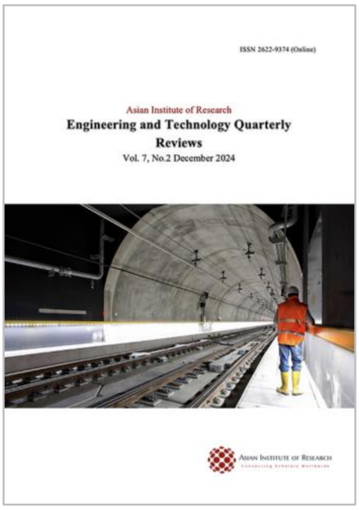

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Lathes' Machine Selection Base on Operational Sensitivity and Costing

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Abstract

The need to estimate the cost of operating a machine tool for the purpose of pricing a job or billing a customer is of great importance. This would establish a good relationship between customers and operators. The cost depends on the sensitivity of the machine tool. In determining the sensitivity of lathes, parameters considered were the finishing time of operation in relation to the machining parameters which were feed, capacity and speed at a unit depth of cut. The component design parameters were metal volume removed, complexity and the skill level involved. Costing was done based on literature and the current prime cost of running and operating the machine shop. The developed numerical model has a coefficient of determination R2 of 0.962 specifying a high degree of agreement for experimental and theoretical data. The results showed that lathe machines with smaller capacity have lower operational sensitivity with more cost effectiveness where as higher capacity, numerical control and CNC lathe machines had higher sensitivity but less cost effective.

Keywords: Sensitivity, Model, Finishing Time, Cost Effectiveness, Capacity

1. Introduction

Costing of machine tool operation is of great importance for the purpose of pricing a job or billing a customer. The cost of operation depends on the sensitivity of the machine tool. A product can be produced through various manufacturing processes. The choice of a production process will however depend on specific parameters and consideration (Bruce, 2002). The operation to be carried out on a work piece determines the tool to be used. The advancement of tool usage led to the invention of machine tool (Bradley, 1972). Machine tools are power-driven devices designed to produce a geometrical surface by cutting away metal through operations such as turning, shaping, milling (Kareem, 2004; Kareem *et. al.*, 2010). Machine tools are basic mechanical machinery used to produce or repair other machine parts which includes lathe, milling and drilling machine.

The global market is filled today with the conventional type, numerical control (NC) and computer numerical control (CNC) machine tools (Kareem *et al*, 2010), in consideration for determining machining sensitivity, categories of machine are selected towards estimating the most efficient and economic one required for production through mathematical modeling with respect to meeting the five firm objectives as stated by Cyert and March (1963), Kareem (2005), Kareem (2006) and Palik (2006). These are profit, production, stock levels, sales and market share considerations. This work will greatly enhance selection of appropriate machine tool (lathe) that will be used in the production of mechanical components, and optimization of profitability from the utilization of the machine tool in the industry. The costing would establish a good relationship between customers and operators.

2. Research Methodology

Various factors affecting operational sensitivity of lathe machine tool were identified. These factors were the volume of the metal removed, complexity of operation, cutting speed, depth of cut, feed rate, accuracy of cut, machine capacity (stock) and operator skill level at which the machine was operated.

Theoretical relationship among the identified operational factors was mathematically formulated and expressed in equation 1 by Boothroyd and Knight, (1989).

$$t_{total} = t_{load} + \frac{V_{vol}}{f_{mach} fdV} + \frac{V_{vol} V^{(1-n)n} t_{ct}}{fdK^{1/n}} \quad (1)$$

Where, t_{total} is true machining time, t_{load}, time for loading and unloading the part to and from machine tool, V_{vol}, Volume removed, f_{mach}, fraction of the time spent in removing metal, t_{ct}, tool changing time, f, feed rate (mm/rev.), d, depth of cut (mm), V, Velocity (m/min) also know as cutting speed, n, an index closely related to the cutting tool materials 0.1-0.6 and K, a constant for the time required to produce N parts. In order to improve operational sensitivity of the system, the formulation was extended to include managerial parameters such as complexity of operation, skill level available, accuracy desired and capacity of machine. The resulted robust model was used in determining the true operation time of job requisition. A new and simple numerical approach, based on multiple regressions by Gujarati (2007) was adopted in obtaining a model that holistically integrated the identified sensitivity driven factors. With true machining time, t_{total} as a function of skill, S, volume removed, V, feed, F, spindle speed, N, stock length, K, complexity, C, and accuracy, A, are presented in equation 2 and 3 as given by Kareem and Ejiko, (2013).

$$t_{total} = f(S, V, F, N, K, C, A) \quad (2)$$

The regression model was formulated from

$$t_{total} = aS + bV + cF + dN + eK + fC + gA + h \quad (3)$$

where a, b, c, d, e, f, g and h are coefficients/constant of regression model.

