OPTIMUM PLANNING FOR MULTI-PROJECT EARTHMOVING OPERATIONS

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ABSTRACT

By virtue of its complex nature, the construction industry comprises a wide spectrum of interrelated variables and factors. This multifaceted character of the construction industry puts the use of engineering modeling tools and techniques on top of project management necessities. This research introduces a macro-level earthmoving management system using Genetic Algorithms (GAs) to reach the optimum allocation of earthmoving equipment. The Earthmoving Equipment Management System (EEMS) functions through four integrated modules: (1) A Central Database containing information about projects and available equipment; (2) An Equipment per Segment Selection module that calculates the cut and fill quantities, plots the Mass Haul Diagrams, and selects the equipment types to be used for each segment; (3) An Equipment Pool module which determines the production and cost for each available equipment, based upon the project site conditions; and (4) An Optimization Engine equipped with a GA optimization solver. This engine formulates the optimum earthmoving cost for all projects, by changing the number of allocated equipment. The Optimization Engine takes into account the number of available equipment and calculates the weekly equipment allocation. The EEMS model was implemented on an earthmoving company conducting five different projects on hand. The model proved to be an effective tool in providing decision makers with optimum equipment utilization on a multi-project scale to minimize the earthmoving cost. The results were then compared with the company's existing micro-level management system, demonstrating better performance on the level of savings, amounting to 13% of total earthmoving cost.

KEYWORDS

Earthmoving equipment, Multi-project optimization, Genetic Algorithms, Macro-level management.

INTRODUCTION

Problem Definition

In a typical earthmoving construction operation, project management is under constant pressure to improve production and efficiency. Attaining the most efficient production rate for earthmoving operations requires optimization of using the available resources, balancing the allocation of resources over the course of the project, selecting the best-suited types of equipment in accordance with the nature of the job, and completing the operation with the least possible cost within the framework of the project deadline. Access to tools and techniques enables the contractor to foresee the possibility of attaining the desired optimum cost of an earthmoving operation. Genetic Algorithms (GAs) is one of the most widely used techniques for optimization of construction resources.

Problem Challenges

This research aims to study the process of equipment optimization for earthmoving operation from a macro-level perspective. The model approach features a GA-based model which enables the project manager to select the most optimum set of earthmoving plant, e.g., loaders, trucks, scrapers, and dozers, from a preset equipment pool. However, the main challenge in developing the model was to undertake the equipment selection from a macro-level perspective.

LITERATURE REVIEW

Significant amount of research involving the use of modeling techniques has been dedicated towards the improvement of earthmoving operations efficiency. Alkas and Harris (1988) used knowledge-based systems for the selection of earthmoving equipment in road construction works. Marzouk and Moselhi (2004) explored the combination of computer simulation with GAs, to optimize the total cost of earthmoving operations. Their suggested model takes into account the number and type of available equipment models to the contractors. Moselhi and Alshibani (2007) introduced the concept of integrating GA's with the Global Positioning System (GPS) and Geographic Information System (GIS). The model was used for crew optimization during planning and control of earthmoving operations. Furthermore, Moselhi and Alshibani (2009) expanded their initial model and developed a new system that utilizes GAs, linear programming, and GIS. The new model widens the optimization scale of earth-moving operations to accommodate heavy civil engineering projects. Lin et al. (2012) combined discrete event simulation techniques with GAs to optimize the time schedule for dispatching earthmoving trucks.

PROBLEM OBJECTIVE

The model’s objective is to allocate different earthmoving equipment types and models into a variety of concurrent projects, while respecting their time constraints, equipment capacity constraint and attaining the overall optimum earthmoving cost.

