Construction Equipment Fleet Management: Case Study of Highway Construction Project

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Abstract: ***Large numbers of construction equipment are required on construction site. The efforts of contractors are to constantly push machine capabilities forward. As the array of useful equipment expand, the importance of careful planning and execution of construction equipment's increases. The objective of the project is to predict the fleet production rate and to optimize the number and size of equipment's in the fleet to match the equipment to project situations. Equipment economics is taken into consideration for the optimization.***

Keywords: Productivity Analysis; Optimization; Ownership and Operating Cost

1. Introduction

Large contractors have been steadily increasing their investment in construction equipment to satisfy their needs in response to increased construction volume in recent years. The technical advancement of earthmoving equipment during the 20th century includes many improvements in key parts of machines making the machine mechanically more efficient. Hence major large construction operations and mega projects uses a large number of various construction equipments. This group of equipments collectively forms a Fleet.

The fleet operations have become complex due to a large number of manufacturers, various capacity and sizes of equipment available which makes the equipment selection a crucial task. After equipment selection the complexity further increases to optimize the size and number construction equipments in the fleet.

Moreover large and highly competitive markets for infrastructure projects especially BOT type of contract, enforces the contractors to complete the project as early as possible to start regaining the investments. This demands a continued improvement in the performance of construction equipments. Hence there is a need of application of management techniques and systems in managing the fleet to complete projects on budget, on schedule, safely, and according to plans and specifications.

Construction Equipment fleet management at its basic level addresses the problem of managing fleets of various construction equipments stationary as well as mobile such as dumpers, excavators, shovels, scrapers, belt conveying systems, graders, pavers, rollers, cranes, HMA plant, RMC plant, transit mixers, etc. Use of Equipment fleet management increases the productivity of overall site and increases the profitability through a proper equipment selection & optimization, production monitoring, tracking of equipments, maintaining a maintenance schedule, etc. Use of various sophisticated tools & techniques can be used for the same such as the telematics, GPS navigation, information transmission systems & various software's.

Fleet Management consist of conceptual sub-components such as equipment selection and assignment, equipment optimization, maintenance, production monitoring, material and position monitoring, etc.

The scope of this work is limited to equipment optimization and benefit analysis at the site through equipment production analysis. The case selected for the project is a highway construction project where considerable amount earthwork is involved.

This project mainly aims to achieve optimum equipment utilization by construction equipment's fleet management.

2. Research Goals

The main goal of the research was equipment optimization and benefit analysis at the site through equipment production analysis. The specific goals of the research included the following:

- Study the highway construction site for current practices of equipment management.
- Perform equipment productivity analysis to optimize the current composition of the earth/material moving fleet.
- Recommend changes to the company to assure the optimum level.
- Perform benefit analysis by comparing the current composition and the recommended theoretical fleet and recommended available fleet.

3. Research Motivation

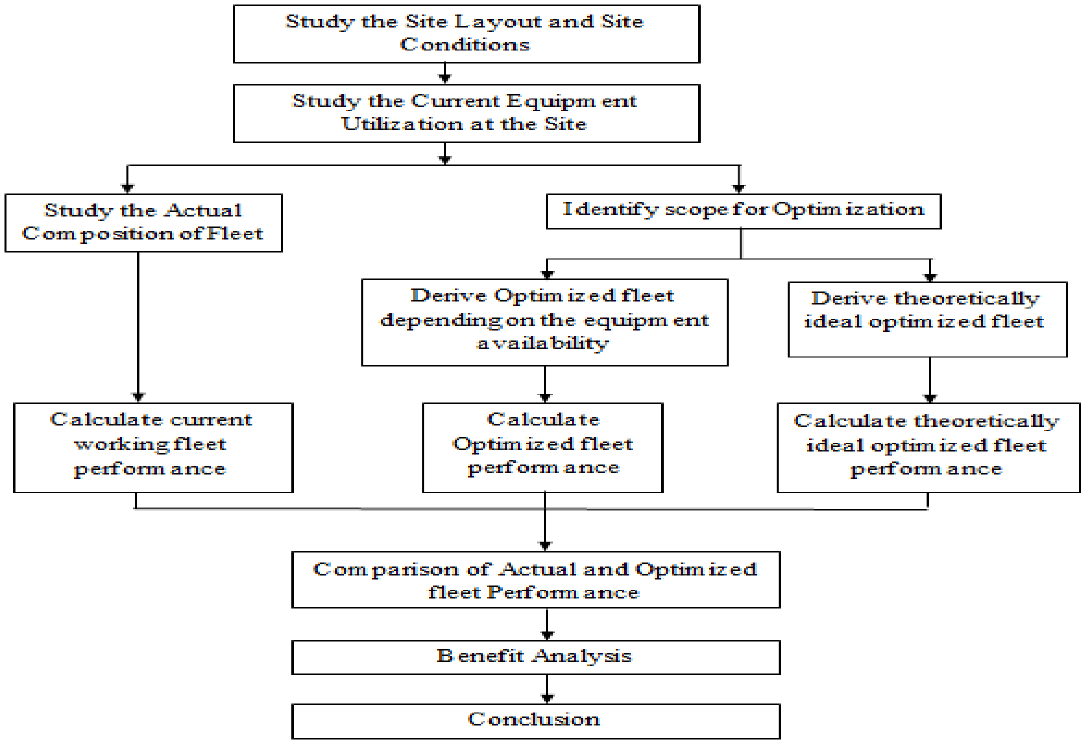
There is lack of effective management of construction equipment's even though large capital investments are made in procurement and operation of the equipment. The cost of construction equipment involved in a project may sometime exceed the cost of the project. Ineffective management of equipment leads to loss in production, delayed production and hence leads to reduced overall profitability of the firm.

