A

Dissertation Report on

Model Development for Optimising Earthwork Operations on Highway Projects

Submitted

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by

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TO WHOMSOEVER IT MAY CONCERN

This is to certify that **Mr. Omkar Unmesh Rasal** a student from **Rajarambapu Institute of Technology, Rajaramnagar Islampur** has successfully completed his project work on "Model Development for Optimizing Earthwork Operations on Highway Project" under the guidance of Mr. Pandurang Dandawate (Chief Managing Director, Dhruv Consultancy Services Ltd., Navi Mumbai) for the period of August 2018 to April 2019 at the Head Office (Mumbai).

During the training period his conduct is found to be good and he has worked sincerely towards the tasks assigned to him.

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DECLARATION

I declare that this report reflects my thoughts about the subject in my own words. I have sufficiently cited and referenced the original sources, referred or considered in this work. I have not misrepresented or fabricated or falsified any idea/data/fact/source in this my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute.

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ABSTRACT

Earthwork is equipment intensive activity as it involves heavy construction equipment like excavator, trucks, grader, roller, etc. which have very high operational cost. Earthwork involves cutting the excess soil or filling the suitable soil wherever deficit and grading, compaction and to create the required grade. The new method of earth allocation plan using principle of linear programming are developed, but presently the most widely used method for earth allocation operation is mass diagram method. In this research work, the conventional mass haul method and linear programming method was considered for comparative analysis. The mathematical model was developed using principle of linear programming to create the critical earth allocation plans. The MATLAB programming software was used to solve the linear programming problem based on principle of transportation model. For comparative analysis, 8 case studies with different plan and profile of road are considered and results in terms of cost, time, and haul patterns are computed for both the methods of earth allocation. It was observed that results obtained with mathematical model provide more optimized results than mass haul diagram for all case studies.

Keywords: Earthwork, Optimization, mass haul diagram, linear programming model.

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Chapter 1

INTRODUCTION AND RELEVANCE

1.1 General

The earthwork is the process in which ground surface in target area is leveled, either by moving or filling geomaterials [1].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 existing earthwork optimization methods are classified into equipment fleet planning (EFP) and earth allocation planning (EAP) [2].EFP identifies the most favorable equipment type, computes the optimal number of equipment, calculate productivity and allocate equipment at right time and place.EAP identifies the optimal cut-fill pairs and minimize the total earthmoving cost by assigning cuts to fill economically. It involves identifying the amount of earth that should be moved from cut areas to fill areas. The earthwork allocation plan is needed to know amount of quantities of soil/rock to be moved from cut section to the fill section or to know amount of soil needed to be borrowed at fill section externally or soil(unsuitable soil) that is needed to be disposed off from cut section.

The different earth allocation methods have been proposed in past for optimizing earth moving to reduce the cost of earthwork activities. Most extensively used method to develop optimization is linear programming; results of which have been improved with different constraints that are included in advanced decision models developed using methods like integer programming and fuzzy linear programming. The models developed by these researches include objective function to minimize the cost of earthwork and decision variables are the quantities of soil to be moved. The parameters required for determining earthwork estimates are quantity of soil to move and haul distance to move the material.

This research develops an optimization model using the linear programming (transportation model) to derive the most economical haul distance for soil movement. Also the lead distance for soil movement is considered as variable and variable lead distance are considered in deriving the final cost of earthwork operation. The earthwork estimator currently use software programs to derive quantities of earthwork of cut and fill but it's quite difficult to identify the movement of soil within road project. For this planning engineers refer to mass haul diagram method of planning. This method provides the average haul distance of soil movement on road project [3]. The report presents the comparative analysis of results obtained with mass haul diagram and linear programming model. The various computer programming software are available for solving the problems in operation research and optimization. The model developed in project will be able of provide the haul distances for soil movement also it will provide the cost of earthwork operations. The duration can be easily estimated for earthwork operation.

1.2 Closure

This chapter presents various methods of earthwork planning, i.e. EAP & EFP. The research here involves studies of EAP. The research proposes to use the mathematical model for optimizing the process of earthwork. Mathematical model will provide haul distances & optimized cost of earthwork operation.

Chapter 2

LITERATURE SURVEY

2.1 General

The research mainly focuses on Earth allocation planning using optimization tools for most economical soil transfer in highway projects. The proposed research includes the development of mathematical model for optimization of earthwork activities in terms of cost. Numerous research papers were selected to study the optimization techniques, Parameters considered by researchers. From the research, objective function of model, decision variables and constraints used in research were studied. Some research was also performed on conventional method of earthwork planning i.e. mass haul diagram used currently by professionals on site. It was necessary to study them as well so as to compare results of mass haul diagram and new methods of earthwork planning using tools of operation research.

Burdett et al., (2018), "Block Models for Improved Earthwork Allocation Planning In Linear Infrastructure Construction"

As per researches illustrated in table no.1,it can be seen that some of them consider parameters that affect equipment productivities employed on construction sites. These parameters are type of equipment,soil type,operational factors,size and condition on site,haul distances,grade of haul road,etc. but majority of researches do not consider equipment's' economic haul distance except done by author. But research conducted focus on optimizing the fuel consumption in earthwork allocation.The fuel consumption is a function of mass of vehicle, cross section area of equipment, travelling distance of equipment and gradient over which it travels.The research suggests use of laws of physics in modeling the fuel consumption considering above mentioned parameters. The researchers suggest distance of travel can distinguish the type of machinery that can be deployed. E.g. for distance less that 50m dozers should be used. If greater than 50m but up to 1500 m scraper should be used and Distance greater than 1500m suggests using trucks . This factor of hauling distance of equipment is not considered by other researchers. Also research developed the block model in latter part of research (former being section method) in which cut and fill are divided into block along with borrow and disposal. The size of single block was specified and volume of block was calculated. [4]

Easa, S.M, (1987), "Earthwork Allocations with Non-constant Unit Cost"

The author developed the mathematical model for optimization of earthwork. Theresearch considers the variations in unit cost for moving earthwork such as unit cost of purchase, cut, haul, and compaction. The research considers that unit cost of purchase and excavation is constant for moving earth from cut to fill whereas unit cost of haul isvarying. But unit cost for purchase and excavation are varying in case of soil movement from borrow pit to fill location. This research here considers unit cost for operation of cut-haul-compaction.

Jayawardane, A.K.W. and Price, A.D., (1994), "A New Approach For Optimizing Earth Moving Operations"

The author has divided earthwork moving problem into 3 stages; namely individual simulation model, linear/integer programming model and network scheduling. The simulation model was employed by author to determine production from available fleet, most economic loading methods, optimum team type, and optimum team size. The optimum team size i.e. combination of equipments like scraper-pusher or loader-truck is optimized considering criteria like cost,time,and production. The end of simulation provided production, unit cost,percentage of work and idle times for various types of equipment,queue time, queue length. This provides realistic input of unit cost required for linear/multiple programming model. [5]

Gwak et al., (2017), "Optimal Cut-Fill Pairing And Sequencing Method In Earthwork Operation."

The author developed computational method called optimal cut fill pairing and sequencing. The method is efficient in solving issues like different soil properties of cut and fill volume, repositioning time of equipment i.e. reducing travel time between two cut pits, volume of cut and fill pits designated as cut or fill prism, cost which will be incurred if rock is encountered, disposal and borrow cost. This research also employed the concept of block or prism of soil or rock. Thus author also considered the order of excavation of cut prism and order in which it should be filled in fill prism. The Matlab software was used to program the mathematical model. The significant issue handled by research is that it considers the soil properties in cut and fill prism i.e. soil which is non-conforming to fill prism requirement is to be rejected.

Parenta et al., (2015), "An Evolutionary Multi-Objective Optimization System For Earthworks"

While other researches focused on single objective of optimization i.e. cost; the research proposed by author focused on multi objective optimization. They considered cost as well as total construction time in optimization by allocation of construction equipment. The process was constrained by project duration and budget allocated. They considered earthwork as production line consisting of activities like excavation, transportation, spreading, and compaction. The author considered optimal allocation of compaction equipment and then allocation of equipment for other tasks like spreading,hauling and excavation. The productivity of equipments for other tasks was equivalent to compaction equipment or was kept closer to it. The research considered total time is accumulated time of each construction phase is function of equipment productivity and material to be handled and total cost is accumulated cost of each construction phase which is function of time(since equipments have time dependent cost).

Ji et al.,(2010), "Mathematical Modeling of Earthwork Optimization Problem"

The research proposed introduced us with a problem of division of road among contractors encountered in road construction projects. The research involved two steps. First stage involved optimization of earth allocation and second involved division of road into section so that there should be least movement of earth between different sections. The ultimate objective of research was to have sufficient earth cutting to fulfill the fill requirement in that section or to avoid overflow of earth in particular section and lack of earth in other section.

Son et al., (2010), "Determination of haul distance and direction in mass excavation"

The paper develops a mathematical optimization model for the determination of these minimum haul distances and directions. The two-dimensional model presented uses linear programming. With this mathematical model, the quantity of earth hauled, the minimum haul Distances, and the locations to haul the material are determined. The vector diagram were prepared which showed the amount of soil and where to haul. The objective function was to minimizes the movement of soil i.e. haul distance for soil. The constraint were the capacities of cut and fill location in terms of amount of cut and deficient soil at fill respectively. The earthmoving cost is calculated based on the haul distance as well as the earthmoving quantity.

Akiije, (2010), "An innovative mass haul diagram development for highway earthwork"

Paper presents an innovative mass haul diagram development for highway earthwork via a general purpose application program approach as compared to tedious conventional hand methodology or using costly specific purpose application programs. Microsoft excel was used to prepare the mass haul curve instead of drawing curves with hands. The aim of this study is to develop a mass haul diagram while employing Microsoft Excel to analysis, design and develop a mass haul diagram for an effective road earthwork project execution.

Morlayet al., (2010), "Mathematical Modeling of Earthwork Optimization Problem"

The significant and unique contribution that has been made in this research is to substitute one unique average weighted haul distance for multiple haul distances between numerous cut and fill cells in the site grid system as simulation modeling input. It is clearly shown that the average weighted haul distance can be used as a critical input for building a simplified simulation model, in place of a detailed simulation model that considers specific earth-movement patterns, while still producing outputs of comparable accuracy.

2.2 Closure

Different research on mathematical model were studied along with that research, the parameter, constraints, objective function were analyzed through various researches. Mass haul diagram method of Earthwork planning was studied. The conclusion was derived to compare the result with conventional method of earthwork planning i.e. mass haul diagram & results given by mathematical model.

Chapter 3

RESEARCH METHODLOGY

3.1 General

The chapter provides comprehensive idea about previous researches that have been done on earthwork planning and conventional methods of earthwork planning performed on site. The objective are derived from the perspective of comparing both the methods of earthwork planning methodologies. The chart has been prepared which depict the steps that were performed in this research.

3.2 Gap analysis

The planning engineers presently consider mass haul method for earthwork planning and deriving the lead distance for earthwork cost estimation. But new linear programming methods are developed and can provide more accurate results. The present research provide the complex methods of earthwork planning using the mathematical models. The mass haul method diagram is simple tool to derive the earthwork plan but existing research do not compare the results of mass haul with new tools of planning using mathematical model. Hence it is necessary to compare the result obtained with both the method of earthwork planning. The result needs to be compared from point of view of cost and time as well as haul distances for moving soil.

3.3 Problem statement

The number of case studies will be considered for comparing the result between mass haul diagram and linear programming method. Initially the various operations carried out on highway project will be studied. Then the unit cost of earthwork will be derived using the equipment productivity data. Productivity of equipment will be collected on one of the case study and will be applicable for all the other. The proposed work focus on using the mass haul diagram method for deriving the haul distances for soil movement. The same will be used for deriving the cost of earthwork operation. Then mathematical model will be developed using the principle of linear programming (Transportation model). The results obtained for cost, duration and haul distances will be compared. The proposed methodology has been shown in Figure 3.1 below.