EEMS (EARTHMOVING EQUIPMENT MANAGEMENT SYSTEM) MODEL FRAMEWORK

Figure 1 describes the general process of the EEMS system and their interrelation. The process consists of four main modules: (1) Central Database; (2) Equipment per Segment Selection module; (3) Equipment Pool module; and (4) Optimization Engine. Figure 2 describes the function of each of the four modules. Firstly, the Central Database contains data pertaining to all ongoing projects, such as schedule information, road characteristics, soil type, etc… Then, the Equipment per Segment Selection module allocates the best equipment type to each earthmoving segment based upon economic haul distances for each equipment type (e.g., at station 2 + 120 m and beyond: Use dozers).On the other hand, the Equipment Pool module indicates the number and type of available equipment. Finally, the Optimization Engine selects the weekly optimum equipment number to be used from each equipment model type to reach the minimum earthmoving operation cost.

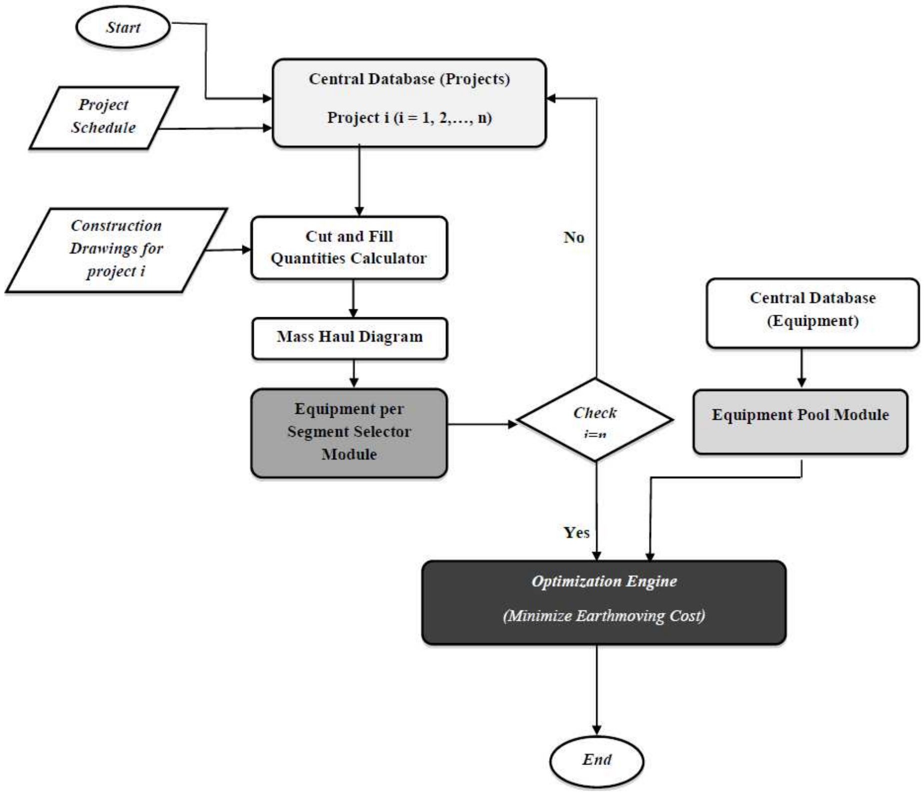


Figure 1 –Process Chart for multi-project earthmoving equipment Management System