Moreover the current practice of equipment is based on experience and equipment availability. There arises problem of loading equipment waiting or hauling unit bunching.

Tipper bunching or queuing will reduce production 10 to 20 % of the ideal production (peurifoy pg.309). Thus there is a scope for equipment optimization of assigned equipment's on a construction project.

4. Methodology

The methodological flow chart shown in figure describes the steps that were followed to achieve the main objectives of the project.



5. EquipmentProductivity Analysis

Production of each equipment involved in the fleet is manipulated as actual and theoretical using the performance charts and other parameters such as distance, speed, number of trips, capacity, cycle time etc. using various mathematical formulae. The unit of measure for the production is always quantity of material excavated or moved on hourly basis i.e. m^3/hr.
Various mathematical standard formulas are used for the direct production calculations for the respective equipment as follows:

1. Excavator output $= \frac{3600 \text{ X Q X F X E X V.C.}}{\text{T}}$
Q = capacity of bucket in m^3 loose
F = fill factor
E = operator efficiency
V.C. = soil conversion factors
T = excavator cycle time (sec)

2. Tipper output $= \frac{\text{V X 60}}{\text{T}}$
v = tipper body volume (m^3)
T = tipper cycle time (min)

3. Dozer output $= \frac{\text{60 X L}}{\text{T}}$ X f X E
L = blade load (m^3)
T = dozing cycle time (min)
f = material type correction factor
E=Efficiency

5. Vibratory Roller Output: $\frac{\text{W X S X L X E X 0.9}}{\text{n}}$

S = avg. roller speed (kmph)
L = compacted lift thickness (mm)
E= operator efficiency
n = no. of roller pass

Parameters: Following are the important parameters required for the productivity calculations;

Capacity: The capacity of each equipment is denoted in m3 measure such as the bucket capacity in excavator or body capacity in case of tipper. This is found out by standard dimensions of each equipment given by the manufacturing company. The equipment's are generally filled at its heaped capacity and not at its struck volume. The struck capacity is that volume actually enclosed by the bucket, while for the heaped capacity an angle of repose is considered. According to standard conditions angle of repose 2:1 slope is considered.

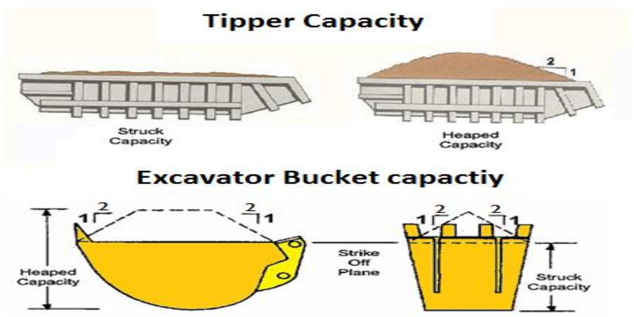


Figure 1: Struck and Heaped Capacity of Volumetric measure

The volumetric measure of the equipment used on the site is given in Appendix-II.

Efficiency

Efficiency factor is the job efficiency of the operator. It is calculated as number of operating minutes per hour divided by 60 min.

Job efficiency for each type of machine operator is calculated by taking mean of the daily machine working time divided by actual working time. The daily machine working time is taken from the timesheets being maintained by the site accountant.
Illustrative calculation:

In the timesheet monthly total is 154.14.

Site working for the month= 27 days.

Avg. Daily working = $\frac{154.14}{27}$ = 6.70 = 6:42 hrs.