In order to establish the efficacy of multiple regression relationship, experimental study was done by carrying out designated operations on lathe models of Conventional type, in the Machine Workshop of Mechanical Engineering Department, the Federal Polytechnic Ado-Ekiti. The designated operations carried out included turning, drilling, threading, on which different levels of operators' skill, volume of material removal, complexity of job, speeds and feeds of operation were utilized. From the data generated through experimental procedure, analysis was carried out on Multiple Regression model using Statistical Package for Social Sciences (SPSS 15.0) software and the true machining time was determined.

2.1 Costing of Machine Tool

In costing the lathe model of machine tool, cost implication that involves the machining charge for recovering the capital cost, labour cost and tooling cost was considered has been treated by Dieter (1991). Formulae for the manufacturing cost and labour cost were given which include;

$$M_t = \frac{C_i}{120000 f_0 n_s}\left[\frac{1}{Y} + \left(f_i + f_m\right)\right] \quad (4)$$

$M_t =$ Manufacturing cost per minute

$C_i =$ Initial purchase price

$f_i =$ Fraction of interest rate to the purchase price

$f_m =$ Fraction of annual cost of power, lighting, heating, training and so on

Y = Machine age

$f_0 =$ Fraction of machine active hour

n_s = Number of days factor for process-oriented jobs

$$M_w = \frac{C_a}{120000}(1 + f_s)r_w \quad (5)$$

$M_w =$ Labour rate per minute

$C_a =$ Worker's annual wage

$f_s =$ Fraction of insurance/pension cost of wages

$r_w =$ Factor of payment for others not necessarily the operator (Dieter, 1991)

These formulas with other data gathered from Thomas *et al.* (2000) as shown in Table 1 are useful in estimating the machine rate per minute. The data collected from Thomas *et al*, 2000, machine tool industries and the internet on CNC lathe in Wikipedia, (2007) and Microkinetics, (2009) as reflected in Tables 1 and 2 were used to estimate the operation charge per minute. With contracting differences found in the utilization of the varying lathe models, there is the need to determine the operational sensitivity for each class of lathe and the economic implication, Hence the need to develop operational sensitivity model in the selection of the most cost-effective lathe.

Table 1: Fractional factors in estimating machine hour rate

factor	**Conventional**	**NC**	**CNC**
f_i	0.15	0.15	0.15
f_m	0.4	0.45	0.18
f_o	0.5	0.75	0.75
n_s	2	2	2
f_s	0.1	0.1	0.1
r_w	1.2	1.2	1.2

Source: Thomas et al. 2000

Table 2: Parameters for Estimating Machining Cost Per Minute

Sub-component charge	**M300**	**M350**	**M500**	**N/C 3650**	**CNC 1236**
Fuel consume/hour	100	150	200	270	100
For 8 hour of 250 work days	₦ 200,000	300,000	400,000	540,000	200,000
Fm = annual cost of power/etc fraction to cost	0.4	0.5	0.5	0.45	0.18
F: = fraction of interest rate if borrow to purchase	0.15	0.15	0.15	0.15	0.15
C_I = purchase price	500,000	600,000	800,000	1200,000	1,119,300
Machine Age	13	17	7	1	1
M_t = manufacturing cost/min	2.61	3.54	5.29	10.67	8.27
F_o= machine active hr fraction	0.5	0.5	0.5	0.75	0.75
N_s = days factor (process-oriented).	2	2	2	2	2
C_a = workers annual wage	360,000	360,000	360,000	600,000	600,000
F_s = insurance/pension fraction	0.1 (10%)	0.1	0.1	0.1	0.1
R_w = inflated ration for other pay (labour intensive)	1.2	1.2	1.2	1.2	1.2
M_w = labour charge/min	3.96	3.96	3.96	6.60	6.6
C_p = turning process cost	6.57	7.5	9.25	17.27	14.87