3.4 Objectives

i. To identify and incorporate various operational alternatives in deriving unit cost of earthwork.
ii. To incorporate the concept of lead as per guidelines given in SSR in identifying the unit cost of earthwork.
iii. To optimize earthwork operations through mathematical modeling.
iv. To validate the model through application on highway projects

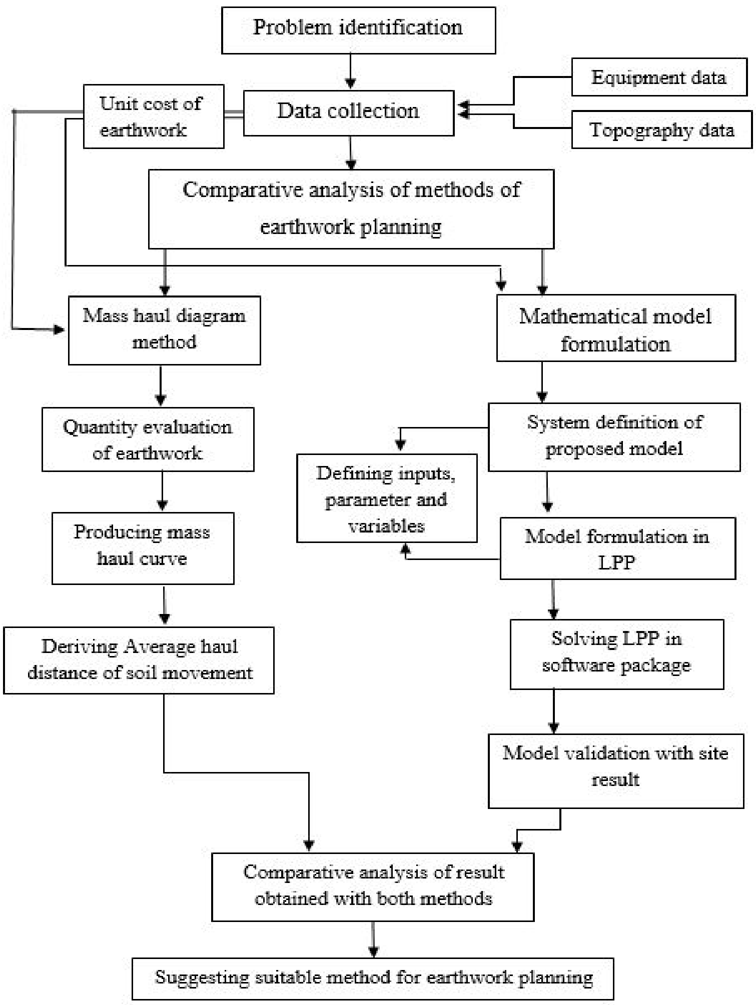

Figure 3.1: Methodology adopted in project work

3.5 Closure

The gap has been identified that previous researches do not compare the results obtained with conventional method of Earthwork & mathematical model. The highway planning engineer use conventional method of EAP, so it was necessary to compare results with both methods of EAP.

Chapter 4

RESEARCH DESIGN

4.1 General

The construction of road includes various operations which are to be performed in succession. The chapter below explains the detailed operation carried out while construction of embankment. Also the chapter includes the study of various operations and equipment that will be required for the operation. Further at the end of chapter, the unit cost of different operations were derived using equipment productivities and Rates of equipment's.

4.2 Construction of embankment and sub-grade filling

The earthwork operation consist of providing, laying and compacting approved earth in layers as per specifications to form the part of embankment and sub-grade. Some earthwork in central verge and earthen shoulders is also there.

4.2.1 Material

It shall be soil, murum, gravel, sand or a mixture of these. Only selected material conforming to MORTH Specification Clause 305.2 shall be used for embankment filling. Materials to be used as sub-grade will also be tested for 4 days soaked CBR and the material also fulfilling the CBR requirement will only be used for sub-grade filling. The material used shall be free from logs, stumps, roots, rubbish and any other deleterious material. Cohesive non-swelling soil will be provided as per Standards and Specifications and approved material.

4.2.2 Transportation of material

Top soil of the approved borrow area will first be removed and stockpiled before excavating the suitable soil for transportation to site. Suitable material will be transported to work site by Dumpers of appropriate capacity. The earth will be dumped at pre-calculated spacing on the original compacted ground or previous layer of earth, as the case may be.

4.2.3 Spreading material in layers and bringing to appropriate moisture content

Before dumping the borrow soil at site, toe points are calculated and toe line will be marked on site at suitable intervals (50 m). Embankment and Sub-grade material will be spread by bulldozer of suitable capacity. Motor Grader with hydraulic control will be used to spread material in layers of uniform thickness not exceeding 200 mm compacted. Earthwork for embankment shall be done in 200 mm compacted thickness layers. Sub-grade shall be done in 200+150+150 mm thick three layers to achieve total compacted thickness 500 mm.

Natural moisture content of material will be checked at the site of placement prior to commencement of compaction. If found to be out of agreed limits, the same will be made good by adding water with a water tanker of suitable capacity with sprinkler capable of applying water uniformly with a controlled rate of flow to variable width of surfaces without flooding. Uniform moisture content (within OMC limits) will be obtained throughout the depth of layer by blading and harrowing. If material is too wet it will be brought to optimum moisture content by aeration and exposing to sun.

First layer of embankment shall be requiring, generally, varying thickness to eliminate the profile deficiency of original ground. Spreading of loose soil, therefore, shall be regulated in most befitting manner suiting the site requirements for proper profile, grade and line.

4.2.4 Compaction

The compaction will be done by Single Drum Vibratory Rollers of 10-Ton capacity in layers with sufficient passes to achieve required compaction. Necessary quality control as per specification will be conducted during and after compaction of each layer. Compaction requirement shall be at least 95% of the MDD of the fill material for embankment construction and 97% of the MDD for sub-grade construction. Statistical Quality Control (SQC) approach shall be adopted for reviewing the compliance to the specified standards.
When density measurement reveals any soft areas in the embankment, these be compacted further. If in spite of that the specified compaction is not achieved, the material in the soft area will be removed and replaced by approved material, compacted to the specification. Subsequent layers will be placed only after the laid layer passes the quality criteria as per specification.

4.2.5 Finishing operations

Geometric checks shall be performed upon completion of each layer of the embankment in accordance with the requirements of Q3 level of Quality Assurance specified in IRC: SP-57-2000.

4.3 Checking ground conditions

“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. These are guidelines and job or site conditions that may influence actual criteria [6]. 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.

Based on various operational conditions encountered on site following equipments can be best suitable [7].

Table 4.1: Operations in earthwork

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

Firstly identify the ground profile visually so as to select the equipment for earthworks considering on job parameters mentioned in Table 4.1
The road profile was divided into Number of cut and fill locations. The division is made at the junction of cut and fill. Then further the divisions were increased with offsets of 100 m on both sides of junction. The lead was calculated from one cut to all the fill locations.

4.4 Cost of equipment

The earthwork activity is equipment intensive i.e. it is dependent on numerous equipment like excavator, hauler, compactor, dozer, grader, etc. So the cost of project must include the cost of equipment needed to build project for evaluating the cost of earthwork operation. It is necessary to define the cost of equipment used for the various operations. Equipment cost comprises of two major components:

a) Hiring charges of equipment

b) Running charges of equipment

c) Overheads

a) Hiring charges of equipment-Taken as per SSR 2018-19 [8] given in usage rate of plant and machineries.

b) Running charges-As per Table 2.5 given in Construction equipment for engineers, estimators and owners, fuel consumption is calculated using equation stated below

Fuel consumption in gallons per hours for hauling equipment

Fuel Consumption = Operating Factor x Fuel Consumption Factor x Horse Power

And

For Other equipment in litres per hours = 0.154 x BHP of equipment

c) Overheads- Considered 5% of total charges per hour

It is important note that contractor can lease or purchase the equipment based on availability with him. For the purpose of study it is considered that equipment are leased. From this point of view, the time basis of rates are considered. It is common practice in construction industry to base rates on one shift of 8h/d or 40h/week or may be 176 h/month. For the case study, the equipment's hiring charges are referred from SSR 2018-19.The cost has been calculated and shown in Table 4.2.

Calculations of rates of equipment's:

Table 4.2: Fuel Consumption for Equipment

Sr no.	Description	Hiring charges	Operational efficiency	HP	Fuel consumption cost	Hiring charge +Fuel consumption	Rate (with 5%) overhead
1	Excavator	1200	0.154(litres/hr/hp)	145	1518	2718	2854
2	Dozer	1800	0.028(gal/hr/hp)	94	671	2471	2594
3	Truck	700	0.014(gal/hr/hp)	224	799	1499	1574
4	Grader	2000	0.022(gal/hr/hp)	152	852	2852	2995
5	Compactor	1591	0.154(litres/hr/hp)	101	1057	2648	2781

4.5 Equipment cycles time and productivity

The other important parameter essential for earthwork cost evaluation is equipment productivity. The earth moving equipment's productivity are 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 [9]. The decrease in productivity will result in increase in production cost. As equipments are considered to be leased it is clear that cost is direct function of equipment productivity.

a) Excavator

Cycle time of excavator includes load, swing, haul, and dump

Production of excavator (m3/hour)= (Bucket capacity x fill factor)/cycle time

b) Dozers

Cycle time of excavator includes push with load, return empty and maneuver

Production of dozer (m3/hour)=$\left(\frac{Bladeload}{pushtime+returntime+maneuver}\right)$

c) Dump Truck

Cycle time of excavator includes load, haul, dump and return Load time: Number of bucket load x bucket cycle time

Balanced number of truck= $\frac{TruckCycleTime}{ExcavatorCycleTime}$

Condition 1:

If Number of truck ¡ balanced number of truck

Then Production of truck = (Truck load x number of trucks)/(Truck cycle time)

Condition 2:

If Number of Truck¿Balanced number of truck

Then Production of truck = $\frac{Truckload}{Excavatorcycletime}$

d) Grader

Production of grader = (Average speed of grader x Width of grader x Height of grader)/(Number of passes required)

e) Compaction

Production of compactor = (Compacted width per roller pass x Average speed of roller x Compacted lift thickness)/ (Number of passes to achieve required density)

4.6 Equipment data collection

The equipment productivity data was for one of the cases study of AU 109.The different equipment required for earthwork were observed for the period of 7 days. The cycle times of equipment like excavators were noted for further calculation. For some equipment line compactor, dozer, and grader the field measurement were taken. The observations have been illustrated below:

a) L and T komatsu PC 200: Cycle time of L and T komatsu PC200 has been listed down in Table 4.3 and Figure 4.1 shows excavator working on site

- Capacity: 0.9 m3
- Numbers: 4

Table 4.3: Cycle time of excavators L and T komatsu PC 200

Sr no.	Load	Swing	Dump	Return	Total cycle time (in Seconds)	Average cycle time (in Seconds)
1	7	4	4	3	18	
2	7	5	3	5	20	
3	6	6	3	5	20	
4	7	5	3	5	20	
5	7	5	4	5	21	
6	6	4	4	6	20	
7	7	4	4	4	19	
8	8	5	3	5	21	
9	8	5	3	5	21	
10	7	5	4	5	21	
11	7	5	3	6	21	
12	7	4	5	4	20	21
13	8	6	4	5	23	
14	7	4	4	5	20	
15	8	4	3	5	20	
16	7	5	3	4	19	
17	8	4	3	5	20	
18	6	5	4	4	19	
19	6	4	5	4	19	
Average	7	5	4	5		

b) Kobelco SK 380 : Cycle time of Kobelco SK 380 has been listed down in Table **??** shows excavator working on site