Daily efficiency out of 8hrs.working day = $\frac{6.7}{8}$ = 0.83.

The timesheets given in appendix-II are used for efficiency calculations.

Fill Factor

According to the type of material being handled, fill factor corrections are applied. Fill factors account for the void spaces between individual material particles of particular type of material when it is loaded into an excavator bucket. Materials such as sand, gravel, or loose earth should easily fill the bucket to capacity with a minimum void space. At the other extreme are the bulky-shaped rock particles. If all the particles are of the same general size, void spaces can be significant especially with large size pieces.

Fill factor are the percentage that, when multiplied by heaped capacity, adjust the volume by accounting for how the specific material will load into the bucket. Fill factor can also be called as bucket efficiency factor. Refer to fill factor table in Appendix-II.

Cycle Time

The sum of time required to complete one production cycle is the cycle time for equipment. The cycle time consist of different elements for different equipment's. Typical cycle time elements for different equipment are as follows:

Excavator:
1. Excavate/load bucket
2. Swing with load
3. Dump load
4. Return swing

Hauler:
1. Load
2. Haul
3. Dump
4. Return

Dozer:
1. Push
2. Return
3. Maneuverer

The cycle time for the equipment's involved in the operation are taken by the mean value of the actual observations taken.

Soil Conversion Factors

Soil Volume is measured in one of the three states:
Bank volume: It is the measure of material as it lies in the natural state.
Loose volume: It is the measure of material after it has been disturbed by a loading process.
Compacted volume: It is the measure of material in the compacted state.

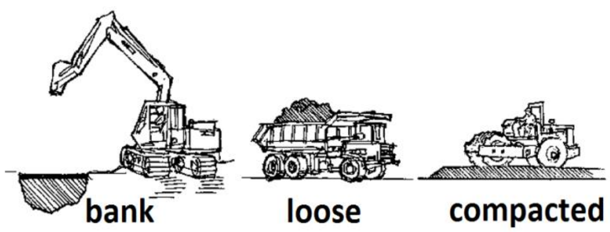


Figure 2: Material Volume changes caused by processing

As the bucket of excavator will handle earth in loose measure, to obtain equivalent bank measure soil conversion factors in Appendix-II are applied.

Fleet Concept

To accomplish a task, machines usually work together and are supported by auxiliary machines. To accomplish a loading, hauling and compaction task would involve an excavator, several haul units, and auxiliary machines to distribute the material on the embankment and achieve compaction.

Such groups of equipment are referred to as equipment fleet/spread. An excavator and a fleet of trucks can be thought of a linked system, one link of which will control the fleet production. If spreading and compaction of the hauled material is required a two linked system is created. Because the systems are linked, the capabilities of individual components of the fleet must be compatible in terms of overall production i.e. the compaction equipment used on a project must have production capability matched to that of excavation, hauling, and spreading equipment.

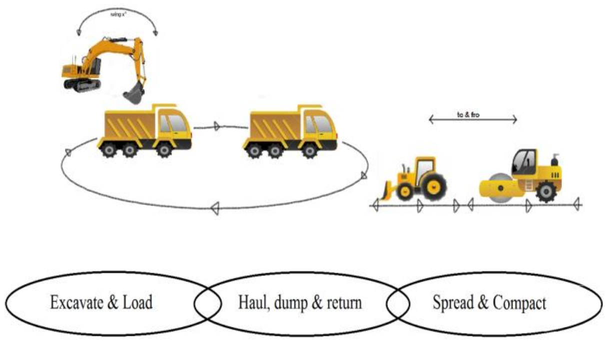


Figure 3: Three link earthwork system

The number of machines and specific types of machines in a fleet will vary with the proposed task. The production capacity of the total system is dictated by the lesser of the production capacities of individual systems.

Equipment Economics

The economics of any equipment in a company is associated with equipment ownership and operation. Ownership expense is the cumulative result of those cash flows the company experiences whether or not the machine is productively employed on a project. Operating cost is the sum of those expenses an owner experiences by working a machine on a project.

Equipment cost is often one of a contractor's largest expense categories. The only reason for purchasing equipment is to perform work that will generate a profit for the company. Expense associated with the productive machine work is often associated with ownership and operating (O&O) cost. O&O cost is expressed in Rupees per machine operating hour. Most of information required for ownership and operating is available in the company's accounting records.

Ownership Cost

The cash outflow the firm experiences in acquiring ownership of a machine is the purchase expense. It is the equivalent cost of the machine for the current year considering time and a specific rate of interest and taxes and the insurance premium. It is a cost related to finance and accounting exclusively, and does not include the wrenches and consumables necessary to keep the machine operating. Annualized purchase expense is the required equivalent cost for the amount paid whiles the purchase of equipment.

