_A}{M_{Wh}} \quad (13)$$

$$L_c = \frac{M_A}{140} \quad (14)$$

Cost Estimation of Utility

The utility cost includes the electricity charge per hour and water supply used in the mixture of cutting fluids. Since, the water usually employ in mixing cutting fluid is neglected in the estimation of utility cost. The electricity cost is significant in machining because machine tools are power driven and electrical energy is the principal source of this energy. Without this form of energy, a machine tool cannot function. This needs to be estimated in the cost of production of jobs on machine tools. The electricity cost of machining was estimated by deriving empirical formula for the required machining power.

The cost of wattage in an hour as stated by Power Holding Company of Nigeria (PHCN) was a primary parameter combined with the required machining power to obtain the power cost for machining or production in an hour as shown in equation 15. P_m is the power required for machining, C_c is cost charge per unit power or wattage in one hour (PHCN rating) and E_c is the power cost for machining in an hour.

$$E_c = P_m C_c \tag{15}$$

By using the unit energy required by the material or work piece material, the power required for machining can be expressed thus in equation 16. ε is the unit energy required for the material in W-s/mm^{3}and M_{RR} is material removal rate or cutting speed in (mm^3/min)

$$P_m = \varepsilon M_{RR} \tag{16}$$

The unit energy of shearing or deforming any material can be obtained from the manufacturer's description. However, the material removal rate or the cutting speed can be obtained from the empirical derivation of equation 17. D, d, f and N are work piece diameter, depth of cut, feed rate and spindle speed respectively

$$M_{RR} = \pi \, D \, d \, f \, N \tag{17}$$

The unit energy required for a material, ε is usually expressed in W-s/mm^3 but it is required to be in hours for the computation of machine hour rate. ε is converted to hours an equations 17 is substituted to into 16 and the resulting outcome is substituted into equation 15 to produce the power cost for machining in an hour as shown in equation 18.

$$E_c = \varepsilon \frac{60}{\pi DdfN} C_c \tag{18}$$

In Nigeria, according to multi-year Tariff Order (July, 2008 – June, 2013), electricity prices are generally lower than the production cost. The tariff was last reviewed in February 2002 (from an average of N4.50/kWh to about N6/kWh) where it has remained to date. Therefore, the cost charge per unit power is thus given as C_c is ₦6/kWh. This cost could be substituted into equation 18 to give equation 19.

$$E_c = \varepsilon \frac{360}{\pi DdfN} \tag{19}$$

General Cost Estimation

The general cost includes overhead cost, repairs, cost of purchasing lubricant/grease, maintenance of machine and floor space, and as well as insurance cost.

Overhead cost is assumed at 10% of machinist or operator's salary per hour and the expression for it is seen in equation 20.

$$C_5 = 0.1L_c \tag{20}$$

Repair and maintenance cost of machine is assumed at 20% of the purchased cost divided by available working hours in a year. This is expressed in equation 21. L_{Pr} And W_{hr} are the lathe purchase cost and working hours of the lathe in a year.

$$C_6 = 0.2\frac{L_{Pr}}{W_{hr}} \tag{21}$$

Cost of working space if workshop or building is assumed to last for 50 years in one hour. This is estimated in equation 22. Where, W_C is workshop/building's cost per hour, W_{sp} is the cost of the workshop or building and S_{lif} is the service life of the workshop in hours over a span of 50 years. However, the relative floor area of a typical lathe used in the workshop needs to be estimated from the entire workshop floor area as shown in equation 23. Where, A^1 is relative area occupied by employed lathe machine tool, A^T is total floor area of the workshop, a^1 is working space for employed/used lathe machine and a^T is total working space for all the machines in the workshop.

$$W_C = \frac{W_{sp}}{S_{lif}} \tag{22}$$

$$A^1 = \frac{a^1}{a^T} \times A^T \tag{23}$$

Equation 24 shows the final cost of working space for a lathe machine in the workshop in an hour when the service life of the workshop is 50 years.

$$C_7 = \frac{A^1}{A^T} \times W_C \tag{24}$$

Repair and maintenance of floor space cost is assumed to be 5% of working space's cost in an hour as shown in equation 25.

$$C_8 = 0.05W_C \tag{25}$$

Annual insurance cost is assumed at 0.5% of purchased cost of the lathe machine as shown in equation 26.

$$C_9 = 0.005\frac{L_{Pr}}{W_{hr}} \tag{26}$$

Estimation of Lathe Production Cost

Machining cost is thus determinable if man hour rate or unit cost rate and release time can be established; the machining cost will then be the product of the unit cost rate and release time. The developed model has provided the release time or machining time of jobs. Therefore, the machine hour rate and unit cost rate for a lathe machine are the constraints that require derivation.

Generally, machines are operated or run for some durations, usually in hours; the type or nature of jobs determines the operation time of the machine that is there is variability in completion time of one job to the other. Therefore, it is highly essential to determine machine hour rate in order to effectively determine the cost of production of different kinds of jobs without minding the variation in jobs' completion time. The cost of producing a typical job on a lathe machine is presented in equation 27 or 28. M_C, MHR and R_{Tw} machining or production cost, machine hour rate and release time or completion time of a job respectively.

$$M_C = MHR \times R_{Tw} \tag{27}$$

Also, for job with cost elements of n, the production cost of the job is expressed in equation 28.

$$M_C = R_{Tw}\sum_{i=1}^{n} C_i \tag{28}$$

Release time of jobs could be expressed with either equation 3 or 5 while the summation of the valuable cost elements is seen in equation 29.

$$M_C = R_{Tw}[\ T_c + C_L + L_c + E_c + C_5 + C_6 + C_7 + C_8 + C_9\ ] \tag{29}$$

CONCLUSIONS

Conclusively, this research provides a multiple linear regression model for the estimation of release time of jobs produced on lathe machine when independent parameters of depth of cut, length of cut and the complexity of jobs are known. This model was validated and it was confirmed to give accurate estimates. A holistic approach for the estimation of machine hour rate on lathe machine was evaluated through a succinct examination on tooling cost, cooling cost, machinist charge, electrical power cost, overhead cost, repair and maintenance of lathe charge, cost of working space on the lathe, repair and maintenance of lathe floor space cost and insurance cost on lathe machine in an hour. Estimation strategy of cost production of jobs can be performed if the requisite information or parameters are known about the machine tool or lathe, workshop and the machinist.

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