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OPTIMUM UTILIZATION OF CONSTRUCTION EQUIPMENTS FOR HIGHWAY PROJECT

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Abstract : A large share of investment funds in all developing countries is finding a way to construction. In India, construction industry is growing rapidly with the development of infrastructure projects, so construction equipment is an important resource. Due to time and quality restrictions, highway construction projects consume a large amount of resources on and off the field in the form of plants and equipment. As a result, it is necessary to optimize these activities in order to save costs. Construction equipment plays a crucial part in four-lane construction, accounting for up to 36% of overall project expenses. However, equipment maintenance has not received adequate attention, resulting in a 40% cost overrun. The purpose of this research study is to examine the most efficient use of construction equipment for the National Highway project. It also contains a cost-benefit analysis of equipment in terms of output, time, and cost. Production capacity, effective working hours, and equipment cost are all taken into account when performing these optimizations. A case study of four lanes of the Chikhali-Tarsod Highway Projects under section Nh-6 (Jalgaon) is used to validate the results.

Index Terms **- Equipment economics, Productivity, Total cost, Optimization.**

I. INTRODUCTION

Equipment plays a significant part in highway construction since earthwork accounts for a large portion of total construction costs; therefore their cost and productivity play a vital role in making the project viable for the company. As a result, if accuracy in estimating ownership and running costs, equipment productivity, and a practical method of procuring equipment is accomplished, the project can be designed with more precision and at a lower cost [1].

Each stage of application, such as sub grade, granular sub-base, dry lean, and pavement quality concrete, necessitates a separate set of equipment. The goal of equipment productivity control is to figure out how long it will work, how much it will produce, and how productive it will be on the job. The primary goal of equipment productivity control is to reduce waste and save money [2].

Planning for the development of detailed cost estimates and schedules is one of the first jobs to be completed on any project. The more accurate the results of the estimator's study are, the better the historical data available to him. This includes deciding which sort of equipment to utilize for a specific project as well as the actual performance qualities of specific equipment components. Factors such as construction methods employed and labour and equipment management are used to determine a contractor's ability to secure a contract and profit from it. Planning and estimates are done before any project is executed; so, if we can accomplish accuracy in terms of calculating the running cost, productivity supplied by equipment, and possible ways of purchasing equipment, we can plan our project with greater precision. Despite the availability of scheduled rates, we are unaware of or do not pay attention to the elements that influence the computation of these numbers (3).

The goal of this research paper is to conduct an output and economic study of highway construction equipments and, as a result, offer results on various aspects affecting ownership and operating costs on a per hour basis when the equipment is used to its maximum potential. This research study calculated overall owning and operating costs of selected equipments including Hydraulic Excavator (Backhoe Loader), RMC Plant, HMP, Bitumen Paver, and Tandem Road Roller for a selected case study (4).

II. RESEARCH METHODOLOGY

2.1 Data

Data for this study was gathered from live highway construction projects on the four lanes of the Chikhali-Tarsod Highway section Nh-6 (Jalgaon), India, including values for landed cost, ownership cost, operating cost, maintenance cost, and so on for equipment from construction equipment workers and retailers. Observing equipment on the Chikhali-Tarsod highway construction project provided data for calculating equipment productivity, such as excavator bucket capacity, quantity of concrete produced and effective working hours for RMC and Hot Mix Plant, speed of bitumen paver & road roller, and so on.

For this research paper, methodology is adopted in following two ways,

a. Methodology for calculating the cost of ownership, operating, and per hour landed:

The overall cost of construction equipment is split into two parts: ownership and operating costs (also known as O & O cost of construction equipment). Depreciation, interest, and insurance costs are all included in the cost of ownership (12 percent of book value). The number of operating hours, location of the job site, operating circumstances, and category of equipment all affect the equipment's running cost. Maintenance, fuel, and equipment operator wages are included in the operational costs.

The steps for calculating the cost of equipment are as follows: -

i. Data collected from retailers on the landed/purchasing cost and residual value of equipment Data acquired from retailers, IS 11590:1995, and manufacturer performance reports on the operating life of equipment (age of equipment) in hours (Caterpillar Performance Handbook, 2015).
ii. Calculation of the landed/purchasing cost of equipment by adding the Basic cost, 18 percent GST on the Basic cost, and
iii. Transportation/Installation costs received from equipment manufacturers/sellers/owners over the life course.
iv. Determining the net value of ownership costs that will be covered over the equipment's lifespan.
v. Data on monthly maintenance costs, per hour fuel/electricity consumption, fuel/electricity cost, and operator's monthly salary was collected by observing equipments working on the Chikhali-Tarsod Highway Project, collecting operating cost data from contractors and equipment owners, and then converting maintenance costs and operator's wages to per hour basis. (Based on a ten-hour workday).
vi. Finally, using equations, calculate per-hour costs that allow for net-value coverage.
vii. Equipment cost per hour = (Landed Cost + Ownership Cost + Operating Cost + Maintenance Cost) /Effecting working hours.

b. Methodology for calculating per hour productivity:

All of the methods and procedures were taken from [6] R.L Peurifoy's book "Construction Planning, Equipment, and Methods," published by The Mc-Graw Hill Companies Inc in Edition 7.

