COST AND PRODUCTIVITY ANALYSIS OF EQUIPMENTS FOR FLEXIBLE PAVEMENT- A CASE STUDY

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Abstract – *Equipments being a necessity of any construction project still needs major research to improve pre-estimation accuracy for productivity and costs related to equipment. A case study conducted to evaluate per hour owning and operating cost(O&O cost) and per hour productivity of excavator, loader, backhoe loader, grader, paver, hot mix plant , soil compactor, tipper truck and tandem roller used in various projects in Punjab and Chandigarh for construction of flexible pavement with appropriate methods are represented in this paper with appropriate results.*

Key Words: Construction equipments, ownership cost, operating cost, productivity, equipment performance.

1.INTRODUCTION

As equipments are clubbed into group for project planning and are not analyzed much separately there are not much resources explaining how to calculate per hour production possible by equipment and how to calculate profitable per hour cost to be charged by client. Hence it is important to encourage researchers to conduct researches in this field so as to let new comers understand the ongoing scenarios and issues related to equipments and to help them by providing necessary information for better management of equipments in project. As a contractor ability to win a contract and to gain profits from it is determined by factors like construction methods used & management of manpower and equipment. The planning and estimates are done before the execution in any project; therefore if we can achieve accuracy in terms of calculating the operating cost, productivity offered by equipment and feasible way of acquiring equipment we can plan our project with more precision. Though scheduled rates available but we do not know or do not focus on the factors that play main role in the computation of these quantities. This paper hence provide results obtained regarding various factors involved in ownership and operating cost on per hour basis when equipment as used to full extent for its purpose with efficiency of 50/60 minutes and similarly per hour productivity that can be achieved by equipment if it is working for efficiency of 50/60 minutes.

Previous researches in this area; [1] Mitchell (1998) represented a regression model by using a quadratic function that could represent repair costs in terms of machine age in cumulative hours by using field data. It demonstrated how this expression could be incorporated in the cumulative cost model, where it can be used to identify optimum economic decisions. Several discussions presented in this paper revolve around this research. [2] Bhurisith et al. (2002) provided results of per year change in productivity rate and unit cost for production of construction equipment. Analysis is performed on six different earth moving equipments for time span of 15 years. It is shown that production rate has increased 1.58% on average per year. The unit price of production has increases 1.77% on an average per year. [3] Haas et al. (2002) evaluated the decrease in measures for construction productivity at industry level and its increase in activity level. For this equipment technology is examined as one factor. The relationship between equipment technology and partial factor safety is examined. Through ANNOVA analysis it is found that activity those experienced change in equipment technology also witnessed greater long-term improvement in partial factor productivity.[4] Lucko (2003) represented a regression model to predict the residual value of different types of equipment. The variables for the regression model used in this research were age in years, manufacturer, condition rating, geographic region, and selected macroeconomic indicators. [5] Yip et al. (2009) performed a time series analysis based on General Regression Neural Networks (GRNN) models to address the prediction of construction equipment maintenance costs. The results show that GRNN can model the behavior and predict the maintenance costs for different equipment categories and fleet with satisfactory accuracy. It also discusses the effects of incorporation of the parallel fuel consumption data as explanatory time series to modeling performance. Vector auto regressive modeling and Regression Analysis was conducted as methodology for research.

2. METHODOLOGY

2.1 Data

Data required for research was collected from on going road construction projects in Patiala and Chandigarh, India, such as values for purchasing cost, maintenance cost, operator's wages etc, for equipments are collected from owners of equipment working on these sites and retailers of construction equipment. Collection of data related to calculation of productivity of equipments, such as hauling speed of tipper, hoe capacity of excavator etc, was made by observing equipments on Patiala road construction project.