Source: Thomas et al., 2000: and www.Microkinetcs.com/lathe 1236

3. Results and Discussion

Linear multiple regression model parameters were estimated from the data obtained through the experiment conducted on operational sensitivity for the three models of the conventional lathe machine (M300, M350 and M500), in the mechanical workshop of the Federal Polytechnic Ado-Ekiti, using SPSS 15.0 (for window) computer package. The parameters for the independent variable namely: volume, federate, speed, stock, complexity, accuracy and skill for the three lathe models are presented in equation 6 which is the Generalized model that considered the whole variables in the experimental data and the analysis was done using linear multiple regression method. A model of time as a function of the other variables was determined as:

$$T = 13.356S - 0.154A + 2.703C - 0.011K - 0.083N + 151.25f + 1.72V - 20.389. \quad (6)$$

Where, S = Skill level of operator, A = Accuracy of component being machined, C = Complexity of operation, K = Stock length, N = Speed in revolution per minute, f = Feed rate in mm/rev and V = Volume of metal removed. The machine age, swing and power variables were excluded from the model predictors in Table 2 because their variables were insignificant in determination of the operating time (T). The Probability value (Pval) for the general model is 0.001(that is $P_{val} \leq 0.005$) which, shows that there are significant differences among the predictor variables with respect to completion time, correlation factor of 0.962 shows a high degree of the result linearity (Oladebeye and Ejiko, 2007; Ejiko and Kareem, 2012). This general model clearly shows that the skill, complexity, feed and volume have much impact on the machining time while accuracy, stock and speed slightly affect the estimated time. This model clearly stands out from others due to the inclusion of vital modes of operation functions and its machine capacity. The relationship between volume and time of cut is presented in Fig 1, for observed (T obsvd) and theoretical time (T gen). The figure shows that for small volume (0.88cm^3 to 5cm^3) of metal removed involving smaller component with complex operation takes more time in completing the job, as the volume increases from 5cm^3 the time of cut then to be proportionate. The theoretical model clearly agrees with the observed relationship between the volume removed and time of cut, this highlights the acceptability of the generalized model.

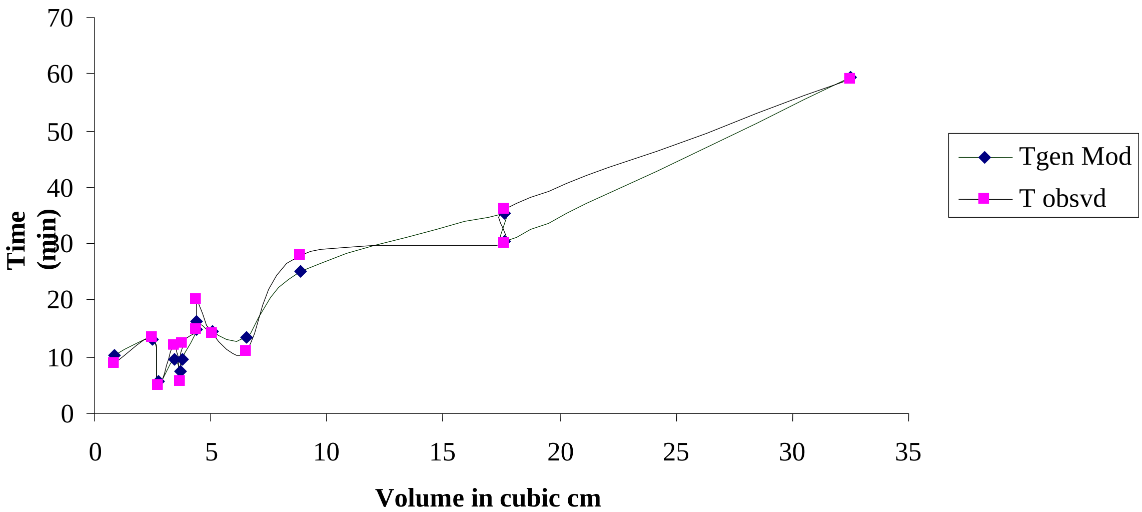

Figure 1: Relationship between Volume and Time of cut for Observed and Generalized Model

