Unit Cost Analysis for Earthwork Operations on Highway Projects

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ABSTRACT

The road construction consists of variety of activities which are performed in succession, for e.g. the excavation-hauling-dozing-compaction or excavation-dozing-compaction or scraping-compaction. These operations are dependent on distance between cut and fill location or cut and waste site location or borrow site to fill location. These operations incur considerable amount of cost in road construction. Thus there is need to optimize these operations to reduce the cost. Different researches have presented methods for optimization of earth moving cost, considering the cost incurred in operation of excavation-hauling-compaction with no importance to above mentioned alternatives of earthwork operation. Also there is another side of deciding equipment operation at particular location, which is an economic distance for equipments utilization used in mass diagram method. These set of operation may incur different unit cost per cubic meters of earthwork.

Keywords – Earthwork, unit cost of earthwork, operation on earthwork

1. INTRODUCTION

The earthwork is the process in which ground surface in target area is leveled, either by moving or filling geomaterials (Parenta et al., 2015).The expected process involves removing extra soil from one section and moving it to fill locations in order to make optimum utilization of available materials on site. The earthwork incurs major part of road construction cost, since earthwork activities are highly equipment intensive which requires construction equipments like excavators, dozers, hauler, scraper and compactor making earthwork cost expensive activities in road construction. The past researches have considered operation like excavation-haul-fill-compaction while deriving unit cost of operation; but other operational possibilities are not considered. Different operations may incur different cost of transferring earth from cut to fill locations. These operation possibilities can be considered on basis of economic haul distance of equipment. These operations are necessary to be considered in optimization of earth allocation process. The research proposed will focus on those operational possibilities and unit cost incurred in the optimization of earth moving process. The existing researches consider operation of excavation-haul-compaction to derive unit cost of operation from production of equipments. The different possibilities of earthwork operation based on economic haul distance may incur different unit costs.

2. EARTHWORK OPERATION SELECTION FLOWCHART:

''Earthmoving'' typically occurs during the initiation of the project. The selection of appropriate equipment, equipment groups, or a subcontractor with the right equipment to do the work efficiently and on time is important. Typically underground utilities or foundation preparation is not started until the rough earthwork or earthmoving is done. On a large project with many mobile pieces of equipment moving a large amount of dirt, earthmoving can be a rather dangerous. The contractor should have a plan to control this.

The following ''rules of thumb'' based on hauling distance should be considered when selecting an earthmoving equipment. If the distance that the dirt must be moved is less than about 5000, then a bulldozer or loader might be used. Bulldozers cut and push the surface dirt using a blade. Many times a bulldozer is the first piece of equipment on the job. Loaders are not very effective for excavating, but are great for carrying or loading excavated dirt one bucket at a time. If the distance is 100 to 1000m, then a scraper might be used. The scraper can excavate, haul, and dump. If the dirt must be moved far than 1000m, then the best choice is to use front-end loaders to load the excavated soil into dump trucks and haul it to another location.