Annualized purchase expense can be calculated using uniform series capital recovery factor.

$$A\ (\text{ownership}) = P\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$$

Where
P =purchase price
I =interest rate for capital
n = no. of years from purchase

Operating Cost

Operating cost is the sum of those expenses an owner experiences by working a machine on a project. Typical expenses include:

Fuel
Engine oil
Hydraulic oil
Hub greasing
Coolant
Filter
Tyres
Operator wages

Ownership and Operating cost for each of the equipment used on the site is tabulated in Appendix-II.

Optimization of Haul Units

The ultimate goal of optimizing a hauling system is to maximize productivity while minimizing total cost. Therefore, it is conceivable that an optimum equipment mix which is based on physical factors alone may not minimize the cost in every location. Thus, cost factors must be considered equally important to engineering fundamentals.

The loading time (L) for the considered tipper is taken for the given loading facility. These are then added to the travel time to calculate the instantaneous cycle time (C) i.e. tipper cycle time (load + haul + dump + return) and the optimum number of haul units (N) from the following, respectively:

$$N = \frac{C}{L}$$

Where,
N = optimum number of haul units.
C = Tipper cycle time
L = Tipper loading time

A virtual fleet is designed to find out the actual benefits been incurred using optimization of the equipment. The optimum no. of haul units required in each case is designed considering four categories as:

Fleet 1: Optimum No. of 18.52 m^3 MAN tipper (Rounding Up)
Fleet 2: (Fleet 2 - 1) + 9.3 m^3 TATA Tipper
Fleet 3: (Fleet 2 - 1) + 14.95 m^3TATATipper

Table 1: Practised Fleet Equivalent Value

Practised Fleet Equivalent Values								
Case	Actual Individual Values				Equivalent Values			
	Tipper Volume (m3)	Loading Time (min)	Cycle Time (min)	Nos.	Tipper Volume (m3)	Loading Time (min)	Cycle Time (min)	Nos.
1	14.95	11	55.06	2	16.14	11.92	54.82	3
	18.52	13.75	54.33	1				
2a	18.52	13.75	29.85	4	18.52	13.75	29.85	4
2b	14.82	16.83	32.93	4	14.82	16.83	32.93	4
3	18.52	10.3	20.38	1	18.52	10.30	20.38	1
4a	9.3	15.13	50.56	2	14.832	24.45	55.45	5
	18.52	30.67	58.71	3				
4b	9.3	6.6	15.87	2	13.91	10.45	19.15	4
	18.52	14.3	22.42	2				
5	18.52	27	40	2	18.52	27.00	40.00	2
6	9.3	6.6	29.18	2	14.832	10.89	31.62	5
	18.52	13.75	33.24	3				

Table 2: Optimum number of Equipment in each case

Case	Nos. (N)	Tipper Loading Time (L)	Tipper Cycle Time (C)	Optimum NO.	Equivalent
1	3	11.92	54.82	4.60	5
2a	4	13.75	29.85	2.17	3
2b	4	16.83	32.93	1.96	2
3	1	10.30	20.38	1.98	2
4a	5	24.45	55.45	2.27	3
4b	4	10.45	19.15	1.83	2
5	2	27.00	40.00	1.48	2
6	5	10.89	31.62	2.90	3

6. Results

The total time to complete an earth- moving project is merely the total quantity of earth to be hauled divided by the production rate of the hauling system. Once the total hourly project costs are known, they can be multiplied by the TT to find the total cost to complete the project. That figure can then be divided by the total quantity of material to be moved (M) to arrive at a unit cost for a given size and number of haul units.

Thus Total Cost (TC) to complete the project can be described by the following formula:

$$TC = \frac{M(C)(Hn + He)}{N\,(Sh)(60)}$$

Where,
M = Project Quantity (M^3)
C = Tipper corrected cycle time (min)
Hn = Tipper O&O cost
He= Excavator O&O cost
N= Number of Tippers
Sh= Size of Tipper (M^3)

Table 3: Project cost using practised fleet

Actual Fleet Project Cost							
Case	Equivalent						Total Cost (Rs.)
	Quantity (M3)	Tipper Cycle Time (min)	O&O Tipper Cost (Rs./hr)	O&O excavator Cost (Rs./hr)	No. of tippers	Size of tippers (M3)	
1	2986	54.82	619.47	1149.12	3	16.14	169458.3
2a	943	55.00	812.33	1149.12	4	18.52	51324.04
2b	3071	67.32	812.33	1149.12	4	14.82	255660.2
3	1732	20.38	812.33	1149.12	1	18.52	62307.03
4a	1732	122.25	643.21	804.77	5	14.83	191359
4b	1125	41.80	600.93	1149.12	4	13.91	50045.62
5	3523	54.00	812.33	804.77	2	18.52	207964.2
6	4746	54.45	643.21	1149.12	5	14.83	253550.4