In validating the model's data were obtained based on customer's request. The requests involved the production of 15 test piece components having 0.007mm accuracy and metal volume removed per piece is 28.997cm^3 for a period of 5 hours; this implies 20 minutes per component. The model was tested to determine the acceptance or rejection of the job. Considering minimum condition of beginners' skill, lowest turning speed and minimum feed rate, the following result was generated and tabulated in Table 3. The result clearly shows that the M300 lathe is not suitable for the job because the minimum time required to complete the job is higher than the customer time (20 min). M350 met the desired customer's target at a speed above 155 rev/min while M500 can be used with a speed slightly above 115 rev/min. Whereas in a case where all the customer's target are met by all Lathe models, The cost per hour of operations on job using these lathe machines was compared and the best costeffectiveLathe, was chosen for the job utilization.Figs. 2a and 2b show the relationship between speed and time of cut using the generalize model, while Fig. 2a shows the relationship for M300, M350 and M500, Fig. 2b establishes the relationship for M500, NC and CNC lathe involving the machining of a component based on customer's request. The figures show that increase in spindle speed of the lathe machine tool will favour the reduction of machining time, and this varies for varying lathe models. The speed of 75rev/min gives the machining time of 32, 28, 25, 21 an16min for M300, M350, M500, NC and CNC respectively, while at 175rev/min the machining time reduces to 23, 19, 16, 15 and 8min, the implication is that operational sensitivity increases with respect to lathe model capacity and speed.

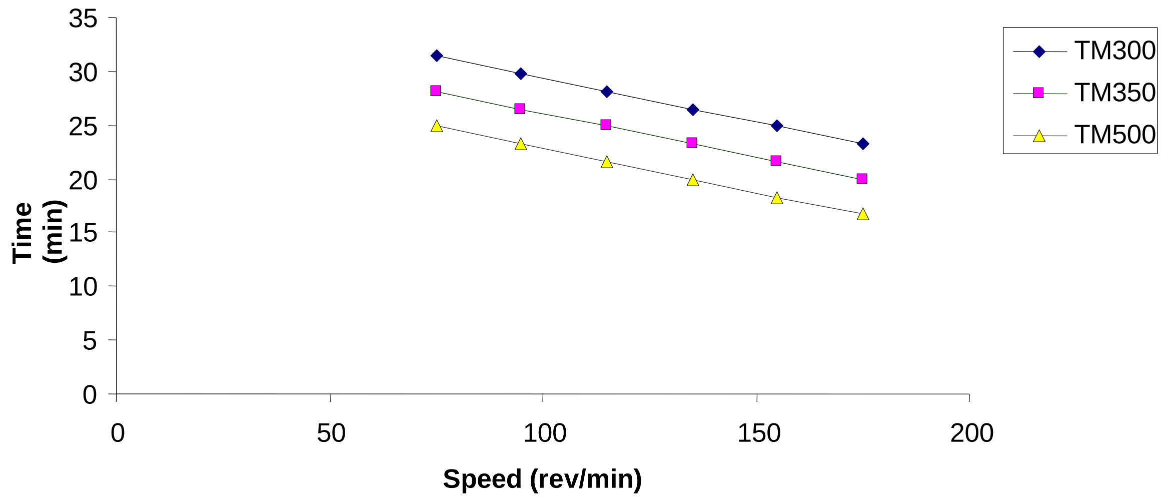

Figure 2a: Relationship between Times of cut and Speed using Generalized Model for Purely Conventional machines

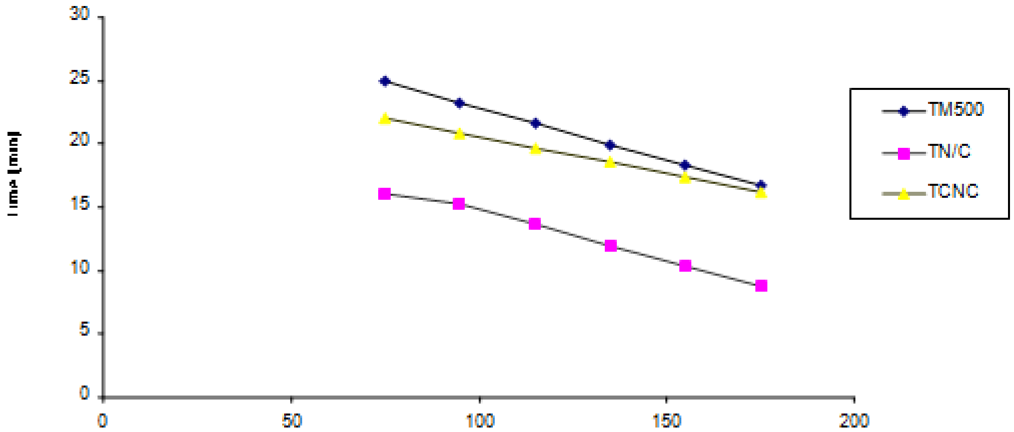

Figure 2b: Relationship between Times of cut and Speed using Generalized Model for Conventional, NC and CNC machines

