Suitably selection for earthwork equipment In Egyptian sites

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Abstract: Heavy construction equipment is routinely used in construction projects that entail earthmoving operations. The right selection of equipment for construction project is inherently a multifaceted cost and benefits evaluation process that is further compounded by the complexity building projects of todays and the systematic tools' lack for consideration of soft factors. Equipment selection by optimization of heavy earthwork operations is a critical keys of success any operation in construction project. The objective of this paper is to develop a simplified model to support construction managers and contractors for estimating time and cost of heavy earthwork operations. Economical operation analysis is conducted for equipment, taking into consideration owning and operating costs of earthwork operations. The model was developed by Java programming code and is capable to integrate with other modules by using features of estimation and optimization. The model implementation shall give optimum equipment selection, not only based on versatility, but also cost effectiveness. To evaluate the model, an actual construction project case study is selected to quantify its degree of accuracy.

Keywords: Construction Management, Construction Equipment, Operation Analysis, Optimization Model, Equipment Economics, Equipment Selection and Decision Making.

1. Introduction

Complexity of today's building projects makes it harder to evaluate alternatives of equipment and take the right selection from many alternatives, Peurifoy et al. (2006) [1]. With the growing awareness of the role played by mechanization and industrialization in project execution, the decreasing availability of skilled manpower, and tight budget and schedule constraints in a competitive construction environment, companies and project management teams often lack the tools to select the best combination of grouped equipment suitable to meet project requirements. Equipment selection is a critical factor in the execution of many construction projects. This is to be much more critical in heavy construction projects where the earthmoving equipment plays a vital role in performing the work. In this type of projects, heavy equipment may represent the largest portion of bidding price, Nunnally (1977) [2]. Consequently, successful contractors and construction managers understand the substantial impacts on their projects when equipment management decisions are not made in a proper and timely manner. Since equipment selection is highly influenced by myriad factors, most contractors tend to rely upon their historical data and experience in similar projects to assist them in determining the optimum fleet. While this is a good approach at the conceptual stages of the project, it is not sufficient to build the earthmoving equipment benchmark due to the dynamic nature of construction projects. Other approaches, such as expert systems, could be useful if only integrated with a database of historical data. To overcome this shortcoming, the proposed model is being developed based on integrating manufacture's data for selected pieces of equipment with a comprehensive economical operation analysis for different scopes of earthwork operations. At this stage, the model is developed to include an optimization of earthmoving equipment based on simple economical operation analysis.