- Capacity: 2 m3
- Numbers: 1

Table 4.4: Cycle time of excavator Kobelco SK 380

Sr no.	Load	Swing	Dump	Return	Total cycle time (in Seconds)	Average cycle time (in Seconds)
1	8	7	4	5	24	
2	8	7	5	6	26	
3	7	6	5	5	23	
4	8	7	6	6	27	
5	9	7	6	4	26	
6	12	5	6	6	29	25
7	8	7	7	5	27	
8	8	6	6	6	26	
9	7	7	8	5	27	
10	9	5	6	6	26	
11	8	6	6	5	25	
12	9	5	7	4	25	
Average	8	6	6	5		

c) Kobelco SK220 XD : Cycle time of Kobelo SK220 XD has been listed down in Table 4.5

- Capacity: 0.9 to 1.2m3
- Numbers: 2

Table 4.5: Cycle time of excavator Kobelco SK220 XD

Sr no.	Load	Swing	Dump	Return	Total cycle time (in Seconds)	Average cycle time (in Seconds)
1	7	5	6	4	22	
2	8	5	4	4	21	
3	9	6	6	4	25	
4	9	5	5	5	24	
5	7	5	5	5	22	
6	8	6	6	5	25	
7	6	4	5	6	21	
8	7	5	5	5	22	24
9	8	6	5	4	23	
10	8	5	6	4	23	
11	9	6	6	4	25	
12	7	5	8	5	25	
13	9	6	5	5	25	
14	8	5	6	4	23	
15	8	5	5	4	22	
Average	8	5	6	5		

d) TATA hitachi EX 200LC: Cycle time of TATA hitachi EX 200LC has been listed down in Table 4.6

- Capacity: 0.86 to 1.5m3
- Numbers: 1

Table 4.6: Cycle time of excavator TATA hitachi EX 200LC

Sr no.	Load	Swing	Dump	Return	Total cycle time (in Seconds)	Average cycle time (in Seconds)
1	5	4	4	4	17	
2	5	5	4	5	19	
3	6	4	3	6	19	
4	5	4	4	5	18	
5	6	5	4	4	19	
6	9	5	3	4	21	
7	8	4	5	5	22	
8	8	5	4	4	21	
9	9	5	5	5	24	21
10	7	4	3	4	18	
11	8	4	3	5	20	
12	7	3	2	4	16	
13	6	7	3	4	20	
14	7	4	4	5	20	
15	6	5	3	4	18	
Average	7	5	4	5		

e) JCB JS205 9C : Cycle time of JCB JS205 9C has been listed down in Table 4.7

• Capacity: 0.85 to 1.7 m3

Table 4.7: Cycle time of excavator JCB JS205 9C

Sr no.	Load	Swing	Dump	Return	Total cycle time (in Seconds)	Average cycle time (in Seconds)
1	8	7	4	6	25	
2	9	7	4	8	28	
3	8	8	4	6	26	
4	9	7	5	6	27	
5	8	7	4	7	26	
6	8	6	5	6	25	24
7	6	7	4	7	24	
8	9	6	4	7	26	
9	9	7	4	6	26	
10	8	7	4	7	26	
11	8	6	5	7	26	
12	6	7	5	6	24	
Average	8	7	4	5		

Figure 4.1: Excavator working at ch. 90+53

f) BEML Grader BG 605 R2 :The Figure 4.2 showns grader working on site

- Blade width-3.70 m
- Height-0.55m
- Average speed with load-5 kmph
- Average speed without load-25 kmph

Figure 4.2: Grader spreading soil at ch.90+100

g) L and T 1190 Vibratory Roller: The Figure 4.3 showns vibratory roller working on site

- Number of passes-6
- Length of roller-2.1 m
- Average speed of roller-5 kmph
- Lift thickness-0.15m

Figure 4.3: compactor spreading soil at ch.90+880

h) Tata LPK 2523 Dumpers: The Figure 4.4 showns Dumper working on site

Numbers: 7

Capacity: 6 brasses

Size of trucks= 5.5(lenght) x 1.5(width) x 1.7(height)

Figure 4.4: Truck dumping soil at ch.90+200

j) Caterpillar D6B: The Figure 4.5 shows Field measurement of Dozer

- Blade width-1.5m
- Wing length of blade-3m
- Average blade height-1m
- Average speed of dozer while push-3 kmph
- Average speed of dozer while returning empty-4 kmph

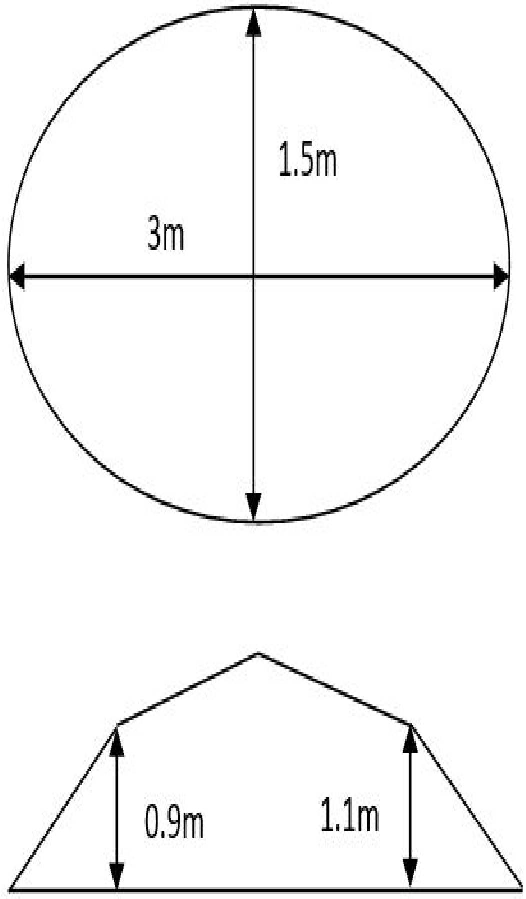

Figure 4.5: Field measurement of dozer

Blade load (lcy) =0.0138 x 9.84252(feets) x 3.28084(feets) x 4.92126(feets)

Blade load (lcy) =2.1930

Blade load (m3) =1.6743

4.7 Cost and productivity analysis

Rate analysis is process of determining the rate of particular item of work from the quantities of material and labor required and their cost [8]. Based on data collected on site of various equipments used on site, the equipment productivities were derived as follows:

Excavator employed at cut section is L and T komatsu PC200 with capacity of 0.9 m3. 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 = $\left(\frac{21}{3600}\right)$

=0.00583 hrs

Production of excavator (m3/hour) = $\frac{BucketCapacity}{CycleTime}$ x fill factor

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

=131.89 m3/hr

Production of Dump Truck (m3/hr)

Truck cycle time:

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

Number of bucket= $\frac{TruckCapacity}{ExcavatorCapacity}$

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

=15.55 No's

Load time=Number of buckets x cycle time of excavator

=15.55 x 0.00583

=0.090 hrs

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

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= $\frac{Truckcycletime}{Excavatorcycletime}$

$= \frac{0.338}{0.0058}$

=57.975 No's

Number of trucks available=7 Numbers

Condition 1:

If Number of truck less than balanced number of truck

Then Production of truck

$= \frac{Truckload x Number of trucks}{Trucks Cycle Time}$

Condition 2:

If Number of Truck greater than Balanced number of truck

Then Production of truck

$= \frac{Truck Load}{Excavator Cycle Time}$

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 $= \frac{14x7}{0.338}$

=289.94 m3/hrs

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

Production of grader

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

$= \frac{\text{3000x3.7x0.55}}{12}$

= 508.75 m3/hrs.

After soil is graded to desired level it is compacted

Production of compactor

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

$= \frac{\text{2.1x5000x0.15}}{6}$

=262.5 m3/hrs.

After the productivity of equipment's is evaluated the rate analysis will be performed so as to find out the cost of unit work i.e. the cost of one cubic meters of work.

Item No. 1: Excavation of road way in cutting

For hydraulic excavator of 0.9 m3 capacity and capacity of 110 m3/hrs
Excavator's productivity: 110 m3/hrs

Cost of excavator: 2854 Rs/hrs
Unit cost of excavation = $\frac{2854}{110}$
= 26 Rs/hrs

Item No. 2: Hauling of soil from location of cutting to fill

Hiring cost of one truck is 1574 Rs/hrs. But it is assumed that three trucks are assumed against one excavator. So total cost of fleet of trucks is 4722
For truck with capacity of 14.025 m3 and average speed of 20 Kmph while carrying load and 30 Kmph while empty the equipment productivity will vary with distance. The Figure 4.6 shows the graph of productivity and cost against the lead distance on site

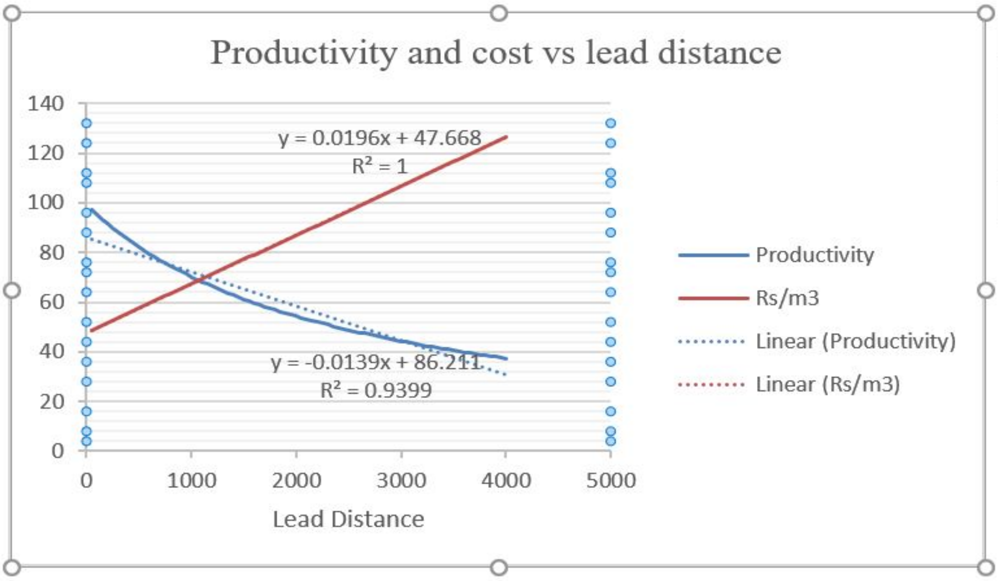

Figure 4.6: Graph of change in productivity and cost with change in lead distance

Item no. 3: Placing and spreading

Spreading using grader with productivity of 508 m3

Cost of grader= 2995

Unit cost of spreading $= \frac{2995}{508}$

$= 5.89$ Rs/m3

Item no. 4: Compaction

Compacting with vibratory roller of productivity of 262.5 m3

Cost of roller=2781

Unit cost of spreading $= \frac{2781}{262.5}$

$=10.59$ Rs/m3

4.8 Closure

The chapter explains the activities that are to be conducted on site for earthwork. Also, the chapter involves study of various operation and corresponding equipment that can be used for the operations. Finally the major input parameter i.e. unit cost required for model was derived for various individual operations of earthwork.

Chapter 5

COMPARITIVE ANALYSIS OF COST

5.1 General

In the previous section the algorithms were developed in Microsoft excel so as to simply the process of evaluation of unit cost of earthwork for different haul distance.

When performing the earthwork estimate, there are three major areas that concern:

1) What is required quantity of excavation?

2) What type of equipments that will be used?

3) What is required haul distance and direction of haul?