Table 4: Project cost using practised Trial fleet1

Trial Fleet 1 Project Cost							
Case	Equivalent Quantity (M3)	Tipper Cycle Time (min)	O&O Tipper (Rs./hr)	O&O excavator (Rs./hr)	No. of tipper	Size of tippers (M3)	Total Cost (Rs.)
1	2986	68.75	812.33	1149.12	5	18.52	192531.6
2a	943	41.25	812.33	1149.12	3	18.52	41845.21
2b	3071	33.66	812.33	1149.12	2	14.82	161226.5
3	1732	20.6	812.33	1149.12	2	18.52	44531.25
4a	1732	92.01	812.33	804.77	3	18.52	154970.9
4b	1125	28.6	812.33	1149.12	2	18.52	40157.65
5	3523	54	812.33	804.77	2	18.52	207964.1
6	4746	41.25	812.33	1149.12	3	18.52	210601.6

Table 5: Project cost using practised Trial fleet 2

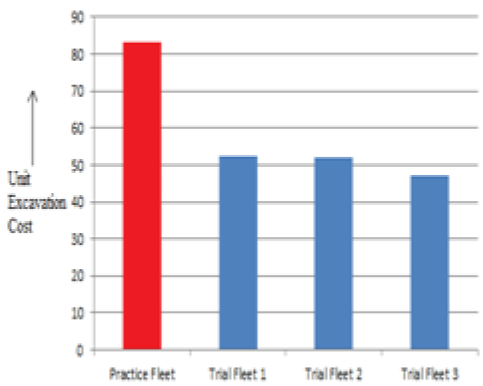
Trial Fleet 2 Project Cost							
Case	Equivalent Quantity (M3)	Tipper Cycle Time (min)	O&O Tipper (Rs./hr)	O&O excavator (Rs./hr)	No. of tipper	Size of tippers (M3)	Total Cost (Rs.)
1	2986	61.6	727.77	1149.12	5	16.67	176102.32
2a	943	34.11	671.39	1149.12	3	15.44	36611.09
2b	3071	29.55	600.93	1149.12	2	11.13	159738.58
3	1732	22.75	600.93	1149.12	2	13.91	55497.04
4a	1732	76.47	671.39	804.77	3	15.44	134339.90
4b	1125	20.9	600.93	1149.12	2	13.91	33116.11
5	3523	39.16	600.93	804.77	2	13.91	165849.53
6	4746	34.22	671.39	1149.12	3	15.44	184853.19

Table 6: Project cost using practised Trial fleet 3

Trial Fleet 3 Project Cost							
Case	Equivalent Quantity (M3)	Tipper Cycle Time (min)	O&O Tipper (Rs./hr)	O&O excavator (Rs./hr)	No. of tipper	Size of tippers (M3)	Total Cost (Rs.)
1	2986	66	754.47	1149.12	5	17.8	181629.89
2a	943	38.49	715.9	1149.12	3	17.33	38360.45
2b	3071	30.54	667.685	1149.12	2	13.4	144910.56
3	1732	22.25	667.685	1149.12	2	16.735	47676.92
4a	1732	86.04	715.9	804.77	3	17.33	141046.63
4b	1125	25.3	667.685	1149.12	2	16.73	35223.54
5	3523	46.76	667.685	804.77	2	16.73	175611.17
6	4746	38.49	715.9	1149.12	3	17.33	193063.33

7. Conclusion

The unit rate of excavation i.e. Rs./m^3 of excavation is found merely by dividing total cost by quantity of work for the particular cases.



Case	Unit Excavation Cost (Rs./m3)			
	Practice Fleet	Trial Fleet 1	Trial Fleet 2	Trial Fleet 3
1	56.75	64.48	58.98	60.83
2a	54.43	44.37	38.82	40.68
2b	83.25	52.50	52.02	47.19
3	35.97	25.71	32.04	27.53
4a	110.48	89.48	77.56	81.44
4b	44.48	35.70	29.44	31.31
5	59.03	59.03	47.08	49.85
6	53.42	44.37	38.95	40.68

8. Graphical Representation

Above is the bar chart showing that unit excavation cost of optimized trial fleet has reduced compared to practiced fleet. Hence optimization leads to cost reduction.

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