2. Review of Literature

Equipment selection optimization at heavy construction work based on multi complex factors; however, studies did not include economic analysis. Moselhi and Marzouk (2000) [3] addressed cost estimation for heavy earthmoving operations; an equipment cost application system was developed for time and cost estimation of heavy earthmoving operations. Developed model was verified by a numerical example with a detailed steps description of the procedure to can be followed. Marzouk and Moselhi (2003) [4] addressed cost applications without considering complex factors in heavy equipment operation analyses, an object-oriented simulation model was developed for earthmoving operations. The proposed model included simulation program, a database for cost applications, optimization and reporting modules. The study was verified with a numerical example by comparing the results of developed model with corresponding outputs of the Caterpillar's production. It was concluded that results were in a good control with percentage difference less than 8%. To optimize equipment selection for different types of activities, different models and methods were proposed. These models were proposed to specific types of construction work due to many factors which are related to equipment selection. Furthermore, researchers had focused on developing an expert system in an attempt to assist construction managers in earthmoving equipment selection. However, their studies did not incorporate the operation analysis of equipment and its associated costs. Alkass and Harris (1988) [5] developed an expert system model for the selection of earthmoving equipment in road construction operations. The expert system was developed in four main stages as follows: (1) To identify tasks and job conditions; (2) To commence the identification of tasks and job conditions of equipment selection based on broad categories; (3) To match earthmoving equipment to proper category; (4) To make the selection of earthmoving equipment, taking into consideration the factors from earlier stages. The study was concluded by stating the developed expert system to minimize and eliminate the deficiency of basic processes and replace it with modern consultation and advice. Amirkhanian and Baker (1992) [6] developed an expert system model for equipment selection in earthmoving operations. A rule-based expert system was used for selecting earthmoving equipment. The system was developed to interpret data pertaining to soil conditions, operator performance, and volume required for the earthmoving operations. Haidar et al. (1999) [7] developed a model for optimizing the excavating and hauling operations and the utilization of equipment in opencast mining. The model was based on a decision-support system for selecting opencast mines equipment. Decision-support system, a hybrid knowledgebase system and genetic algorithms were used to design the system. Shapira and Goldenberg (2005) [8] developed a model based on an analytical hierarchy process (AHP) which was intended to provide solutions for two main issues: (1) systemic evaluation of soft factors compared to costs; and (2) providing users with results to compare with different alternatives based on several criterions. At the end, output results must select the equipment based on highest score. The study which was conducted by Marzouk and Moselhi (2004) [9] developed a fuzzy clustering model for estimating haulers' travel time capable of being integrated with diverse simulation and estimation models. The proposed model exploits regression analysis and subtractive clustering. Feifei et al. (2010) [10] presented a flexible and common Petri net model for equipment allocation optimization for a given construction duration, cost and labor. A case study was conducted on a real construction project involving earthmoving operations. Lucko (2011) [11] applied a statistical model to forecast the residual value of used heavy construction equipment in the United States. The objective was to evaluate the performance of model in radically changed economy in the second half decade. This model was a comprehensive multiple linear regression analysis for various categories of common types and sizes of equipment. Anjaneyappa et al. (2014) [12] mentioned that various types of light compacting equipment like rammers, vibratory plate compactors, single-drum walk-behind rollers, and double-drum walk-behind rollers are being used for compaction of the materials in constrained areas. Locally available loamy soil was compacted to different layer thicknesses of 50, 100, 150, and 200 mm using selected plate compactors, single-drum walk-behind rollers, and double-drum walk-behind rollers. Field moisture–density relationships for this equipment are established in their studies. Marks et al. (2013) [13] demonstrated how the design of construction equipment impacts the visibility of its operator. The contribution of the developed technique to the body of knowledge is that it can precisely evaluate and compare different equipment models and design characteristics. The blind spot measurement data for several similar pieces of equipment provides design suggestions that increase operator visibility. By increasing operator visibility through advanced equipment design, safety can be promoted on construction sites and in any other work environment, particularly with nearby ground workforce equipment. Xu et al. (2013) [14] presented a resource sharing-based construction equipment allocation problem with multiple stages under a fuzzy environment. A multiobjective multistage decision-making model is established in which the equipment failure rate is regarded as a fuzzy variable. In contrast to traditional assignment problems, the principle of resource sharing modes including space and time sharing is considered to be based on the project practice. In addition, a dynamic programming-based genetic algorithm is developed to find feasible solutions and a dynamic programming-based initialization, and crossover and mutation are designed to avoid infeasible solutions. Finally, practical example is used to demonstrate the practicality and efficiency of the model. The comparisons and analysis of results are presented to highlight the performance of the optimization method, which is proved to be more effective and efficient than the standard genetic algorithm. Kim et al. (2012) [15] presented a comparative analysis of the generation of GHGs by various equipment types used in different construction activities. Twenty-four cases involving a typical road construction project in Korea were selected for comparison. Mitchell et al. (2011) [16] Professionals in the construction industry must be able to accurately forecast costs. Forecasting of equipment repair costs is one element of the larger problem of predicting overall costs. The cumulative cost model can provide construction engineers with a valuable tool for better understanding the nature of repair costs as they relate to production fleets. Data that are being collected (or that could be collected) can assist in the determination of the rate of accumulation of repair costs for a machine for a given period of use or the estimation of fleet repair budgets for a job or period. There are two different methodologies for constructing the repair cost portion of the cumulative cost model: life-to-date (LTD) repair costs and the period-cost-based (PCB) model. Kannan (2011) [17] related some of the recent academic research to industry practices. In doing so, it validates some parts of the research and makes new observations in three areas: repair costs, residual values, and total cost of ownership (TCO) and productivity. It also provides a few pointers for future research. ElMisalami (2010) [18] presented new methodology to quantify the value of Sell/Hold decision of construction equipment at any period of its useful time. Ng et al. (2009) [19] explored the critical success factors (CSFs) for equipment-intensive subcontractors Seventeen CSFs for them have been identified, and the results indicate that majority of them are internal factors. A one-way ANOVA test has been carried out, which confirms the consistency in perceptions of different construction stakeholders surveyed. Through a factor analysis the CSFs are grouped into six major components namely: (a) market position; (b) equipment-related factors; (c) human resources; (d) earnings; (e) managerial ability to adapt to changes; and (f) project success related factors. The findings of this research should not only help subcontractors to improve their performance but also to assist main contractor to identify a successful equipment-intensive subcontracting firm. Hammad et al. (2007) [20] aimed to extend previous equipment researches of large infrastructure projects. Tatum et al. (2006) [21] used five systems that make up earthmoving equipment implement, traction, structure, power train, and control and information to analyze this technical advancement. The analysis of each system includes its purpose and operation, technical limitations and key technologies, and a chronology of major advancements. The findings are the benefits of using the five systems for analysis of technical change, the sequence and timing of key technical advances in each system, the fundamental technologies that fostered these advances, and the integration of systems into balanced equipment designs. This increased understanding from this analysis results in significant implications and relevance for civil designers working on integrated teams, contractors selecting methods and planning operations, equipment suppliers developing new machines, construction educators teaching the technical basics of equipment, and researchers developing advanced modeling and simulation tools.