The remainder of research includes study of conventional method used for deriving cost of earthwork and comparing the same with cost derived by linear programming. To compare the costs with both methods, 8 case studies were considered. Major parameter in both methods was the volume of earthwork in cut and fill.

5.2 Mass haul diagram

5.2.1 Background

Mass haul is graphical representation of cumulative amount of earthwork moved along centerline and distance over which the earth and material is moved [10]. Mass haul is excellent method of analyzing linear earthmoving operations. To prepare the mass haul diagram the most essential thing is road's proposed profile and existing ground levels. Quantities of earthwork were estimated in cutting as well as filling. The Table 5.1 shows the volume of cut and fill for sample road section. The horizontal axis of profile and mass haul represent the chainages, usually at intervals of 10m. The vertical axis of mass haul diagram represents cumulative volume in cubic meters of earth.

Mass diagram provides information related to
1) Volume of materials
2) Average haul distance and
3) Type of equipment to be selected
Mass haul has some peculiar properties like earthwork in cutting may produce ascending curve while that earthwork in fill produce descending curve. The middle axis of the mass haul view is known as the balance line.A balance line is a horizontal line of specific length that intersects the mass diagram in two places [11]. The balance line can be constructed so that its length is the maximum haul distance for different types of equipment. The location of the mass haul line relative to the balance line indicates material movement in the current design. When the mass haul line rises above the balance line, it indicates a region in which material is cut. When the mass haul line falls below the balance line, it indicates a region in which material is filling. Maximum or minimum points on curve represent the change point i.e. from cut to fill or vice versa. Wherever the mass haul curve crosses the datum line it represent the balanced section i.e. amount of cut is exactly as amount of fill. Final position of mass curve represent whether the road portion has excess soil or deficit.
The mass ordinate with use of excel software were plotted on X and Y axis. The Table 5.2 shows the X and Y coordinates for sample case study.

5.2.2 Plotting the mass haul diagram

The coordinates were used to plot a curve in Autodesk auto CAD software. The polyline command was used to draw the curve. It can be seen in diagram that curve fall and rises again and then falls again. As shown in Figure 5.1 The falling curve in initial portion upto 90+220 represents the fill portion. The curve rises

Table 5.1: Mass ordinated for plotting mass haul diagram for project AU 109

Chainage Chainage	**Volume Cut (m3)**	**Volume Fill (m3)**	**volume of fill**	**Status Status**	**Algebraic sum**	**Mass ordinate**
90000	0	210	233	fill	-233	0
90020	0	365	405	fill	-405	-405
90040	0	254	282	fill	-282	-687
90060	0	653	724	fill	-724	-1412
90080	0	565	627	fill	-627	-2038
90100	0	626	695	fill	-695	-2733
90120	0	665	738	fill	-738	-3472
90140	0	475	528	fill	-528	-3999
90160	0	714	793	fill	-793	-4792
90180	0	605	671	fill	-671	-5463
90200	0	375	417	fill	-417	-5880
90220	0	535	594	fill	-594	-6473
90240	0	197	218	fill	-218	-6692
90260	214	0	0	cut	214	-6477
90280	170	0	0	cut	170	-6307
90300	487	0	0	cut	487	-5821
90320	419	0	0	cut	419	-5401
90340	388	0	0	cut	388	-5014
90360	670	0	0	cut	670	-4343
90380	568	0	0	cut	568	-3775
90400	671	0	0	cut	671	-3104
90420	843	0	0	cut	843	-2261
90440	378	0	0	cut	378	-1883
90460	540	0	0	cut	540	-1342
90480	576	0	0	cut	576	-766
90500	612	0	0	cut	612	-154
90520	674	0	0	cut	674	520
90540	358	0	0	cut	358	878
90560	299	0	0	cut	299	1177

Chainage Chainage	**Volume Cut (m3)**	**Volume Fill (m3)**	**volume of fill**	**Status Status**	**Algebraic sum**	**Mass ordinate**
90580	358	0	0	cut	358	1535
90600	211	0	0	cut	211	1746
90620	31	0	0	cut	31	1777
90640	0	0	0	fill	0	1777
90660	0	228	253	fill	-253	1524
90680	0	192	213	fill	-213	1311
90700	0	102	113	fill	-113	1197
90720	0	212	235	fill	-235	962
90740	0	389	432	fill	-432	530
90760	0	258	286	fill	-286	244
90780	0	278	309	fill	-309	-65
90800	0	344	382	fill	-382	-447
90820	0	280	311	fill	-311	-759
90840	0	424	470	fill	-470	-1229
90860	0	448	497	fill	-497	-1727
90880	0	224	249	fill	-249	-1975
90900	0	208	231	fill	-231	-2206
90920	0	356	395	fill	-395	-2601
90940	0	224	249	fill	-249	-2850
90960	0	364	404	fill	-404	-3254
90980	0	463	514	fill	-514	-3768
91000	0	462	513	fill	-513	-4281

Table 5.2: Ordinates for plotting on X and Y axis for mass haul diagram for project AU 109

Chainage	**X and Y coordinate Respectively**
90000	90000,0
90020	90020,-405.380791199996
90040	90040,-687.381286200026
90060	90060,-1411.73454120003
90080	90080,-2038.45699140006
90100	90100,-2733.45083520006
90120	90120,-3471.51090300007
90140	90140,-3999.29416920011
90160	90160,-4792.08611700015
90180	90180,-5463.3127962002
90200	90200,-5879.85363840022
90220	90220,-6473.41035420024
90240	90240,-6691.56755640027
90260	90260,-6477.38843640025
90280	90280,-6307.36225640027
90300	90300,-5820.69673640027
90320	90320,-5401.49673640028
90340	90340,-5013.81545640027
90360	90360,-4343.35345640029
90380	90380,-3774.97783640031
90400	90400,-3103.86295640031
90420	90420,-2261.04127640032
90440	90440,-1882.60927640032
90460	90460,-1342.29925640034
90480	90480,-766.07013640036
90500	90500,-154.350456400353
90520	9,05,20,520.03
90540	9,05,40,878.09
90560	90,56,01,177.06
90580	90,58,01,534.83
90600	90,60,01,746.10
90620	90,62,01,777.27
90640	90,64,01,776.81
90660	90,66,01,523.75
90680	90,68,01,310.51
90700	90,70,01,197.17
90720	9,07,20,961.67
90740	9,07,40,529.95
90760	9,07,60,243.56

Chainage	X and Y coordinate Respectively
90780	90780,-65.0837466004972
90800	90800,-447.457456800491
90820	90820,-758.604331800491
90840	90840,-1229.0909076005
90860	90860,-1726.52117940048
90880	90880,-1975.47943860052
90900	90900,-2206.10555940052
90920	90920,-2601.31715220054
90940	90940,-2850.27541140053
90960	90960,-3254.03322720054
90980	90980,-3768.28292940055
91000	91000,-4281.21206460056

again from chainages 90+200 up to 90+500 which represent cutting of soil. The curve at 90+500 rises above balance line. The portion of area between 90+000 to 90+550 is balanced section i.e. volume of excess soil in cut will be utilized to fill the volume of soil in deficient locations. The end curve at chainage from 90+780 represents the unbalanced fill section.

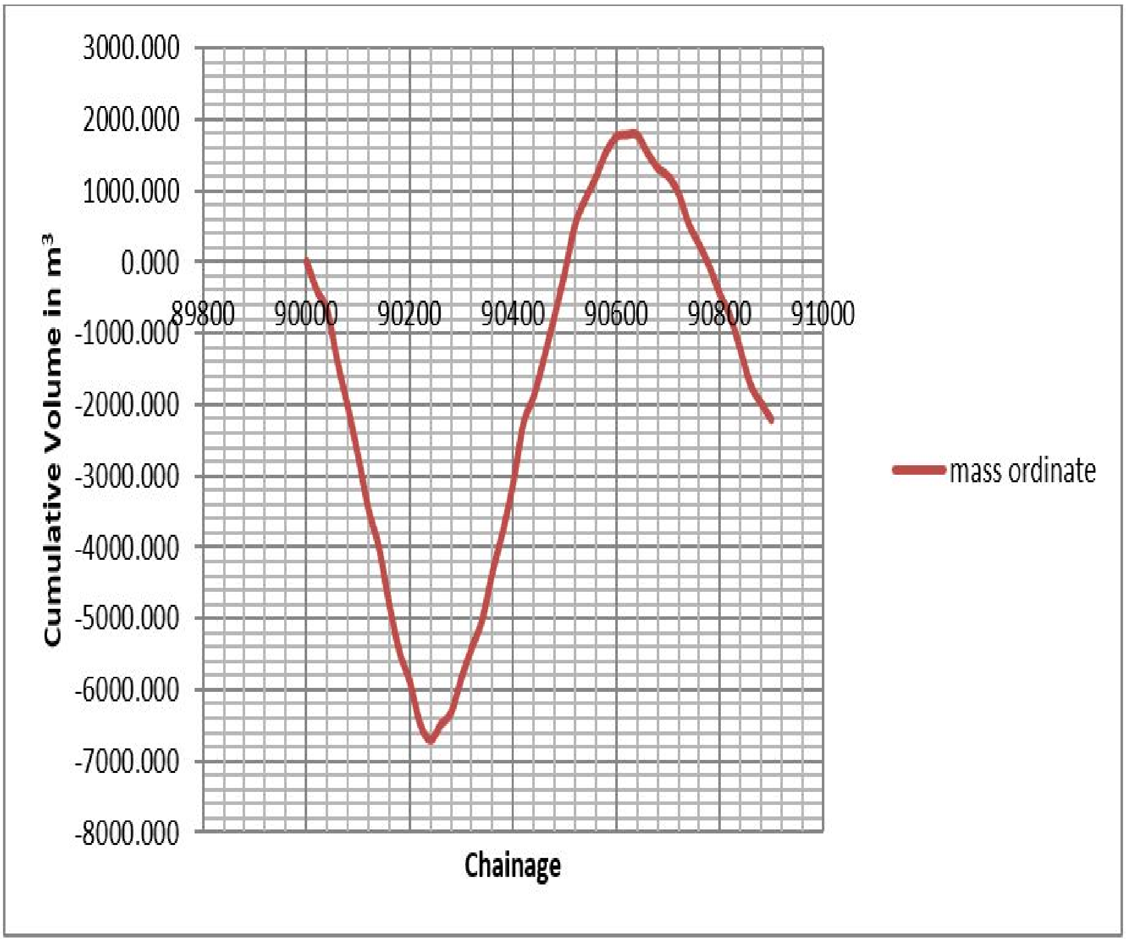

Figure 5.1: Mass haul diagram curve for project AU 109

5.2.3 Average haul distance

The mass haul diagram can be used to identify the average haul distance for the soil on road profile. For calculating the cost of earthwork it is very essential to identify the haul distance over which the soil will be moved as well as how much volume of material that should be moved [12]. The average haul distance can be determined by dividing the area enclosed under the curve by the sum of absolute value of peaks and low point. As shown in mass haul diagram below Figure 5.2 for AU 109, below the balance line, area under the curve is 1776724.This area was calculated by plotting the coordinates on Auto desk auto CAD software. The polyline was drawn over the area enclosed below the below balance line. As seen in curve volume of earthwork is 5996 m3.