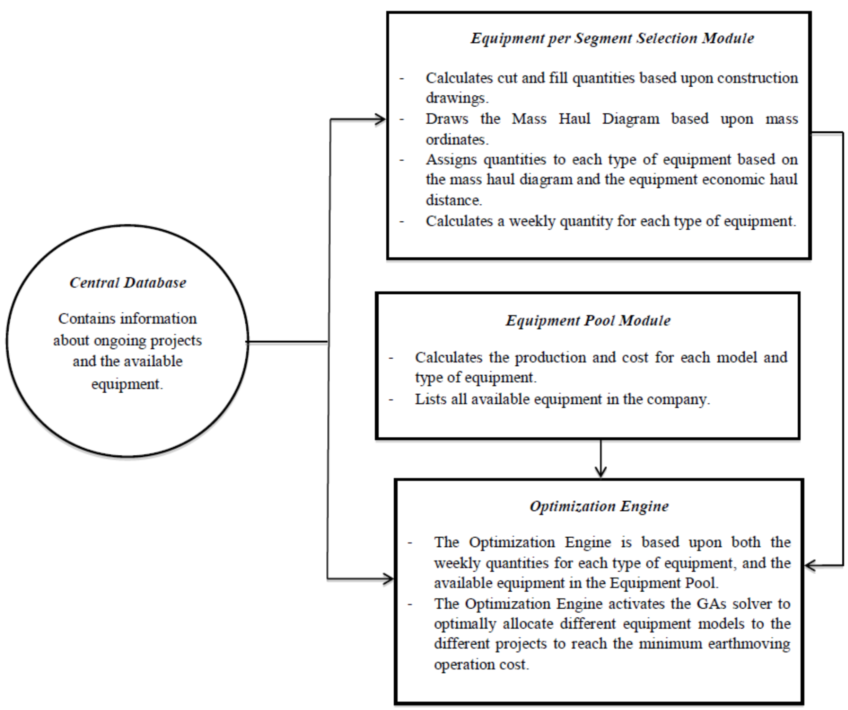


Figure 2 –Framework for the Earthmoving Equipment Selection (EEMS) model

Central Database

Projects Database

This database comprises a list of ongoing projects by the earthmoving company, along with their planned time schedules. Moreover, the Projects Database includes the data regarding soil and road characteristics for earthmoving operations and uses this information as an input for equipment selection in the following stage of the model process.

Equipment Database

The Equipment Database contains different types and models of earthmoving equipment, together with their available numbers. The module also obtains the production and cost figures associated with every piece of equipment, and display this information in an Equipment Database, as shown in the extract provided in Table 1.

ID	Equipment Model	Equipment Type	Operating System	Available Number	Production (m^3/hr)	Cost ($/hr)
1	CAT 953D	Loader	Tracked	10	144	42.22
2	Volvo A25E	Truck	Wheeled	75	26	64.68
3	CAT D11N-11U	Dozer	Crawler	6	500	122.63
4	CAT613B	Scraper	Push-loading	20	22	47.32

Table 1 –Extract from the Equipment Database displaying some of the available equipment models

Equipment per Segment Selection Module

Cut and Fill Quantities

Construction drawings constitute the primary source of information reflecting the size of earthmoving operations associated with the roads under study. Using the computer-aided version of the construction drawings, the entire length of roads was divided into equal segments in increment of 10m. The cut and fill quantities act as a preliminary data to develop the mass haul diagram for the road profile.

Mass Haul Diagram

Incorporating the segment database with the natural ground level corresponding to every station and with the desired design road foundation level, the mass haul diagram was developed to show the cut and fill quantities for the entire road profile. Figure 4 shows a sample of the developed mass haul diagram where the x-axis represents the segments increment (10 m) and the y-axis represents the mass ordinate (m^3). In addition, the mass haul diagram acts as a tool that helps in the selection process of the optimum equipment type to be used for each segment based on the economic haul distance for each equipment type.