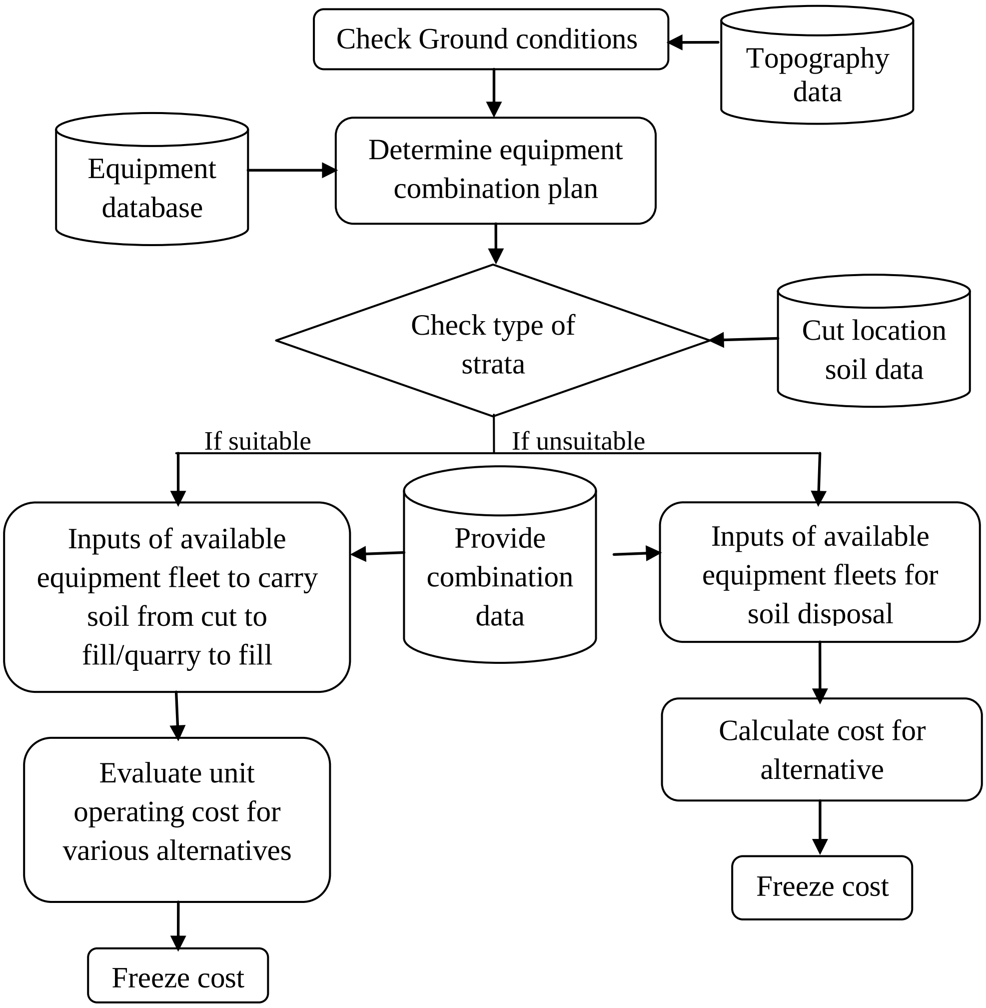


Fig. 1: Equipment selection flow charts

2.1 Checking ground Conditions:-

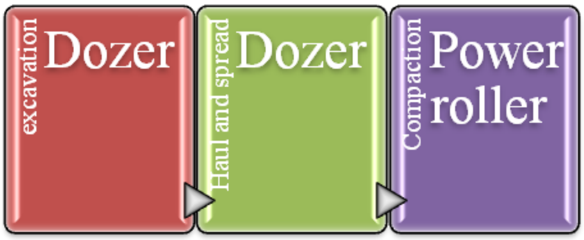
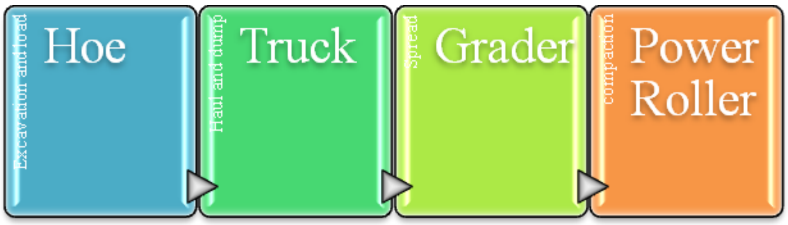
Based on various operational conditions encountered on site following equipments can be best suitable

Sr. no.	Activity	Job parameter	Equipment
1.	Excavation	Soft soil and hard soil	Dozer ,scraper, excavator
		Soft rock	Dozer ripping
		Hard rock	Machine drilling
		Above Grade	Excavator hoe
2.	Loading, hauling and unloading	0 to 100m	Dozer and wheel loader
		100 to 1000m	Scraper, loader, excavator into truck
		Above 1000m	Loader or excavator into dump truck
3.	Spreading		Grader and dozer
4.	Rolling		Power roller

Table.1: Operations in earthwork

2.2 Equipment fleets

Based on Equipments available and operations, various equipment fleets can be proposed as shown in table below:-

Sr no.	Operation	Equipment fleet
1.	Carrying suitable soil from cut to fill location	Minimum cost of following fleet shall be choosen Alternative 1:  Alternative 2:-  Alternative 3:-