Table 3: Varying Speed against Time using Generated Model

Job component operation based on varying speed S/№	Speed(rev/min)	Time(min)		
		M300	M350	M500
1	75	31.5	28.2	24.9
2	95	29.8	26.5	23.2
3	115	28.2	24.9	21.6
4	135	26.5	23.2	19.9
5	155	24.9	21.5	18.8
6	175	23.2	19.2	16.7

Cost implication graph in Fig 3 clearly shows that the cost of operating machine at a lower speed is higher, which implies uneconomical operational sensitivity. At higher range of speed for turning mild steel the conventional and numerical control machines are more cost-effective than the computer numerical control lathe machines. The figure shows that at lower speed the cost of operation is usually higher, at 75rev/min the cost in naira of M350, M500, NC and CNC lathe model, are 330, 280, 230 and 220, respectively while, at 175rev/min the cost was estimated to be 149, 153, 150 and 241in naira. As the speed increases the cost of operation tend to reduce. The cost of operation in naira at higher speed for M500, NC and CNC tend to become equal.

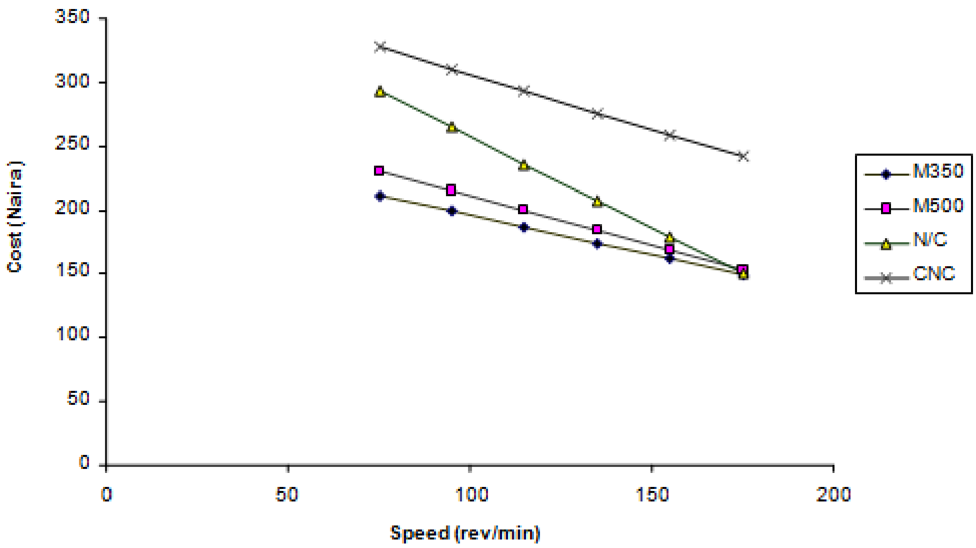

Figure 3: Relationship between manufacturing cost and speed of Operation for conventional NC and CNC machines

4. Conclusions and Recommendations

This paper expressed the operational sensitivity model for selection of appropriate Lathe machine in the production of mild steel components. The numerical models based on multiple regressions were developed from the experimental data obtained from machining operations of some specified jobs. The Lathes in machine shop of Mechanical Engineering Department of The Federal Polytechnic Ado Ekiti was used as a case study. The resulting models possessed high correlation factors which show high levels of agreement among the observed and theoretical values of variables (Skill, Feed, Accuracy, Stock, Volume removed, Speed and Complexity) relationship, as input, with respect to the time of completion, as output. The developed model has successfully estimated the machining time for varying job requests in the machine tools industries.

This paper establishes a selective measure in the choice of economical machine tools for operations. In summary, the result obtained shows that lathe model, with smaller capacity possesses lower operational sensitivity with respect to time, whereas models with higher capacity, numerical control and CNC machines attracted higher operational sensitivity and cost.

The implementation of the model has enhanced effective utilization of available resources including lathe machines, from which good interrelationship between customers'requests and operators' available time was established. This has resulted in effective operation charges in the machine shops.

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