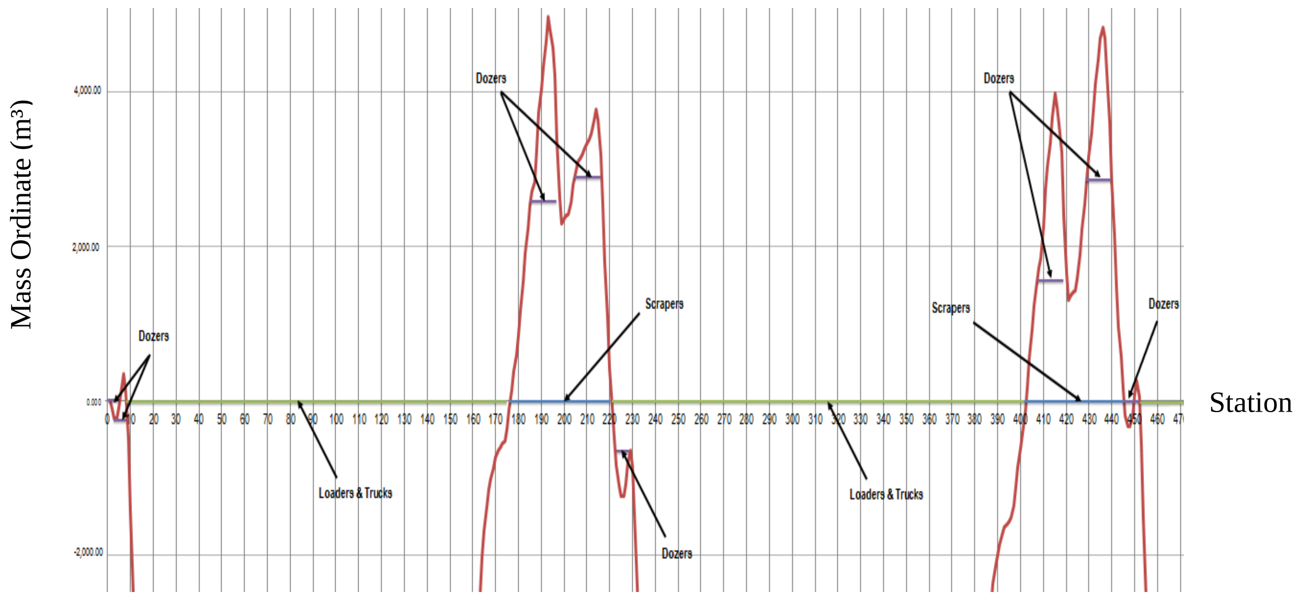


Figure 3– Sample for a Project Mass Haul diagram

Peurifoy and Schexnayder (2002) indicated that the economic haul distances for dozers, scrapers, and trucks are 100 m, 100-1600 m, and greater than 1600 m respectively. Moreover, the average grade percent of hauls is calculated multiplying the change in elevation by 100, and dividing this product by the average haul distance.

Equipment Pool Module

Peurifoy and Oberlender (2001) exerted an extensive amount of research to explain the concepts of equipment cost estimation. The equipment cost was divided into ownership and operating cost. The end target is to reach a cost per hour figure comprising the aggregate ownership and operating cost for every piece of equipment. Moreover, detailed production calculations were done for each equipment model type, taking into consideration the soil characteristics and all the factors affecting the earthmoving operation efficiency, in order to reach the hourly production rate for each equipment model type. The calculation methods for production rates of loaders, trucks, dozers, and scrapers were based on the information provided in Peurifoy and Schexnayder (2002).

Optimization Engine

The Optimization Engine features the MS Excel® Evolver™ V.5.5 add-in, and uses the GA optimization option. GA's were based on the theories of genetics and natural selection. They search through a solution space for optimum solution to a problem. To approach a specific problem using GAs, first the solution should be represented using a chromosome or a string-shaped structure. Each parameter in the solution would have a certain location in the chromosome. A chromosome by itself is a complete representation of a possible solution to the problem. Each chromosome represents a search point in the search space. A predefined number of chromosomes represent a population. In a typical GA, the first population of chromosomes is randomly initialized. The flowchart for a typical GA optimization process can be found in Shahin and Salem (2004). A series of randomized processes of parent selection, crossover, and mutation are systematically applied to the consecutive populations. The evolution process continues until a time limit is reached, a certain number of populations have evolved, or some error level is achieved. GA's have been used to find optimum solutions for a wide spectrum of complex combinatorial problems in civil engineering where the possibility of a huge number of combinations or alternatives makes it infeasible to examine each one of them to find an optimum solution.