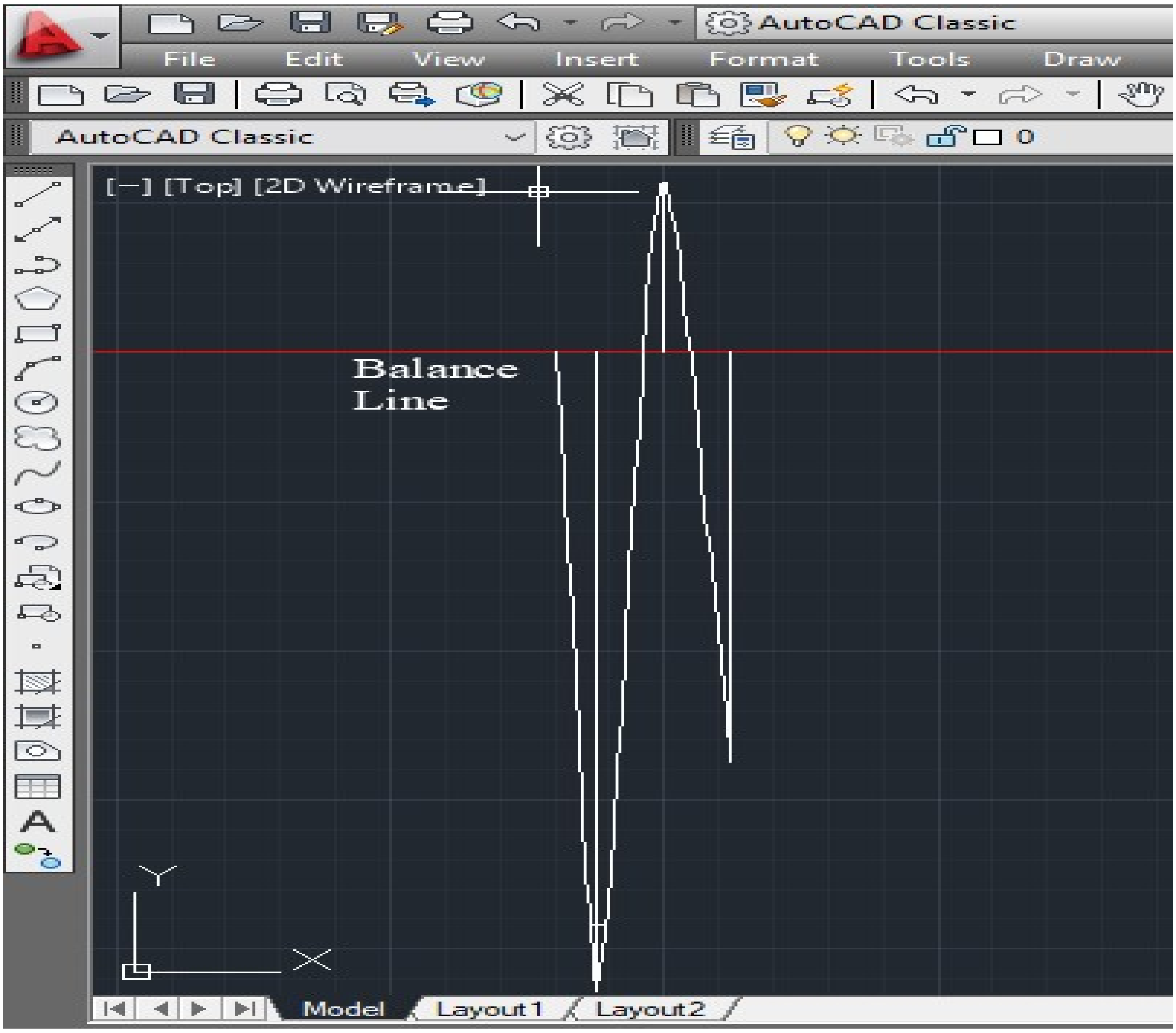

Figure 5.2: Mass haul diagram curve plotted in Auto CAD to calculated area under curve

Average haul distance = $\frac{1776724}{5996}$

= 296 m

Using the above approach, the haul distance can be calculated. The cost of hauling soil from cut location to fill was calculated using the unit cost of transferring soil, spreading and compaction. Cost of excavation of soil is different. Final cost of earthwork was summation of cost of hauling, spreading, compaction and cost of excavation.

5.2.4 Earthwork cost using mass haul diagram

Following sample calculation for cost of earthwork using mass haul diagram are derived for AU 109 project and are shown in Table 5.3 below. The haul distances were derived

Below the baseline

Table 5.3: Cost of earthwork using mass haul diagram for project AU 109

Sr no.	Chainage	To	Area under curve	Excavation to be moved	Haul distance Haul distance	Unit cost of haul	Cost of haul
1	2	3	4	5	6	7	8
1	90203	90292	37211	695	53.541	65	45175
2	90000	90504	1776724	5996	296.318	70	419720

Above baseline

Sr no.	Chainage	To	Area under curve	Excavation to be moved	Haul distance	Unit cost of haul	Cost of haul
1	2	3	4	5	6	7	8
1	90575	90666	20163	317	63.6057	65	20605
2	90504	90775	411500	1459	282.043	70	102130

Deficient soil needed to be borrowed

Sr no.	Chainage	To	Area under curve	Excavation Excavation	Haul distance Haul distance	Unit cost of haul	Cost of haul
1	2	3	4	5	6	7	8
5	-	-	-	4281	1775	311	1331391

Note: Unit cost of haul in column no. 7 Incudes cost of hauling, spreading and compaction

Cost of hauling, spreading, compaction i.e. summation of all values of column no.8 is 1919021

Cost of excavation = Volume of excavation x Rate of excavation for 1 m3

= 12749 x 26

= 331474

Total cost of earthwork = Rs.2250495

5.3 Model development

5.3.1 Background

A model in the sense used in operation research is defined as a representation of an actual object or situation. It shows the relationships (direct or indirect) and inter-relationships of action and reaction in terms of cause and effect. The main objective of a model is to provide means for analyzing the behavior of the system for the purpose of improving its performance [13]. Or, if a system is not in existence, then a model defines the ideal structure of this future system indicating the functional relationships among its elements. Mathematical model is one which employs a set of mathematical symbols (i.e., letters, numbers, etc.) to represent the decision variables of the system. These variables are related together by means of a mathematical equation or a set of equations to describe the behavior (or properties) of the system. The solution of the problem is then obtained by applying well-developed mathematical techniques to the model.

Linear programming is a powerful quantitative technique (or operational research technique) designs to solve allocation problem. The term 'linear programming' consists of the two words 'Linear' and 'Programming'. The word 'Linear' is used to describe the relationship between decision variables, which are directly proportional. For example, if doubling (or tripling) the production of a product will exactly double (or triple) the profit and required resources, then it is linear relationship. The word 'programming' means planning of activities in a manner that achieves some 'optimal' result with available resources. A program is 'optimal' if it maximizes or minimizes some measure or criterion of effectiveness such as profit, contribution (i.e. sales-variable cost), sales, and cost. Thus, 'Linear Programming' indicates the planning of decision variables, which are directly proportional, to achieve the 'optimal' result considering the limitations within which the problem is to be solved.

Decision Variables

The decision variables refer to the economic or physical quantities, which are competing with one another for sharing the given limited resources. The relationship among these variables must be linear under linear programming. The numerical values of decision variables indicate the solution of the linear programming problem.

Constraints

The constraints indicate limitations on the resources, which are to be allocated among various decision variables. These resources may be production capacity, manpower, time, space or machinery. These must be capable of being expressed as linear equation (i.e. =) on inequalities in terms of decision variables. Thus,

constraints of a linear programming problem are linear equalities or inequalities arising out of practical limitations.
Non-negativity Restriction
Non-negativity restriction indicates that all decision variables must take on values equal to or greater than zero.

5.3.2 Required inputs/ Definition

The required quantities of cut and fill at various location in Plan and profile of road were determined initially. Profile of road was divided into Number of section based on cut and fill then further subdivision were made to increase accuracy. Based on the division made the possible soil movement pattern were identified from cut to fill locations [14].
In addition to this data there is possibility of imbalance between cut and fill soil quantities i.e. either the cut volume exceed the fill volume or vice versa [15]. So the remote input parameter needed to be added like the borrow location or waste locations from where the deficient soil can be borrowed or excess soil can be dumped respectively.
The division of road profile is explained in earlier sections. The cut sections are denoted by notation C1,C2,C3.....Cn while the fill section are denoted by F1,F2,F3.....Fn. Borrow location denoted by 'B' and waste location denoted by 'W' is considered to be Cut location and fill location respectively. The inputs are defined in table no 5.4 below. Initially distance matrix is prepared between each cut locations 'U' to each fill locations '' as shown below.

CUT/FILL	**F1**	**F2**	**F3**	**.**	**.**	**.**	**Fn**
C1	D11	D12	D13	.	.	.	D1n
C2	D21	D22	D23	.	.	.	D2n
C3	D31	D32	D33	.	.	.	D3n
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
Cn	Dn1	Dn2	Dn3	.	.	.	Dnn

Where 'D' Denotes lead distances between each cut and fill location as shown in Table 5.4
Let 'Q u,v' denotes the amount of cut in cubic meters to be hauled from cut 'u'

Table 5.4: lead distance matrix for project AU 109

CUT/FILL	F1	F2	F3	F4	F5
C1	200	80	380	490	650
C2	300	180	280	390	550
C3	410	290	170	280	440
C4	500	380	80	190	350
B1	1080	1200	1660	1770	1930

to fill ‘v’.

Based on distance as input and algorithms created in Microsoft excel, unit costs are derived for variable distance. Unit cost denoted as ‘Cu,v’ of two operation considered in project is as follows:

1) Using excavator: Ce(U,V)+Ch(U)+Ch(V)+Cc(V)

2) Using dozer : Ced(U,V)+ Chd(U,V)+Cc(V)

Ce(U)...................unit cost in Rupees of excavating the 1 cubic meter of soil at location C

Ch(U)....................unit cost in Rupees of hauling 1 cubic meters of soil from location C to F

Cp(V)....................unit cost in Rupees of placing and spreading 1 cubic meters of soil at location F

Cc(V)...................unit cost in Rupees of compaction of 1 cubic meters of soil at location F

Ced(U,V)...................unit cost in Rupees of excavation with dozer of 1 cubic meters of soil at location C

Chd(U,V)................unit cost in Rupees of hauling with dozer of 1 cubic meters of soil from location C to F

Example of unit cost matrix for AU109 project is shown in Table 5.5.

Table 5.5: Unit cost matrix for project AU 109

CUT/FILL	F1	F2	F3	F4	F5
C1	94	91.64	97.54	99.7	102.84
C2	95.97	93.61	95.57	97.73	100.88
C3	98.13	95.77	93.41	95.57	98.72
C4	99.9	97.54	91.64	93.8	96.95
B1	297.38	299.74	308.78	310.94	314.08

The fill quantities will be adjusted for compaction with the fill factor. Quantities have been already derived for mass haul and fill quantities are applied with fill factor, the same have been used in this section.

5.3.3 Model formulation

The objective function is to reduce the total cost of earthwork. The total cost includes the cost of moving the soil including excavation, placement, and compaction between each cut to fill location or waste locations and between each borrow locations to fill locations. The amount of soil in cut and fill in each section is denoted by qty cut and qty fill respectively [4]. The decision variable for the model is denoted by Qu,v describes the volume to be cut from section u and moved to fill v. The proposed model is as follows:

Minimize cost:

$$\sum_{u \in cut} \sum_{v \in fill} C_{u,v} \times Q_{u,v}$$

Subject to:

$$\sum_{v \in fill} Q_{u,v} = qty\_cut$$

$$\sum_{u \in cut} Q_{u,v} \leq qty\_fill$$

$$Q_{u,v} \geq 0$$

Objective function

The objective function is to minimize the product of unit cost of earthwork operation times the volume of soil to be hauled.

Constraint:

1) Constraint 1 ensures that volume of material excavated from each cut locations is equal to defined amount of cut.