III. DATA COLLECTION

3.1 Description of the case study

For data collection, case study of National Highway NH-6 (Package –IIA) is selected. From project data, condition of existing equipment management is observed. The method of construction in pavement and working of each equipment are thoroughly studied and further output &cost analysis of each equipment is performed.

The Package-IIA of the project highway starts at Tarsod from km 360.000 to km 422.700 in Jalgaon District and ends at Chikhali in Buldhana district observed total length is 62.7 km. The project is located in the State of Maharashtra to be executed on Hybrid Annuity (DBOT Annuity) by National Highway Authority of India (NHAI).

3.2 Data collection

Data related to each equipment performance and cost was collected from contractor's records from site for primary data collection from the months of 'October 2020' to 'May 2021.' Fuel consumption, maintenance costs, labour operating costs, and equipment working hours were gathered for further production and economic analysis.

IV. RESULT ANALYSIS

One resource for each activity plays a critical role in highway projects, and this resource is referred to as the driving resource. The productivity of the entire activity is determined by equipment performance, and the final output is defined as that resource's output. For the months of October 2020 to May 2021, this chapter includes a cost analysis for five equipments: Hydraulic Excavator (Backhoe Loader), RMC Plant, HMP, Bitumen Paver, and Tandem Road Roller.

4.1 Productivity Analysis

a. Theoretical Productivity Calculation for Hydraulic Excavator:

The highway site at Ch. 381 km to 410 km having bucket size of 1.20 m3 and 3 dumpers used of 10 cum. Work is in progress from Ch. 381 km + 10 km to dump site at 410+05 (Borrow area), having lead of 5.0 km and height of cut is 1.5 m.

i. Size of bucket (Q) = 1.2 m3
ii. Material = Rock & Earth mixture
iii. Hence, Bucket fill factor= 1.05 Depth of excavation is 1.5 m, which is 30 % to 45 % of maximum depth.
iv. Height and Swing factor
v. Average height of excavation = 2.0 m
Optimum height = 50 % of maximum height = 2.0 x 0.5 = 1.0 m
Optimum height in %= (1.5 x 100) /1 = 150
Therefore, Height and Swing factor, (AS:D) = 0.875
vi. Cycle times (t) = 21 seconds
vii. Efficiency factor (F), 45 – min/hour (Assumed)
Class of material (Earth & wet) swell factor is 80 %.

$$\text{Production rate} = \frac{3600\text{sec} \times Q \times F \times (AS:D)}{t} \times \frac{E}{60} \times \frac{1}{\text{Volume correction}}$$

$$= \frac{3600 \times 1.2 \times 1.05 \times 0.875}{21} \times \frac{45}{60} \times \frac{1}{(1 + 0.8)}$$

= 78.75 cum / hr.

viii. Convert production cum /hr. to tons/hr.
Hence, Production = 78.75 x 2.5 = 196.88 tons/hr.

ix. Match Excavator to available dumper
Loading time dumper = No. of bucket passes x hoe cycle time
No. of bucket = Payload Hauler/ Payload Bucket= 1.2 x 1.1= 1.43 m3
Ideal no of passes = 13 m3 / 1.43 m3 = 9.09 …Take 9
But, actual no. of passes = 12
Total loading time – For 9 passes = 2.25 min,
For 12 passes = 3.0 min.

x. Haul time = 12.8 min

xi. Return time = 5.5 min, Dump time = 2.0 min

xii. Truck cycle time =
For 9 passes, truck cycle time = 22.55 min
For 12 passes, truck cycle time = 23.3 min
Dumpers required = Truck cycle time/ truck load time
For 9 passes, No of dumpers = 22.55/ 2.25 = 10.02
For 12 passes, No of dumpers = 23.3/ 3.0 = 7.77

xiii. Production =
For 9 passes, 2.25 min, Production (excavator) = [45 min/hr. x (1.2 x 10 cum)] / 2.25
= 240 m3/hr.(Optimized Output)
For 12 passes, 3.0 min, Production (excavator) = [45 min/hr. x (1.2 x 10 cum)] / 3.0
= 180 m3/hr. (Actual Output)
For 9 passes, 10 no, 22.55 min Production (dumper) = [45 min/hr x 1.2 x 10 cum x 10 nos.] / 22.55
= 239.47 m3/hr
For 12 passes, 8 no, 23.3 min Production (dumper) = [45 min/hr x 1.2 x 10 cum x 8 nos.] / 23.3
= 185.41 m3/hr

b. Theoretical Output Productivity Calculation for Ready Mix Concrete Plant = 60 m3/hr. (Plant Capacity).