2.2 Methodology for per hour ownership and operating cost (O&O cost)

Following steps are used to calculate ownership cost:-

i) Data collected related to purchasing cost and residual value of equipments from retailer, Data collected related to working life of equipments in hours from retailer, IS 11590:1995 and performance reports manufacturers (Caterpillar Performance Handbook, 2015). Overall percentage of insurance and taxes to be levied on equipments throughout their life collected from equipment owners.

ii) Calculation of net value to be covered throughout life which is difference of purchasing cost and residual value.

iii) Calculation of per hour cost which allows the coverage of net value by following formulae.

$$\text{Cost per Hour to cover net value} = \frac{\text{Purchasing cost}(P) - \text{Residual Value}(S)}{N = \text{Life of equipment}(\text{in hours})}$$

iv) Calculation of per hour cost to be covered due to insurance and taxes levied on equipment by following formulae.

$$\text{Per Hour Cost} = \frac{\left(\frac{P(N+1)}{2N}\right) \times \text{Annual Rate}(\%)}{\text{Usage Hours/Year}}$$

Hence submission of per hour cost to cover net value and per hour cost to cover amount spent on insurance and taxes gives per hour cost of ownership (C_1).

Following steps are used to calculate ownership cost:-

i) Data related to monthly maintenance cost, per hour fuel/electricity consumption, fuel/electricity cost and operator's monthly salary has been collected by observing equipments working in Patiala-Sangrur Highway Project, from contractors & equipment owners. Converting maintenance cost and operator's wages on per hour basis. (Considered the per day working hours = 8)

ii) Data related to per hour repairing cost including replacement of tire/track from provisions provided by IS 11590:1995 and Caterpillar Performance Handbook.

Submission of all these costs gives total per hour operating cost (C_2).

Hence,

Per hour ownership and operating cost = C_1+C_2

2.3 Methodology for per hour productivity

All the methods and procedures are adopted from the book named "Construction Planning, Equipment and Methods"- by [6] R.L Peurifoy, *The Mc Graw Hill Companies Inc, Edition 7.*

2.4 Machine performance

It is the ratio of per hour O&O cost and productivity. It provides amount in rupees which equipment cost for 1 unit of productivity.

2.5 Validation of results

Rates quoted from the results of per hour ownership and operating cost are compared with the rates available in "Delhi Schedule of Rates 2014"- Central works department (India). Results for per hour productivity of equipments working at an efficiency of 50/60 minutes are compared with pre-estimated values by the contractors of the various projects and came out to be considerable.

3. RESULTS AND DISCUSSION

3.1 Data for calculation of O&O cost

Following tables (Table 1-5) represent the data related to purchasing cost, maintenance cost, per hour insurance/taxes to covered considering overall percentage of 20%, operator's wages on monthly basis which can be converted to hourly basis considering 8 hours working in a day, life of equipment and per hour fuel consumption of equipment when working at its full efficiency of 50/60 minutes considering diesel cost to be Rs.50/liter and electricity consumption cost to be Rs.10/Kwh.

Table -1: Purchasing cost of equipment

S.No	Equipment	Purchasing Cost
1	Excavator	₹ 40 Lakh
2	Grader	₹ 65 Lakh
3	Backhoe Loader	₹ 26 Lakh
4	Loader	₹ 18 Lakh
5	Soil Compactor	₹ 20 Lakh
6	Tandem Roller	₹ 27 Lakh
7	Tipper Truck	₹ 20 Lakh
8	Paver	₹ 55 Lakh
9	Hot Mix Plant	₹ 3.5 Crore

Table -2: Monthly maintenance cost of equipment

S.No	Equipment	Amount
1	Excavator	₹ 14,500
2	Grader	₹ 24,000
3	Backhoe Loader	₹ 12,000
4	Loader	₹ 12,000
5	Soil Compactor	₹ 12,500
6	Tandem Roller	₹ 12,500
7	Tipper Truck	₹ 10,000
8	Paver	₹ 26,000
9	Hot Mix Plant	₹ 120,000

Table -3: Per hour fuel consumption

S.No	Equipment	Type of Fuel	Quantity
1	Excavator	Diesel(liters)	13 to 15
2	Grader	Diesel(liters)	20 to 21
3	Backhoe Loader	Diesel(liters)	10 to 12
4	Loader	Diesel(liters)	12
5	Soil Compactor	Diesel(liters)	20
6	Tandem Roller	Diesel(liters)	14 to 16
7	Tipper Truck	Diesel(liters)	10 to 13
8	Paver	Diesel(liters)	18 to 20
9	Hot Mix Plant	Electricity(KwH)	96 to 110