2) Constraint 2 ensures that volume of material that is transported to fill location is less than equal to defined amount of fill.
3) Constraint 3 ensures that volume transported between the cut and fill locations is not negative.
Based on the process of division of road described earlier, the quantities of either cut fill or both were evaluated in that section. These quantities will act as constraint qty in cut and qty in fill.
The linear programming problem was solved in MATLAB programming software. To solve the linear programming problem the command Linprog is used. The results obtained are in terms of volume of soil and location of cut/borrow from which soil should be moved and dumped to fill/ waste shown in Table 5.6 below. Also the results will provide the cost of entire earthwork operation.

Table 5.6: Soil transfer results for project AU 109

	F1	**F2**	**F3**	**F4**	**F5**
C1	0	1678	0	0	0
C2	0	1120	230.21	973.03	1194.77
C3	0	0	192.73	1111.12	1457.14
C4	0	0	157.06	341.85	400.09
B5	3705	422	0	0	0

From the above result the soil hauling vector diagram can be plotted which can be very efficient for coordination between planning team and execution team.

5.3.4 Model validation

The result of one of the case study obtained using mass haul diagram was implemented on site for the purpose of validation. The data for the case study was collected earlier for e.g. equipment productivity and road profile. The soil hauling plan was prepared and Microsoft project was used to prepare the plan. The schedule was submitted on site for implementation. The daily data of soil movement, equipment's deployed on site, chainage at which it was deployed, duration for which it was deployed, Number of trips of trucks, etc. was collected form site over the period of time specified for work given as per schedule. Based on work done on site the cost of entire operation was evaluated. The cost was compared with cost provided with schedule given in Microsoft project using output of LP model.

Table 5.7: Schedule of work prepared using output of LP model for project AU 109

Tasks	**Tasks 01**	**Baseline Cost**
AU 109	AU 109	0
	Start of work	0
	Excavation at C1,hauling to F2 and spreading and compaction	227205
	Excavation at C2, hauling to F2 and spreading and compaction	160380
	Excavation at C2, hauling to F3 spreading and compaction	40095
	excavation at C3, hauling to F3 spreading and compaction	26730
	excavation at C4, hauling to F3 spreading and compaction	26730
	excavation at C2, hauling to F4 spreading and compaction	147015
	excavation at C3, hauling to F4 spreading and compaction	173745
	excavation at C4, hauling to F4 spreading and compaction	53460
	excavation at C2, hauling to F5 spreading and compaction	200475
	excavation at C3, hauling to F5 spreading and compaction	227205
	excavation at C4, hauling to F5 spreading and compaction	66825
	Borrow from B1 to F1 Spreading and hauling	721710
	Borrow from B1 to F2 spreading and hauling	80190
	Finish of work	0
Grand Total		**2151765**

The actual cost incurred on site for the entire operation considering the plan given by mass haul diagram was about Rs 2449430. It can be seen that results given by LP model shown in Table 5.7 are optimized compared to that given by mass haul diagram method.

5.4 Closure

The cost were derived with two different methods of EAP and earth transfer pattern i.e. mass haul & mathematical model which was the principal of linear programming. Initially the cost was derived with mass haul diagram which uses average haul distance, and later mathematical model was developed using principles of linear programming. The objective function was defined & corresponding constraints were also provided, and model was solved in MATLAB. Finally the model was validated with the results obtained using conventional method of planning performed on site.

Chapter 6

RESULTS AND DISCUSSIONS

In the previous section, we have seen how to calculate cost with mass haul method and by linear programming. Based on the results obtained with mass haul and linear programming model the soil transfer movement on highway project can be seen with vector diagram as shown in figure below.

Firstly different operations that are conducted on highway for embankment construction were studied .Numerous literatures and codes specified by Indian road congress were referred for the study of operation for earthwork operation. The operation that was carried out on case studies used excavator for soil removal, Dump trucks for hauling, graders for spreading the soil and vibratory roller for compaction to required density.

Secondly the variable lead distances were considered for calculation of unit cost which is a major input parameter for mathematical model. Lead distances were also used to calculate productivity analysis. It was observed that as lead distance goes on increasing the unit cost is affected for the component of hauling. It was observed also observed productivity is affected with increase in lead distance.

The Third stage included the comparative analysis of results related to earth allocation plan obtained with both method i.e. mass haul planning and Linear programming model. The optimization model was developed in third stage of project.

- **Observation with mass haul diagram method**

The results obtained are more approximate in term of lead distance for soil movement. The section of road from chainage 90+000 to 90+500, the average haul distance was derived 296 and soil volume to be moved was to be 5226 with constant unit cost of Rs 70/m3 only for hauling and total of earthwork operation of Rs 112.48/m3.

- **Observation with LP model**

The results obtained are most defined from the perspective of lead distance for soil movement The section of road from the chianage of 90+000 to 90+500,was already divided based on cut and fill locations. More localized result and closer lead distance can be seen in case of patterns of soil movement given by LP model. For e.g. As seen in Figure 6.3 the soil volume of 1678m3 from division of cut C1 is transferred to F2 with the unit cost of Rs 91.64 /m3 also to transfer soil from C2 to F2 the soil volume of 1120m3 is to be transferred with unit cost of operation as 93.61.Also variation can be seen regarding borrowing of soil. Here it suggest that soil volume of 3705 is to be borrowed at location C1 form borrow sites with unit cost of 297.38.

- **Inference**

As seen in Figure more defined and accurate results can be observed in case of result obtained with linear programming model. These results are optimized in terms of cost for localized soil transfer, which affect overall project cost for earthwork. But along with soil movement diagram, it was necessary to validate the result form the point of view of cost. So the data for total 8 case studies was considered in this process. As shown in the column no.5, 6 and 7 it can be seen that results obtained with linear programming model are more optimized in terms of cost with respect to mass haul planning method. Though the case studies are chosen for 1 kilometers of stretch the percentage decrease in cost varies. It can be concludes that this variation is due to variation in amount of volume of earthwork as well as variable soil properties.

The results of 8 case studies are summarized below:

Table 6.1: Summary of cost with mass haul diagram and LP model depicting optimization

Case study	Chainage	Km	Earthwork volume	Cost in Rs with mass haul	Cost in Rs with LP model	Percentage decrease in cost with LP model
i	ii	iii	iv	v	vi	vii
Kusumba Malegaon	65+000 to 66+000	1	9943	1600326	1484800	7.2
Kusumba Malegaon	66+000 to 67+000	1	32357	3484461	3234700	7.2
Kusumba Malegaon	75+000 to 76+000	1	47526	4630977	4143600	10.5
NSK 70A	120+000 to 121+000	1	8764	930777	533200	42.7
NSK 70B	127+000 to 128+000	1	3415	338676	192000	43.3
AU 109	90+000 to 91+000	1	12983	2250495	2077600	7.7
Kusumba Malegaon	77+000 to 78+000	1	26831	2969210	2658500	10.5
Arawali-Kante	76+880 to 86+880	10	416509	5.6E+07	5.5E+07	0.2

The population size of 9 was considered with margin of error as 15% and confidence interval of 95%, sample size of 8 case studies were considered in deriving the conclusions.

The Regression graph was drawn shown in Figure 6.1 to validate the result. The R2 value of 1 was observed which shows that relation between results obtained with both methods. The regression graph suggest the average decrease in cost of earthwork by cost of Rs 272599 with respect to cost of mass haul diagram method.

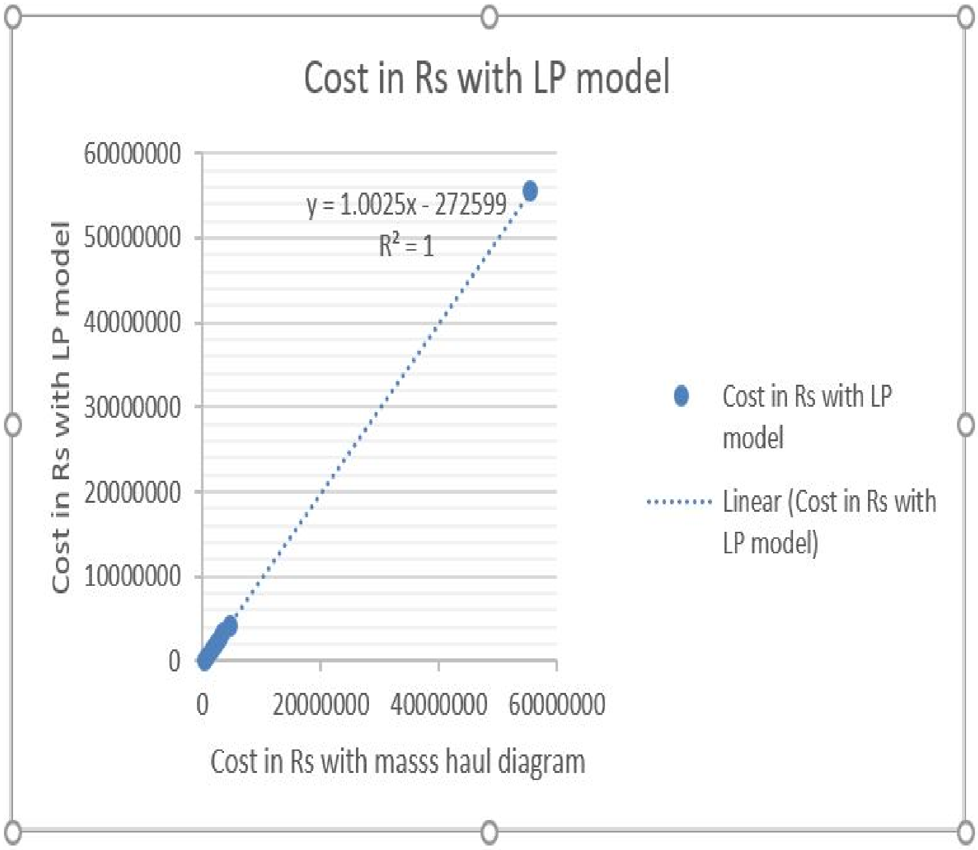

Figure 6.1: Graph of regression analysis of cost with mass haul diagram and LP model