c. Theoretical Bitumen Paver Productivity Calculation

Hot mix plant production	- 160 TPH
DBM thickness	- 100 mm
Paving Width	- 9.0 m
Considering density of material	- 2.2 Ton / m3

Hence,
Vol. of material per km = DBM tk. x Paving Width
= ((100 x 9.0 x1000)/ 1000) = 900 cum / km
Wt. of material per km = Vol. of material x density of material
= 900 x 2.2 = 1980 Ton / km

Therefore, Average speed of paver to be maintained = (Hot mix plant production) / (Wt. of material per km)
= (160 / 1980)= 0.081 km / hr.

Or, we need to cover 81 m in one hour to maintain balance between plant production and paving. Also, in actual trend distance covered per hour was 100 m. Therefore,

Output in cum / hr. = Actual trend distance x DBM thickness x Paving Width
= 100 m x 0.1 m x 9.0 m
= 90 m3/hr.

d. Theoretical Output Productivity Calculation for Hot Mix Plant = 160 TPH = 64 m3 / hr. (Plant Capacity)

e. Theoretical Output Productivity Calculation for Tandem Road Roller
Compaction width (W) = 2.0 m
Roller speed in kmph (S) = 3.0
Number of roller passes (P) = 6… (98.88% compaction achieved)
Efficiency factor (E) = 50 min/hour (Assumed),
Compacted lift thickness in mm (L) = 100 mm Production = (W x S x L x E) / P
Production = (2.0 x 3 x 100 x 50) / (60 x 6)
= 83.33 m3/hr.

Table -1: Performance of Equipment

Sr. No.	Name of Equipment	Theoretical Output (m3/hrs)	Effective Production (m3/hr.)	Net Production m3/hr.	Output Efficiency in %
1	Excavator	78.75	39.48	25.13	**50.13**
2	RMC Plant	60.00	23.88	15.80	**39.79**

3	Bitumen Paver	90.00	64.80	51.84	**72.00**
4	HMP	64.00	28.04	19.20	**43.82**
5	Road Roller	83.33	58.76	49.72	**70.51**

Table -2: Utilization of Equipment

Sr. No.	Name of Equipment	Planned Available Hours	Actual Working Hours	Utilization in %
1	Excavator	520	296.25	**63.65**
2	RMC Plant	260	172.00	**66.15**
3	Bitumen Paver	260	208.00	**80.00**
4	HMP	260	178.00	**68.46**
5	Road Roller	260	220.00	**84.62**

4.2 Cost Analysis

The monthly landed cost of each equipment is calculated by considering purchase cost, age of equipment, GST cost and transportation / installation charges associated with per working hours in month of October 2020.

Table -3: Hourly Landed Cost of equipment

Sr. No.	Name of Equipment	Age (yrs.)	Landed Cost in Rs.	Monthly Working hour	L. C. per working hour in Rs.
1	Excavator	2.4	2413395.00	296.25	24485.21
2	RMC Plant	2.2	7500000.00	172.00	24543.38
3	Bitumen Paver	1.11	18880000.0	177.50	114767.12
4	HMP	2.1	38468000.0	178.00	130275.95
5	Road Roller	1.8	2800730.00	205.00	19662.66

The monthly ownership cost of each equipment is calculated by considering Depreciation cost, Interest cost, Insurance cost (12 % of book value) associated with it.

Table -4: Hourly Ownership Cost of equipment

Sr. No.	Name of Equipment	Depreciation cost in Rs.	Interest cost in Rs.	Insurance cost in Rs.	Ownership Cost per working hour in Rs.
1	Excavator	103723.82	12242.61	8161.74	124128.16
2	RMC Plant	476718.40	22089.04	14726.03	513533.47
3	Bitumen Paver	1786830.1	57383.56	40168.49	1884382.23
4	HMP	1695716.6	117248.3	78165.57	1891130.62
5	Road Roller	538854.67	9831.33	6881.93	555567.93

The monthly operating cost of each equipment is calculated by considering fuel consumption cost, Operating manpower cost, Helper or cleaner cost, Quality engineer cost etc. associated with it. Summary of the equipment operating cost per hour for equipment which is major cost effective is given below.