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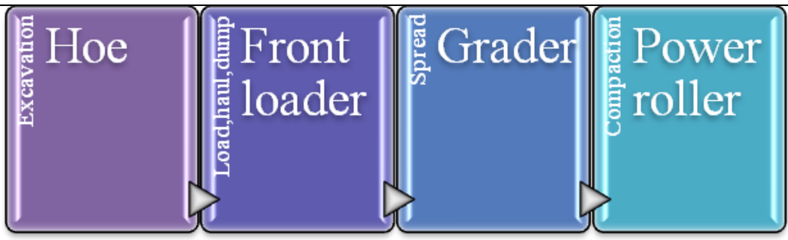
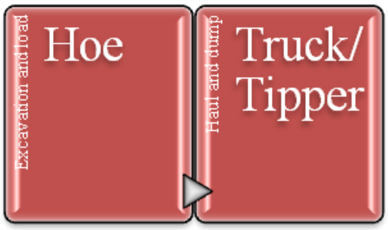
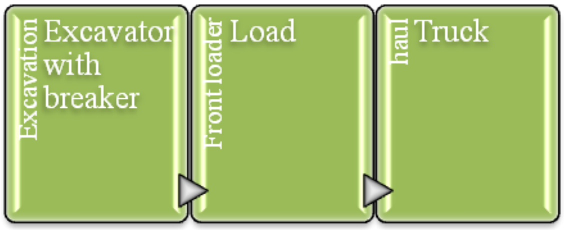
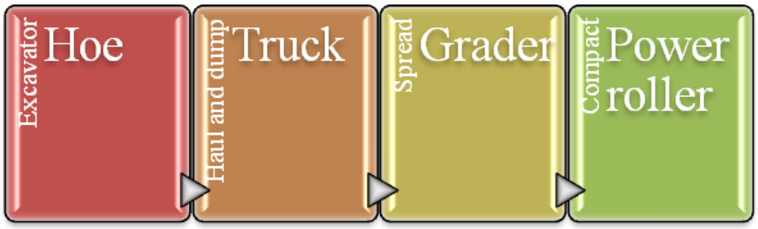
		
2.	Carrying unsuitable soil from cut and disposal	If soil encountered  If hard rock encountered which requires processing 
3.	Carrying suitable soil from borrow to fill location	

Table 2: Equipment fleet

2.3 Unit Cost evaluation:

The other important parameter essential for earthwork cost evaluation is equipment productivity. The earth moving equipment's productivity is essential in preparing plan and time schedule for activities included in earthwork operation. The productivity is analytical method defined as unit actual output per hours. The productivity is measure of equipments ability to produce at original rate. The decrease in productivity will result

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in increase in production cost. As equipments are considered to be leased it is clear that cost is direct function of equipment productivity.

2.3.1Excavator:

Production of excavator (m^3/hour) = $\frac{\text{Bucket capacity} \times \text{fill factor}}{\text{Cycle time}}$…………………………………………………………………………. (1)

2.3.2 Dozers

Production of dozer (m^3/hour) = $\frac{\text{Blade load}}{\text{Push time} + \text{Return time} + \text{Maneuver}}$……………………………………………………..……….……. (2)

2.3.3 Dump Truck

Load time:

$\text{Number of bucket load} \times \text{bucket cycle time}$…………………………………………………………..………..……
….. (3)

Balanced number of truck= $\frac{\text{Truck cycle time}}{\text{Excavator cycle time}}$……………………………………………………………………..……….……… (4)

Condition 1:

If Number of truck < balanced number of truck

Then Production of truck = $\frac{\text{Truck load} \times \text{Number of trucks}}{\text{Trucks cycle time}}$……………………………………………………………………….…….. (5)

Condition 2:

If Number of Truck>Balanced number of truck

Then Production of truck= $\frac{\text{Truck load}}{\text{Excavator cycle time}}$…………………………………………………………………………….……………... (6)

2.3.4 Grader:

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Production of grader=

$$\frac{\text{Average speed of grader} \times \text{Width of grader} \times \text{Height of grader}}{\text{Number of passes required}} \quad \ldots\ldots (7)$$

2.3.5 Compaction:

Production of compactor=

$$\frac{\text{Compacted width per roller pass} \times \text{Average speed of roller} \times \text{compacted lift thickness}}{\text{Number of passes to achieve required density}} \quad \ldots\ldots (8)$$

2.4 Cost of Equipment

Cost of equipments consist of following-Hiring charges of equipment were taken as per SSR 2018-19, given in usage rate of plant and machineries and these cost were supplemented with cost of average fuel and consumption on site.