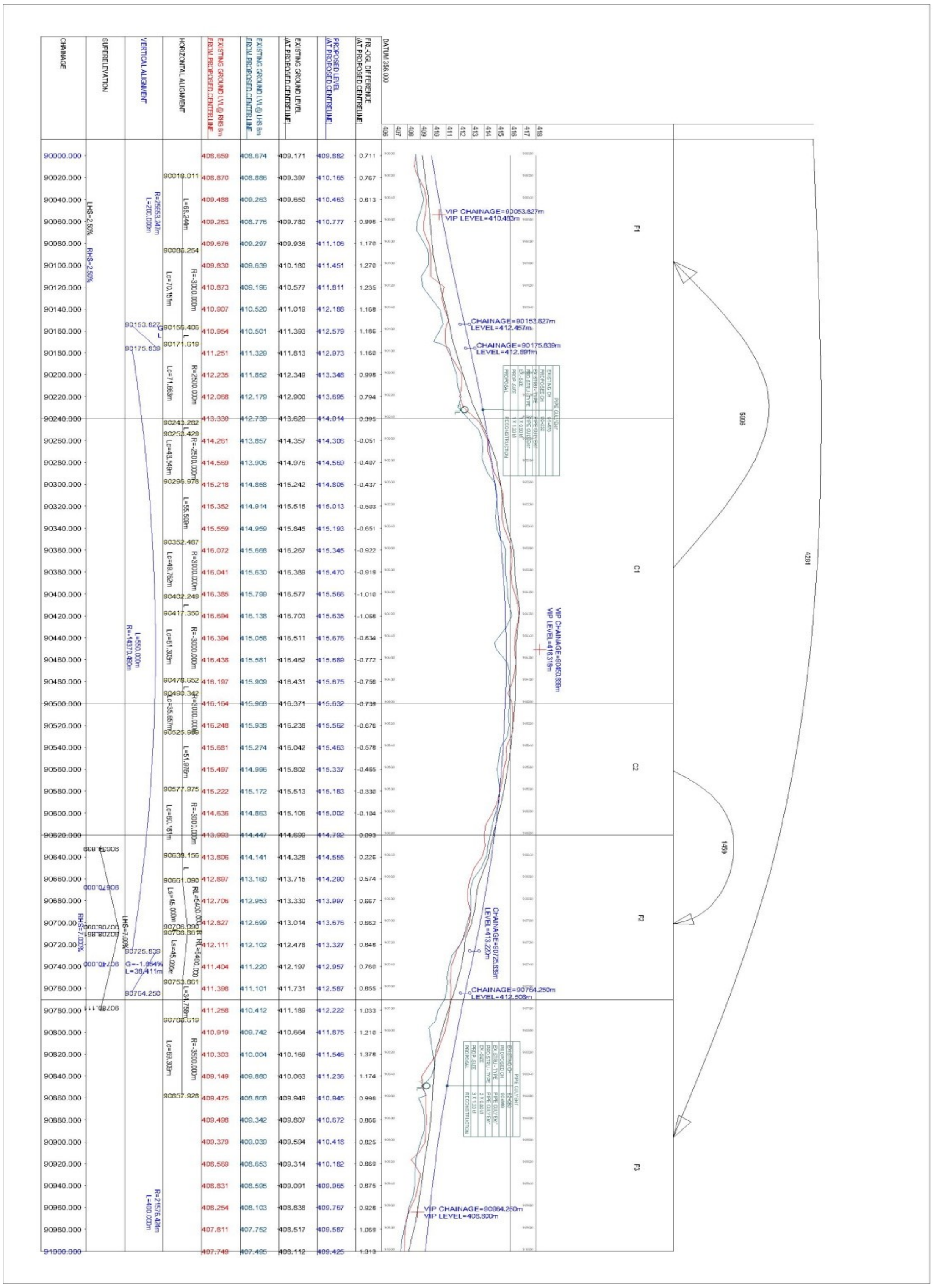

Figure 6.2: Vector diagram for soil hauling from outputs of Mass haul diagram

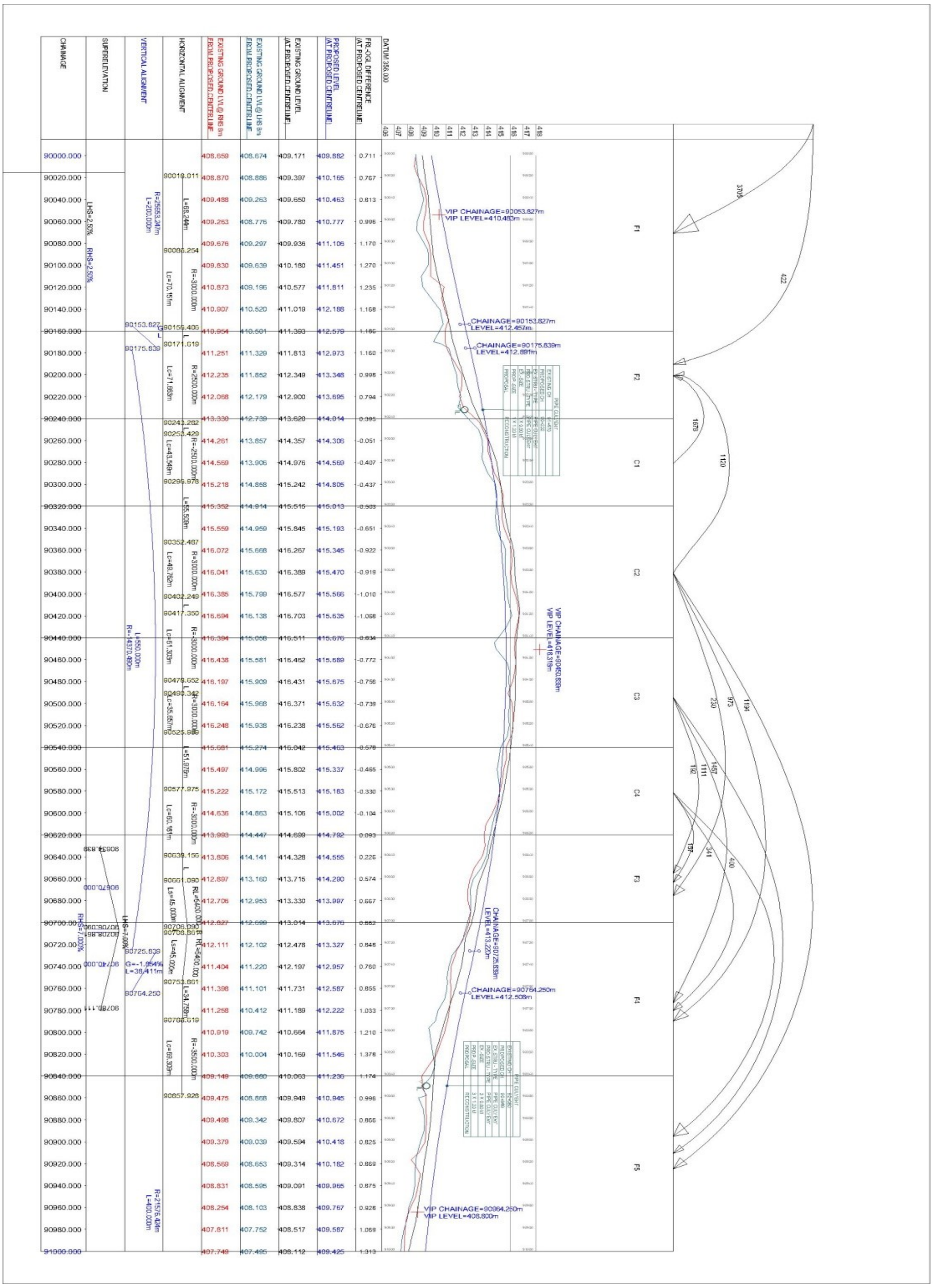

Figure 6.3: Vector diagram for soil hauling from outputs of LP Model

Chapter 7

CONCLUSION

This research presents the methods of earthwork planning which are currently in practice namely mass haul diagram method and linear programming model. The paper present the optimization model which uses the principle of linear programming (transportation model).The MATLAB programming was used to solve tedious optimization problem. The following conclusions were derived from the conducted study:

1. Various operations are studied that are carried out on highway construction site for earthwork construction. The operation of excavator for removal, dump trucks for hauling and graders for spreading and vibratory roller for achieving required density is considered for research.

2. The unit cost is derived for variable lead distances for hauling operation of soil form cut to fill locations and used as major input parameter.

3. The methodology used in paper for earthwork planning is easy to implement and provided the accurate results than conventional earthwork planning method of mass haul diagram. The lead distance for soil transfer are more accurate and localized in case of LP model than that of average haul distance in case of mass haul diagram method.

4. The result for 8 case studies were compared in terms of cost and also the movement for soil transfer and amount of soil were drawn using vector diagram which gives a comprehensive idea of how the earthwork should be done on site.

5. Although the model uses the distance as input which are considered from the centre of cut location to centre of fill location, but still provides much accurate result in comparison to mass haul diagram method.

6. The results obtained clearly showed that cost is optimized in case of results obtained in linear programming model on contrary to mass haul diagram method which provide much approximate result in terms of average haul distance of soil movement and higher cost.
7. The reduction of cost is approximately about 272599 as obtained from regression analysis graph with LP model with respect to mass haul diagram.
8. The LP model has been validated in terms of actual cost of earthwork operation on site based on schedule prepared using outputs of mass haul diagram.

Limitations: The proposed model do not consider variable soil properties for purpose of calculations. Hence productivity of equipments deployed on site also remain constant. The further research includes comparing the results with variable type of soil.

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LIST OF PUBLICATIONS ON PRESENT WORK

[1] Omkar U. Rasal, Sushma S. Kulkarni, "Unit Cost Analysis for Earthwork Operations on Highway Project ", *International Research Journal of Advance Research in Science and Engineering,*, Vol. 8, Issue: 7, 2394-1529, July 2019. (Published)

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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.

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Model Development for Optimizing Earthwork Operations on Highway Projects

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***Abstract*— Earthwork is equipment intensive activity as it involves heavy construction equipment like excavator, trucks, grader, roller, etc. which have very high operational cost. Earthwork involves cutting the excess soil/filling the suitable soil wherever deficit, grading and compaction to create the required grade. The new method of earth allocation plan using principle of linear programming are developed, but presently the most widely used method for earth allocation operation is mass diagram method. In this research work, the conventional mass haul method and linear programming method was considered for comparative analysis. The mathematical model was developed using principle of linear programming to create the critical earth allocation plans. The MATLAB programming software was used to solve the linear programming problem based on principle of transportation model. For comparative analysis, 8 case studies with different plan and profile of road are considered and results in terms of cost, time, and haul patterns are computed for both the methods of earth allocation. It was observed that results obtained with mathematical model provide more optimized results than mass haul diagram for all case studies.**

***Keywords*— Earthwork, Optimization, Mass haul diagram, linear programming model.**

I. Introduction

The earthwork is the process in which ground surface in target area is levelled, either by moving or filling soil [14].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 equipment like excavators, dozers, hauler, scraper and compactor making earthwork cost expensive activities in road construction. The existing earthwork optimization methods are classified into equipment fleet planning (EFP) and earth allocation planning (EAP) [6].EFP identifies the most favourable equipment type, computes the optimal number of equipment, calculate productivity and allocate equipment at right time and place. EAP identifies the optimal cut-fill pairs and minimize the total earthmoving cost by assigning cuts to fill economically. It involves identifying the amount of earth that should be moved from cut areas to fill areas. The earthwork allocation plan is needed to know amount of quantities of soil/rock to be moved from cut section to the fill section or to know amount of soil needed to be borrowed at fill section externally or soil (unsuitable soil) that is needed to be disposed off from cut section.

This research deals with deriving the most economical earth allocation plan for the highway projects.The earthwork estimator currently use software programs to derive quantities of earthwork of cut and fill, but it's quite difficult to identify the movement of soil within road project. For this planning engineers refer to mass haul diagram method of planning. Mass haul diagram method provides the earth allocation plan in terms of average haul distance and volume of soil movement on road project. This paper develops optimization model using the linear programming (transportation model) to derive the most economical earth allocation plan i.e. in terms of haul distance for soil movement and volume of soil to be moved. Also the lead distance for soil movement is considered as variable and variable lead distance are considered in deriving the final cost of earthwork operation. Paper present the comparative analysis of results in terms of cost obtained with mass haul also developed by scimago: SCIMAGO INSTITUTIONS RANKINGS

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A

Synopsis Report on

"Model Development for Optimizing Earthwork Operations on Highway Project"

Submitted By

Mr. Rasal Omkar Unmesh

Roll no.1727005

Under the Guidance of

Dr. Mrs. Sushma S.Kulkarni

&

Mr. Prabharkar Vanjari

(Co-Guide)

Civil Engineering Department

In Partial fulfillment of the degree M Tech

Kasegaon Education Society's

RAJARAMBAPU INSTITUTE OF TECHNOLOGY, RAJARAMNAGAR

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Affiliated to Shivaji University Kolhapur

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SYNOPSIS OF M. TECH DISSERTATION

1. Name of Program : M. Tech. (Civil-Construction Management)

2. Names of the Student : Mr. Omkar U.Rasal

3. Date of Registration : August, 2018

4. Name of Guide : Dr. Mrs. Sushma S.Kulkarni
: Mr.Prabhakar Vanjari(Co-Guide)

5. Sponsored Details : Innovision Technologies, Navi Mumbai

6. Proposed Title : **"Model Development for Optimizing Earthwork Operations on Highway Projects"**

7. Synopsis of Dissertation Work:

7.1 Introduction and Relevance:

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 existing earthwork optimization methods are classified into equipment fleet planning (EFP) and earth allocation planning (EAP) (Gwak et al., 2017).EFP identifies the most favorable equipment type, computes the optimal number of equipment, calculate productivity and allocate equipment at right time and place.EAP identifies the optimal cut-fill pairs and minimize the total earthmoving cost by assigning cuts to fill economically. It involves identifying the amount of earth that should be moved from cut areas to fill areas. The earthwork allocation plan is needed to know amount of quantities of soil/rock to be moved from cut section to the fill section or to know amount of soil needed to be borrowed at fill section externally or soil (unsuitable soil) that is needed to be disposed off from cut section.