The objective function is to minimize the cost of the earthmoving operations for the company, while satisfying all the projects' resources and time constraints. The optimization engine variables consist of the number of equipment used from each model in each project. The constraints are (1) project time constraint; (2) equipment availability constraint; and (3) the waiting-time rule (Truck/Loader production rate) constraint. The objective function is interpreted by Equation (1) below:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} ((X_1Y_1) + (X_2Y_2) + (X_3Y_3) + \ldots + (X_kT_k) + P) \qquad \text{Equation (1)}$$

Where: **i** denotes the working week sequential order; **n** denotes the total number of weeks; **j** denotes the working project; **m** denotes the total number of projects; **X** denotes the number of working hours corresponding to each equipment model; **Y** denotes the hourly cost for each equipment model; **k** denotes the total number of equipment models (Loaders, trucks, dozers, and scrapers); and **P** denotes the penalty introduced in case of not meeting the waiting time rule.

CASE STUDY

To illustrate the ability of the proposed system in selecting optimum crew configuration in earthmoving operations, a case study was analyzed. The case study considers an earthmoving company performing five concurrent earth-moving projects for roads in various communities in Egypt with quantities 592,598 m^3, 394,380 m^3, 295,271.52 m^3, 493,489 m^3, and 344,826 m^3 respectively. Figure 4 displays the planned start and finish dates for the five projects. Moreover, Figure 3presents a Mass Haul Diagram for one of the projects, where it chooses the type of equipment to be used in each segment. The company has a certain number of available equipment model types defined in the equipment pool, comprising loaders, trucks, scrapers, and dozers. Table1shows an extract of the equipment pool. Therefore, due to the dynamic nature of the problem, where different projects are working at different time and with different quantities, the EEMS optimization model was developed to reach an optimum allocation of available equipment over the five concurrent projects, spanning a period of 12 weeks.

The model objective was to minimize the earthmoving operational cost. This translates into reaching the optimum allocation of equipment to achieve the weekly calculated optimum quantities. The EEMS model constraints were as follows: (1) The equipment availability constraint where the used number should not exceed the available number of earth-moving equipment (by type); (2) The time constraint where the equipment working hours shouldn’t exceed the weekly working hours; (3) the equipment waiting time constraint, where the number of trucks matches the number of loaders to avoid unrealistic equipment utilization. Figure 5 displays a progress screenshot for the Evolver^{TM} optimization engine while running, whereas Figure 6 shows the optimization output sheet. Finally, the model provides the company with a weekly plan for equipment allocation for all projects, in order to minimize the cost and optimally use the equipment. The total cost for completing these projects after running the model showed to be $ 2,374,243, which was significantly less than the initial cost calculated using the existing micro-level management planning approach adopted by the company.