Table -5: Hourly fuel consumption

Sr. No.	Name of Equipment	Standard Consumption lit / hours	Monthly Avg. Mileage (Litres/hour)	Monthly Working hour	Fuel consumptio n cost in Rs.
1	Excavator	16-18	16	296.25	379200.0
2	RMC Plant	6-8	6	172.00	82560.00
3	Bitumen Paver	12-14	12	177.50	170400.0
4	HMP	12-14	12	178.00	170880.0
5	Road Roller	10-12	10	205.00	164000.0

Fuel Cost per Liter = Rs. 80 /-

Table -6: Hourly Labour cost

Sr. No.	Name of Equipment	Labor Type	Salary Per Month in Rs.	Monthly Working hour	Operating manpower cost in Rs.
1	Excavator	Operating Manpower	18000	296.25	7167.34
		Helper	8000		3185.48
		Quality Engineer	30000		11945.56
2	RMC Plant	Operating Manpower	18000	172.00	4161.29
		Helper	8000		1849.46
		Quality Engineer	30000		6935.48
3	Bitumen Paver	Operating Manpower	20000	177.50	4771.51
		Helper	8000		1908.60
		Quality Engineer	30000		7157.26
		Operating Manpower	28000	178.00	6698.92
		Helper	8000		1913.98
		Quality Engineer	30000		7177.42
5	Road Roller	Operating Manpower	18000	205.00	4959.68
		Helper	8000		2204.30
		Quality Engineer	30000		8266.13

No. of Working Day = 31, Hour/day =24

Table -7: Hourly Operating Cost of equipment

Sr. No.	Name of Equipment	Age (yrs.)	Monthly Working hour	Operating Cost per working hour in Rs.
1	Excavator	2.4	296.25	401498.38
2	RMC Plant	2.2	172.00	95506.23
3	Bitumen Paver	1.11	177.50	184237.36
4	HMP	2.1	178.00	186670.32
5	Road Roller	1.8	205.00	179430.10

Table -8: Hourly Maintenance Cost of equipment

Sr. No.	Name of Equipment	Age (yrs.)	Monthly Working hour	Maintenance Cost in Rs.
1	Excavator	2.4	296.25	12305.00
2	RMC Plant	2.2	172.00	5000.00
3	Bitumen Paver	1.11	177.50	26685.00
4	HMP	2.1	178.00	12000.00
5	Road Roller	1.8	205.00	470.00

Table -9: Per hour O&O Cost of equipment

Sr. No.	Name of Equipment	Monthly Working hour	Total Equipment Cost in Rs.	Per hour O&O cost in Rs.
1	Excavator	296.25	562416.76	1898.45
2	RMC Plant	172.00	638583.09	3712.69
3	Bitumen Paver	177.50	2210071.72	12451.11
4	HMP	178.00	2220076.89	12472.34
5	Road Roller	205.00	755130.70	3683.56

V. CONCLUSIONS

Equipment arranged in the highway project sites are normally found to be of two categories i.e. driving and non-driving.

1. The effective production rates of the hydraulic excavator (Backhoe Loader) equipments is found to be nearly 39.48 cum/hr. which is less than theoretical production 78.75 cum/hr. From productivity analysis performed, actual excavator-dumper using 10 dumpers and 12 bucket passes has production Rs. 180 cum/hr. But, optimized production is found for 8 dumpers and 9 bucket passes which is Rs. 240 cum/hr. Excavator production cost is found on site is Rs. 1898.45 cum/hr.
2. The effective production rate of the RMC Plant & Hot Mix Plant at site is found to be around 23.88 cum/hr. & 28.04 cum/hr. as the capacity of plant is 60cum/hr. & 64 cum/hr and the production cost for RMC Plant is found nearly Rs. 3712.69 cum/hr& for Hot Mix Plant at site is Rs. 12472.34 cum/hr.
3. Similarly, the effective production rate of the Bitumen Paver & Tandem Roller in a site is calculated to be around 64.80 cum/hr. & 58.76 cum/hr. as the theoretical production is 90cum/hr. & 83.33 cum/hr and the production cost for Bitumen Paver is found on site is Rs. 12451.41 cum/hr& for Tandem Roller for achieving 98.88 % compaction is Rs. 3683.56 cum/hr.
4. When evaluating at the availability and utility of the equipments, the gap in performance becomes clear. The use of the equipments is generally low, ranging from (20-60%) percent, showing that the equipments are poorly planned and maintained on the job site.
5. The effect of Covid 19 had continuous impact in construction industry causing delay in activities scheduled, unavailability of man power which has a clear reflection in October 2020-May 2021. Therefore, performance of equipments can be seen in below average range for the same period.
6. The total cost of the equipments is primarily proportional to the landed cost, ownership cost, operating cost, and maintenance cost, with more variation due to working hours, as the second wave of Covid 19 arrived, and the worst part is that we were not prepared for it by any means, hoping it would not arrive. In reality, compared to the impact of the first wave in metro cities and urban areas, the second wave proved to be more harmful and had a much greater influence on the increase in Covid patients in urban areas. As a result, it accounts for the lion's share of total spending (40-50%).

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