The different earth allocation methods have been proposed in past for optimizing earth moving to reduce the cost of earthwork activities. Most extensively used method to develop optimization is linear programming; results of which have been improved with different constraints that are included in advanced decision models developed using methods like integer programming and fuzzy linear programming. The models developed by these researches include objective function to minimize the cost of earthwork and decision variables are the quantities of soil to be moved. 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 research proposed will also focus on geotechnical properties of soil and productivity of construction equipments which will be a major input parameter.

7.2 Literature Review:

Sr No.	Literature Review	Methods Used In Optimization	Objective Function	Whether Factors Affecting Production Were Considered?	Whether Economic Haul Distance Were Considered?
1.	Gwak et al.,2017	Multiple integer linear programming	To optimize cost in earthwork allocation	Yes	No
2.	Burdett et al., 2014	Linear programming and mixed integer	To reduce fuel consumption	Yes(factors affecting fuel consumption like mass, c/s	Yes

		programming		area distance and gradient)	
3.	Khaled Nassar, Ossama Hosny	Mixed integer programming	To find the least cost route by minimizing No. of steps	Yes(grade and rolling resistance)	No
4.	Easa,S.M.,1987	Mixed integer linear programming	To optimize cost in earthwork allocation	Yes	No
5.	Ji et al., 2010	Linear programming and Binary linear program	To optimize transportation cost in earthwork allocation	No	No
6.	Jayawardana et al.,1994	Linear programming and mixed integer programming	To optimize cost in earthwork allocation	Yes	No
7.	Parenta et al., 2015	Non-dominated sorting genetic algorithm and linear programming	To reduce cost and time of earthwork	No	No

Table no.1.Summary table of literature reviewed

As illustrated in table no.1 different researchers have tried to reduce earth moving cost. Commonly used methods are mass hauling diagram method, linear programming, fuzzy linear programming and mixed integer linear programming. The common objective of researchers was to reduce earth moving cost i.e. their objective function included cost per unit of earth mass and with decision variable of quantity to be moved.

7.2.1 Burdett et al., (2018): "Block Models for Improved Earthwork Allocation Planning In Linear Infrastructure Construction"

As per researches illustrated in table no.1, it can be seen that some of them consider parameters that affect equipment productivities employed on construction sites. These parameters are type of equipment, soil type, operational factors, size and condition on site, haul distances, grade of haul road, etc. (Jayawardane & Price, 1994), but majority of researches do not consider equipments' economic haul distance except done by author (Burdett et al., 2018). But research conducted focus on optimizing the fuel consumption in earthwork allocation. The fuel consumption is a function of mass of vehicle, cross section area of equipment, travelling distance of equipment and gradient over which it travels. The research suggests use of laws of physics in modeling the fuel consumption considering above mentioned parameters. The researchers suggest distance of travel can distinguish the type of machinery that can be deployed. E.g. for distance less that 50 m dozers should be used. If greater than 50 m but up to 1500 m scraper should be used and Distance greater than 1500 m suggests using trucks (Burdett et al.,(2018). This factor of hauling distance of equipment is not considered by other researchers. Also research developed the block model in latter part of research (former being section method) in which cut and fill are divided into block along with borrow and disposal. The size of single block was specified and volume of block was calculated.

7.2.2 Easa, S.M, (1987): "Earthwork Allocations with Non-constant Unit Cost"

The author developed the mathematical model for optimization of earthwork. The research considers the variations in unit cost for moving earthwork such as unit cost of purchase, cut, haul, and compaction. The research considers that unit cost of purchase and excavation is constant for moving earth from cut to fill whereas unit cost of haul is varying. But unit cost for purchase and excavation are varying in case of soil movement from borrow pit to fill location. This research here considers unit cost for operation of cut-haul-compaction.

7.2.3 Jayawardane, A.K.W. and Price, A.D., (1994): "A New Approach For Optimizing Earth Moving Operations"

The author has divided earthwork moving problem into 3 stages; namely individual simulation model, linear/integer programming model and network scheduling. The simulation model was employed by author to determine production from available fleet, most economic loading methods, optimum team type, and optimum team size. The optimum team size i.e. combination of equipments like scraper-pusher or loader-truck is optimized considering criteria like cost, time, and production. The end of simulation provided production, unit cost, percentage of work and idle times for various types of equipment, queue time, queue length. This provides realistic input of unit cost required for linear/multiple programming model.

7.2.4 Gwak et al., (2017): "Optimal Cut-Fill Pairing And Sequencing Method In Earthwork Operation."

The author developed computational method called optimal cut fill pairing and sequencing. The method is efficient in solving issues like different soil properties of cut and fill volume, repositioning time of equipment i.e. reducing travel time between two cut pits, volume of cut and fill pits designated as cut or fill prism, cost which will be incurred if rock is encountered, disposal and borrow cost. This research also employed the concept of block or prism of soil or rock. Thus author also considered the order of excavation of cut prism and order in which it should be filled in fill prism. The Matlab software was used to program the mathematical model. The significant issue handled by research is that it considers the soil properties in cut and fill prism i.e. soil which is non-conforming to fill prism requirement is to be rejected.

7.2.5 Parenta et al., (2015): "An Evolutionary Multi-Objective Optimization System For Earthworks"

While other researches focused on single objective of optimization i.e. cost; the research proposed by author focused on multi objective optimization. They considered cost as well as total construction time in optimization by allocation of construction equipment. The process was constrained by project duration and budget allocated. They considered earthwork as production line consisting of activities like excavation, transportation, spreading, and compaction. The author considered optimal allocation of compaction equipment and then allocation of equipment for other tasks like spreading, hauling and excavation. The productivity of equipments for other tasks was equivalent to compaction equipment or was kept closer to it. The research considered total time is accumulated time of each construction phase is function of equipment productivity and material to be handled and total cost is accumulated cost of each construction phase which is function of time(since equipments have time dependent cost).

7.2.6 Ji et al., (2010): "Mathematical Modeling of Earthwork Optimization Problem"

The research proposed introduced us with a problem of division of road among contractors encountered in road construction projects. The research involved two steps. First stage involved optimization of earth allocation and second involved division of road into section so that there should be least movement of earth between different sections. The ultimate objective of research was to have sufficient earth cutting to fulfill the fill requirement in that section or to avoid overflow of earth in particular section and lack of earth in other section.

7.3 Gap analysis:

The above researches do not consider the possibilities of operation like other than excavation-haul-compaction. These mentioned researches have considered unit cost of operation of excavation-haul-compaction in optimization process. But there are other operational methods of earthwork of which unit operation cost are needed to be considered. It is known that for shorter distance it is possible to move soil using dozer/front loader operation while for larger distance it is becomes essential to use hauler. The soil borrowed from borrow pits can be efficiently collected and can be spread with the help of scraper. These possibilities are associated with economic haul distance of equipment. The above researches have not mentioned other operational possibilities and unit costs associated with it.

7.4 Problem Statement:

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.

The existing researches considering operation of excavation-haul-compaction 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.

7.5 Objectives:

i. To identify and incorporate various operational alternatives in deriving unit cost of earthwork.
ii. To incorporate the concept of lead and lift as per guidelines given in SSR in identifying the unit cost of earthwork.
iii. To optimize earthwork operations through mathematical modeling.
iv. To validate the model through application on highway projects

7.6 Plan of Proposed Work:

Phase I - (July - Sept2018)

a. Study of literature related to earthwork optimization

Phase II - (Oct - Dec 2018)

a. Collection of data related to equipment, topography and geotechnical investigation carried out on site
b. Identifying various operational alternatives based on soil type and distance; and incorporating them for deriving unit cost
c. Studying concept of lead and lift and incorporating it in unit cost of haul
d. System definition of proposed model(Defining the inputs, parameters and variables)
e. Mathematical model formulation(Objective function and constraints)

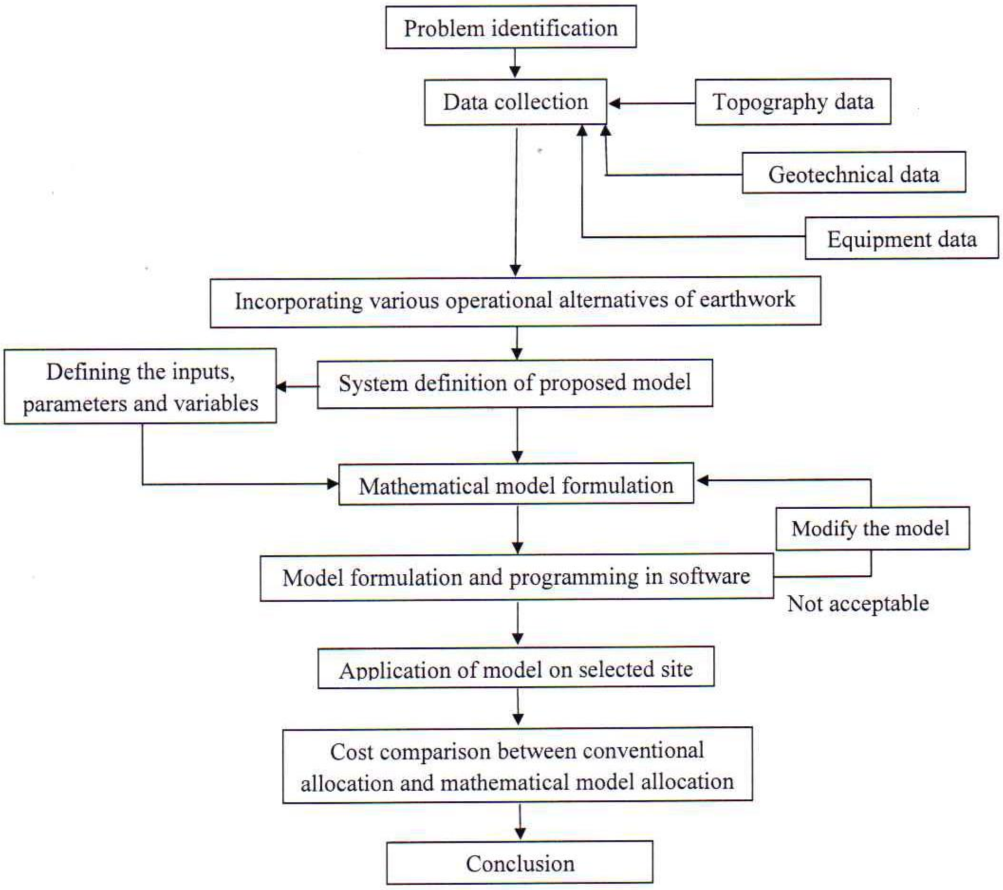
Phase III - (Jan – Feb 2019)

a. Use software for programming model
b. Creating digital elevation model of selected site
c. Deriving earth volumes in cut and fill sections and specifying borrow and disposal locations
d. Application of model on chosen site

Phase IV - (March - April 2019)

a. Results i.e. comparison between cost by conventional allocation using DSR/SSR rates and mathematical model
b. Conclusion and Report writing

7.7 Action Plan of Proposed Work:



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Model Development For Optimizing Earthwork Operations On Highway Project

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