Figure 4 – Time schedule for five different concurrent earthmoving projects

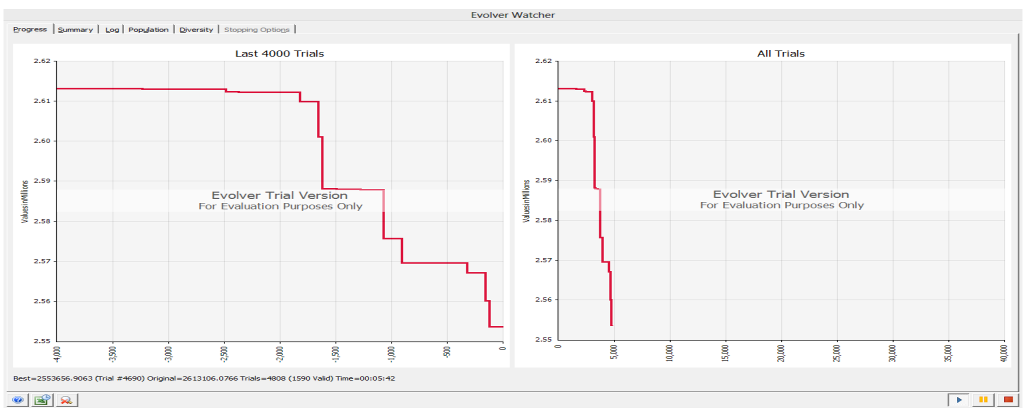
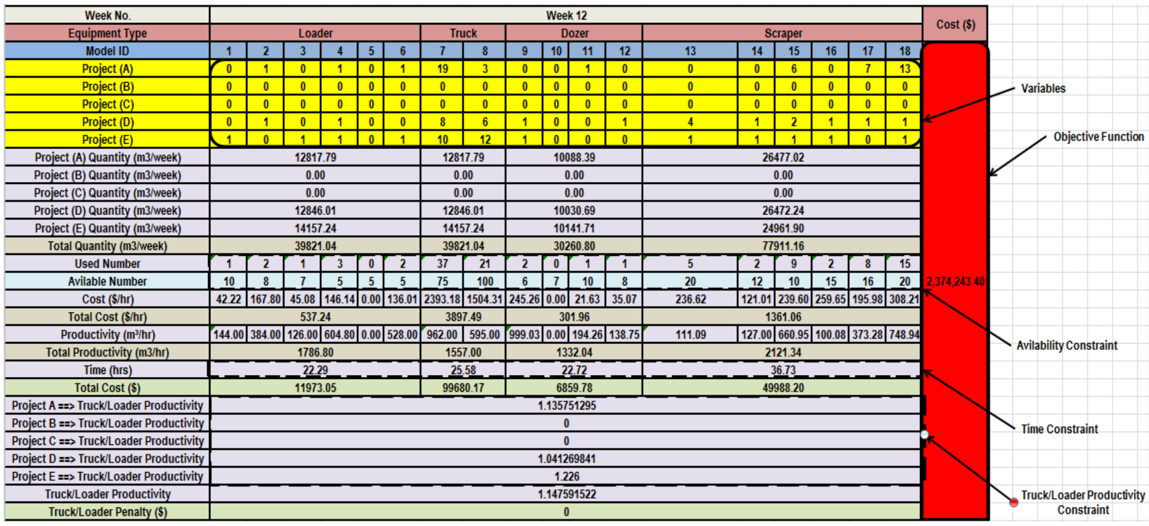


Figure 5 – The Evolver Progress in minimizing the Objective function (Earthmoving Cost)



Week No.	Week 12																		Cost ($)
Equipment Type	Loader						Truck		Dozer				Scraper						
Model ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Project (A)	0	1	0	1	0	1	19	3	0	0	1	0	0	0	6	0	7	13	
Project (B)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Project (C)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Project (D)	0	1	0	1	0	0	8	6	1	0	0	1	4	1	2	1	1	1	
Project (E)	1	0	1	1	0	1	10	12	1	0	0	0	1	1	1	1	0	1	
Project (A) Quantity (m3/week)	12817.79						12817.79		10088.39				26477.02						
Project (B) Quantity (m3/week)	0.00						0.00		0.00				0.00						
Project (C) Quantity (m3/week)	0.00						0.00		0.00				0.00						
Project (D) Quantity (m3/week)	12846.01						12846.01		10030.69				26472.24						
Project (E) Quantity (m3/week)	14157.24						14157.24		10141.71				24961.90						
Total Quantity (m3/week)	39821.04						39821.04		30260.80				77911.16						
Used Number	1	2	1	3	0	2	37	21	2	0	1	1	5	2	9	2	8	15	
Avilable Number	10	8	7	5	5	5	75	100	6	7	10	8	20	12	10	15	16	20	2,374,243.40
Cost ($/hr)	42.22	167.80	45.08	146.14	0.00	136.01	2393.18	1504.31	245.26	0.00	21.63	35.07	236.62	121.01	239.60	259.65	195.98	308.21	
Total Cost ($/hr)	537.24						3897.49		301.96				1361.06						
Productivity (m³/hr)	144.00	384.00	126.00	604.80	0.00	528.00	962.00	595.00	999.03	0.00	194.26	138.75	111.09	127.00	660.95	100.08	373.28	748.94	
Total Productivity (m3/hr)	1786.80						1557.00		1332.04				2121.34						
Time (hrs)	22.29						25.58		22.72				36.73						
Total Cost ($)	11973.05						99680.17		6859.78				49988.20						
Project A ==> Truck/Loader Productivity	1.135751295																		
Project B ==> Truck/Loader Productivity	0																		
Project C ==> Truck/Loader Productivity	0																		
Project D ==> Truck/Loader Productivity	1.041269841																		
Project E ==> Truck/Loader Productivity	1.226																		
Truck/Loader Productivity	1.147591522																		
Truck/Loader Penalty ($)	0																		