Table -4: Operator's wages and per hour insurance/taxes cost to be covered

S.No	Equipment	Operator's wages	Per hour cost for insurance and taxes
1	Excavator	₹ 16,000	₹ 370
2	Grader	₹ 24,000	₹ 600
3	Backhoe Loader	₹ 17,000	₹ 200
4	Loader	₹ 16,000	₹ 145
5	Soil Compactor	₹ 15,000	₹ 200
6	Tandem Roller	₹ 14,500	₹ 250
7	Tipper Truck	₹ 12,000	₹ 110
8	Paver	₹ 22,000	₹ 370
9	Hot Mix Plant	₹ 150,000	₹ 3500

Table -5: Life of equipment and repair provisions by IS 11590:1995

S.No	Equipment	Life in Year	Life in Hours	Percentage of Repair provisions
1	Excavator	10	12000	100%
2	Grader	10	30000	200%
3	Backhoe Loader	10	15000	200%
4	Loader	8	12000	200%
5	Soil Compactor	8	10000	100%
6	Tandem Roller	8	10000	100%
7	Tipper Truck	8	16000	175%
8	Paver	6	9000	200%
9	Hot Mix Plant	5	5000	100%

3.2 Results for O&O cost

Calculations performed for per hour O&O cost with the help of data given above gave following results represented in table-6.

Table -6: Per hour O&O cost

S.No	Equipment	Per hour O&O cost
1	Excavator	**₹ 1,850**
2	Grader	**₹2,750**
3	Backhoe Loader	**₹ 1,550**
4	Loader	**₹ 1,300**
5	Soil Compactor	**₹ 1,700**
6	Tandem Roller	**₹ 1,500**
7	Tipper Truck	**₹ 1,000**
8	Paver	**₹ 3,150**
9	Hot Mix Plant	**₹ 17,000**

3.3 Results for productivity

3.3.1 Excavator

For bucket capacity of 1.5m^3, fill factor 80% and cycle time of 30 seconds including loading bucket, swinging, dumping and return of bucket following calculation gave its per hour productivity;

$$\text{Production rate} = \frac{3600\text{ sec} \times 1.5 \times 80\%}{30\text{ sec}} \times \frac{50}{60} = 120\text{ cum/hr}$$

Hence an excavator excavated **120 cubic meter** of material in volume in one hour for bucket capacity of 1.5m^3 and working at minimum efficiency of 50 min per 60 min.

3.3.2 Backhoe loader and loader

Similarly as above a back hoe loader and loader with capacity 3m^3 loaded **114 cubic meter** of material in one hour and with hoe capacity of 0.6m^3 did same work for **75 cubic meter** of material in one hour.

3.3.3 Tipper truck

With struck volume capacity of 10m^3 and bucket filling the tipper had volume of 1.5 m^3 so 6 to 7 buckets were required to fill the tipper truck with loading time of around 3-3.5 minutes. Haul time of loaded tipper observed for 30 and 25 km of hauling distance and at hauling speed of 35 kmph was 51 and 43 minutes respectively. Return time for the empty tipper for distance of 30 and 25 km with hauling speed of 55 kmph was observed to be around 33 and 27 minutes respectively

Dump time for truck including congestion at dumping area was 2 minutes. Therefore truck cycle time including load time, dump time, haul time and return time for distances 30 and 25 km came out to be 89 and 75 minutes respectively. Also for an undisturbed function of excavator loading the tipper truck for distances of 30 and 25 km required 45 and 38 number of trucks respectively.