Sr no.	Description	Rate(with fuel consumption and 5% overhead)
1.	Excavator	2854
2.	Dozer	2594
3.	Truck	1574
4.	Grader	2995
5.	Compactor	2781

Table 3 Fuel Consumption for Equipments

3. UNIT COST ANALYSIS FOR DIFFERENT OPERATIONS

Assume soil is to be transferred from cut location to the Fill location. The lead between cut location and fill location is 3681 km.

The two operations based on available set of equipments can be proposed which are as follows:

3.1 Excavation by dozer then haul by dozer then spreading and fine grading by grader then compaction with roller

Or

3.2 Excavation by hoe then haul by dump truck and then spreading and fine grading by grading then compaction with roller

Operation 1: Excavation by dozer then haul by dozer then spreading and fine grading by grader then compaction with roller

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Production of dozer (m^3/hour) = $\frac{\text{Blade load}}{\text{Push time} + \text{Return time} + \text{Maneuver}}$

Blade load= 1.674 m^3

Push time= $\frac{\text{Lead distance(m)}}{\text{Avearage speed of dozer with load}(\frac{m}{hrs})}$

$= \frac{3681}{5000}$

=0.7362 hrs.

Return time= $\frac{\text{Lead distance(m)}}{\text{Average speed of dozer while empty return }(\frac{m}{hrs})}$

$= \frac{3681}{10000}$

=0.3681 hrs.

Maneuver time=0.05 min. (assume)

Production of dozer= $\frac{1.674}{0.7362 + 0.3681 + 0.00083}$

= 1.52 m^3/hrs

Cost of dozer per hour=2595 Rs. Per hours

Unit cost per cubic meter of soil transfer=$\frac{2594}{1.514}$

=1713 Rs/m^3

After soil is hauled and graded to fill location it is compacted

Production of compactor= $\frac{\text{Compacted width per roller pass} \times \text{Average speed of roller} \times \text{compacted lift thickness}}{\text{Number of passes to achieve required density}}$

$= \frac{2.1 \times 5000 \times 0.15}{6}$

=262.5 m^3/hrs.

Unit cost per cubic meters of soil= $\frac{2781}{262.5}$

= 10.59 Rs/m^3

Total unit cost of operation=Unit cost of dozer for excavation and haul+ Unit cost of grading+ Unit cost of compaction

=1713+10.59

=1723 Rs/m^3

Operation 2: Excavation by hoe then haul by dump truck and then spreading and fine grading by grading then compaction with roller

Excavator employed at cut section is L and T komatsu PC200 with capacity of 0.9 m^3. Cycle time of excavator is 7 seconds of load, 5 seconds of swing, 4 seconds of dump and 5 seconds of return without load.

Total Cycle time of excavator= $\frac{21}{3600}$

=0.00583 hrs

Production of excavator (m^3/hour) = $\frac{\text{Bucket capacity}}{\text{Cycle time}} \times \text{fill factor}$

$=\frac{0.9\times 0.85}{0.0058}$

=131.89 m^3/hr

Unit cost of excavation=$\frac{2854}{131.89}$

Unit cost of excavation=21.63 Rs/m^3

Production of Dump Truck (m^3/hr)

Truck cycle time:

Load time in truck+ Haul time with load+ Dump time +Haul time without load

Number of bucket= $\frac{\text{Truck capacity}}{\text{excavator capaccity}}$

Number of bucket = $\frac{14.00}{0.9}$

=15.55 No's

Load time= Number of buckets $\times$ cycle time of excavator

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$=15.55 \times 0.00583$

=0.090 hrs

Haul with load= $\frac{3681}{30000}$

=0.18405 hrs

Return without load= $\frac{3681}{40000}$

=0.092 hrs

Dump time=2 min. (Average)

$= \frac{2}{60}$

=0.0333

Total cycle time of dump truck=0.090+0.1227+0.092+0.033

=0.338 hrs

Balanced number of truck= $\frac{\text{Truck cycle time}}{\text{Excavator cycle time}}$

$=\frac{0.338}{0.00583}$

=57.975 No's

Number of trucks available=7 Numbers

Condition 1:

If Number of truck < balanced number of truck

Then Production of truck= $\frac{\text{Truck load} \times \text{Number of trucks}}{\text{Trucks cycle time}}$

Condition 2:

If Number of Truck>Balanced number of truck

Then Production of truck= $\frac{\text{Truck load}}{\text{Excavator cycle time}}$

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Here it can be seen Number of trucks available is less than balanced number of truck. Hence trucks will control production.