Figure 6–Optimization sheet showing the Objective function, Variables, and Constraints

RESULTS AND ANALYSIS

The results of the model showed a great difference between macro and micro-levels of earthmoving operation management, as shown in Figure 7. Micro-level management aims at managing a single project to reach the optimum equipment utilization, reflected by achieving the minimum earthmoving operational cost. On the other hand, macro-level management aims at managing earthmoving operations for a certain company possessing a number of various projects. Projects are required to be completed within the time schedule in order to avoid delay penalties. Furthermore, equipment should be optimally and realistically allocated onto the projects. Figure7 shows a model sample week difference between a micro and macro-level of earthmoving operation management where the micro-level option focuses entirely on a single project, and attempts to minimize its operational cost. However, the macro-level approach tackles all of the company's ongoing projects, while aiming to minimize the total company's operational cost. The macro-level earthmoving approach resulted lower cost, where it achieved better equipment utilization fulfilling the model constraints, compared to the micro-level earthmoving approach. The macro-level approach achieved 13% savings as opposed to the existing micro-management approach followed by the company.

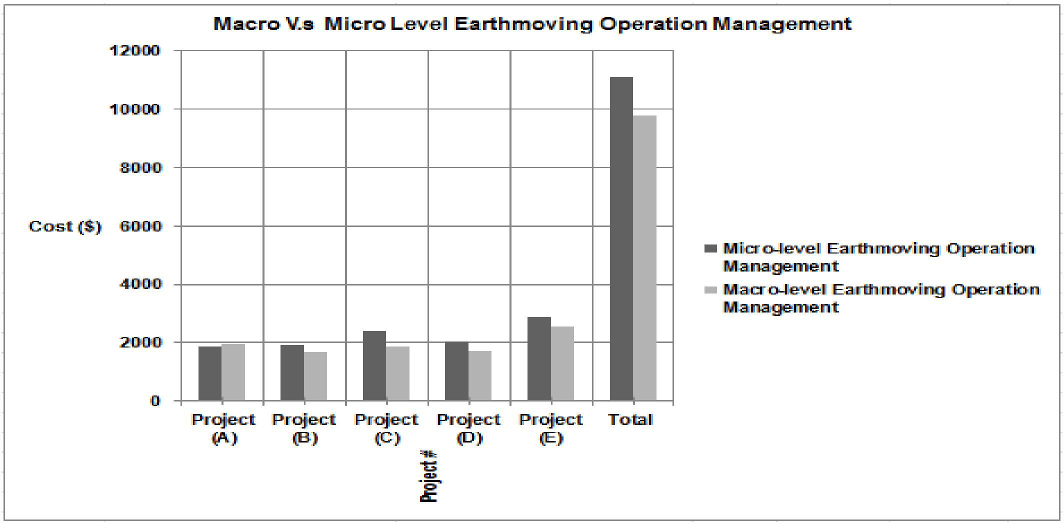


Figure 7 – Comparison of earthmoving equipment cost (micro-level vs. optimized macro-level)

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