With all the above mentioned data the per hour productivity of tipper to transport material while working at full extent with efficiency of 50 min per 60 minute came out to be **252 cubic meter.**

3.3.4 Grader

Following data is used to calculate time estimate of grader; 6 number passes are made (including mixing, levelling and final shaping) for distance of 1km travelled in one pass at an average speed of 5 kmph therefore it **2 hours** to complete the task of grading 1km of distance with minimum of 6 number of passes.
For productivity considering blade length 3.17 m (For actual blade length of 3.6 m and 30 degree blade angle), maximum efficiency of 60% and distance of 1 km to be travelled in one pass and total number of 6 passes to be made per 1 km, following calculation shows per hour productivity of grader in an hour

$$\text{Production(Sq.m/Hr)} = \frac{5 \times 3.17 \times 1000 \times 0.6}{6} = 1585\text{ Sq.m/Hr}$$

Hence it is **1585 m^2/hr** for 6 number of passes

3.3.5 Soil compactor, tandem roller and hot mix plant

For 1.6m of width compacted per pass at a speed of 3kmph and compacted lift thickness considered 150 mm and total number of passes made are 8 by soil compactor then it gives **60 cubic meter** of productivity in one hour.

$$\text{Production}\left(\frac{\text{cum}}{\text{hr}}\right) = \frac{1.6 \times 3 \times 150 \times \left(\frac{40\text{min}}{60\text{min}}\right)}{8} = 60\text{ cum/hr}$$

Similarly for tandem roller (Volvo-DD110B) per hour production is **30 cum/hr** (Considering 4 passes and 90 mm lift thickness for DBM and BC).

(As per IS: 3066-1965 and IS: 5890-2004) The capacity of hot mix plant is given in terms of tones per hour. It is specified in following manner x/y tons per hour, given for two different values of moisture content in aggregate. Where; (x) is for 6% of moisture content in aggregates and (y) is for 2% of moisture content in aggregate. Productivity per hour of plant depends on its capacity. Though an output analysis can be done to calculate time period required to achieve desired quantity to lay flexible pavement. The plant used in projects had capacity of 90/120 Tones per hour and production was maintained at **90 tons per hour**.

3.3.6 Paver

Production of paver should be such that it balances with the production of hot mix plant. Hence the average speed of the paver can be accounted considering that paver is also paving 90 tons of material per hour to balance the production of hot mix plant. Calculations are as follows for Hot mix plant production = 90 TPH, DBM thickness = 110 mm, one time paving width = 3.5 m and considering density of material = 2.2 Ton /m^3. Hence,

Volume of material per Km= 3.5m x 0.11m x 1000m =385 cum /Km

Weight of material per Km= 385 x 2.2 = 847 Ton/km

Therefore,

Average speed of paver to be maintained= 90/ 847 = 0.106 Km/hr

Or, we need to cover 106 m in one hour to maintain balance between plant production and paving. Also, in actual trend distance covered per hour was 100 m

In terms of cubic meter per hour = 100m x 0.11m x 3.5 m ≅ 40 m^3/hr. **Result = 40 cubic meter per hour.**

4. CONCLUSIONS

From this research based case study, it is concluded that:-
Excavator cost ₹ 15 per cubic metre of excavation. (It is equipment's performance which is ratio of per hour cost and productivity).Grader costs ₹ 1.5 to ₹2 per square metre for 6 numbers of passes. Backhoe loader costs ₹21 per cubic metre of material loading by loader and ₹14 per cubic metres by hoe. Loader costs ₹11 per cubic metre of material loading. Soil compactor costs ₹28 per cubic metre of material compacted. Tandem roller costs ₹50 per cubic metre of bituminous layer compacted. Hot mix plant costs ₹190 per ton production of of DBM and BC material. Tipper truck costs ₹4 for transportation of 1 cubic metre of material. Paver costs ₹80 for paving per cubic metre of bituminous material in flexible pavement. Dozer costs ₹8 for dozing per cubic metre of material. This per unit productivity cost can be used as reference for tendering purposes or for pre estimation of percentage of project cost for equipments and their operators. To have uninterrupted transportation and loading of material for 30 km hauling distance 45 trucks are required and for 25 km hauling distance 38 trucks are required.4 days are required by Hot mix plant for production of mixes for 1 km road stretch. Paver must cover 100 m of distance in an hour to balance production in hot mix plant. This per hour productivity will help in time estimation of each activity in flexible pavement construction comprising equipments for planning purposes or we can say time of usage of each equipment can be estimated and managed to prevent idling of equipment on the site hence preventing losses.

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