Hence Production of dump trucks= $\frac{14\times7}{0.338}$

=289.94 m^3/hrs

Unit cost of carrying soil= $\frac{1574\times7}{289.94}$

=38 Rs/m^3

After soil is hauled to fill location it is to spread to desired level

Production of grader= $\frac{\text{Average speed of grader}\times\text{Width of grader}\times\text{Height of grader}}{\text{Number of passes required}}$

= $\frac{3000\,(\frac{m}{hrs})\times3.7\times0.55}{12}$

= 508.75 m^3/hrs.

Unit cost per cubic meters of soil= $\frac{2995}{508.75}$

= 5.88 Rs/m^3

After soil is graded to desired level it is compacted

Production of compactor

= $\frac{\text{Compacted width per roller pass}\times\text{Average speed of roller}\times\text{compacted lift thickness}}{\text{Number of passes to achieve required density}}$

= $\frac{2.1\times5000\times0.15}{6}$

=262.5 m^3/hrs.

Unit cost per cubic meters of soil= $\frac{2781}{262.5}$

= 10.59 Rs/m^3

Total unit cost of operation=Unit cost of excavator for excavation+ Haul using truck+ Unit cost of grading+ Unit cost of compaction

=21.63+38+5.88+10.59

= **76.1 Rs/m^3**

The second alternative is chosen as it has minimum cost.

4. RESULT AND CONCLUSION

In this research, the difficult operational alternatives that are carried out on highway project are studied. The specific focus was given on earthwork operations using dozer and excavator. The operation of dozer was found to be economical up to shorter haul distance and operations with longer haul are more feasible with excavator and trucks. This can be clearly seen in graph between unit cost with excavator and truck and dozer operation. The unit cost of operation for dozer is low for shorter haul distances of up to 90 m and then exceed above unit cost of earthwork using operation of excavator and truck. These operations will incur different unit cost of earthwork and operation with minimum unit cost can be considered suitable for deciding equipment on site. The research suggests use of different operations based on unit cost of operations.

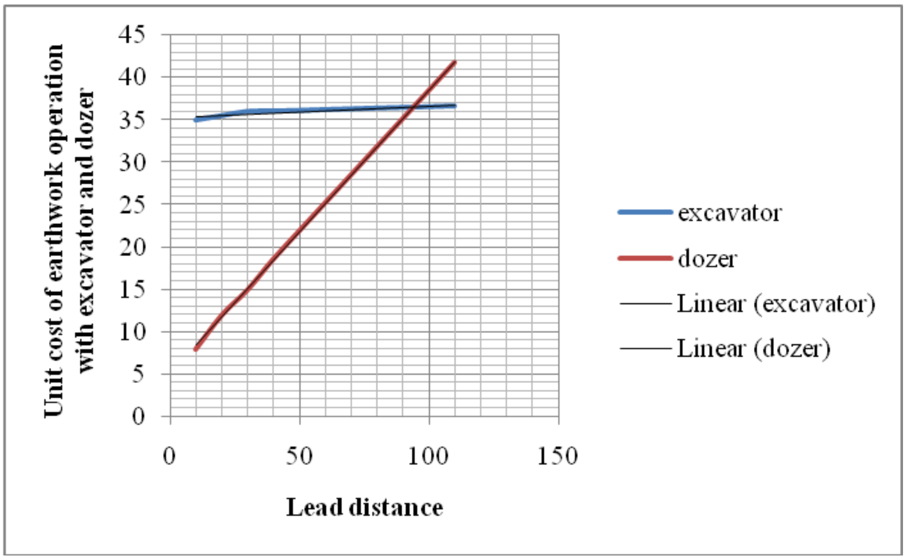

Fig. 2 Graph of unit cost of earthwork with dozer and excavator with lead distance

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