3. Paper Objectives

As a response to the earthmoving equipment, various methods and models had been discussed previously in literature. However, the majority of studies did not consider economical operation analysis. Instead, the studies focused on developing systems, algorithms, or a framework to assist the user for selection of earthmoving equipment in heavy earthwork operations. Moreover, most of these studies included time and cost estimation at the conceptual stage of the project; however, this study includes economical operation analysis at the conceptual stage and following the commencement of the project. Furthermore, the proposed model is being developed to incorporate owning and operating costs of selected earthmoving equipment configuration (i.e. hourly fuel consumption, lubricant charges, repair reserves, tire replacement, etc…).

4. Equipment Economics

In heavy construction projects, equipment is the major resource that project managers depend upon to perform the required work. Equipment may be owned or rented for a period of time. According to Schaufelberger (1999) [22], earthmoving equipment may represent the largest investment on the long term for construction companies. Economic analysis of equipment must be obtained in order to properly determine the optimum equipment. This step is considered critical in order to support decision-makers and to evaluate rental option. The construction equipment economic analysis is mainly focused on determining owning and operating costs as well as the economic life for each type of equipment, Nunnally (1977) [2]. In order to complete the equipment economic analysis, all costs associated with selected equipment must be considered. In this study, Caterpillar's (2013) [23] method is being used to obtain data pertaining to ownership and operating costs.

5. Factors Affecting Equipment Selection

Main consideration in any endeavor is to get the job done according to timeframe and cost limitations. In order to achieve this goal, proper calculation of productivity rates for equipment, while considering variable factors, is required. According to Gransberg et al. (2006) [24], first factor to consider would be matching the right equipment to the proper type of activity. Second factor would be the availability of the right equipment with proper service, maintenance, and repair reserves. Gransberg et al. (2006) [24] proposed two another factors that can be considered when selecting proper equipment: (1) Type and condition of work site; which includes the distance to be traveled; and (2) Desired productivity; which is a critical factor that affects equipment selection. Furthermore, Schaufelberger (1999) [22] stated two general factors that should be considered in the process of equipment selection: (1) Cost effectiveness; which involves the consideration of equipment size besides its proper type; and (2) Versatility; which involves selecting equipment that can perform multiple tasks at work site.

6. Equipment Selection

Equipment selection is the critical factor in construction projects. Rational selection of suitable equipment leads to profits for contractors. At the same time, miscalculating the proper size and number of required equipment for the project may result in suffering from overhead costs or losing the contract Tavakoli and Taye (1989) [25]. Therefore, contractors consider selection of earthmoving equipment a vital factor for any construction project to be successful, Marzouk and Moselhi (2004) [9].

7. Methodology

Economic analysis for selecting equipment type is considered essential for developing the optimization model. In this paper, the developed model allows users to attain optimized equipment for various types of earthwork. The analysis operation is performed in eight major activities of earthwork. The economic analysis is carried out while taking into consideration variable factors affecting the equipment productivity. The summarized conceptual model of research is shown in Fig. 1.

7.1. Data Collection

As mentioned previously, Caterpillar (2013) [23] obtained equipment specifications and data needed to carry out the economic operation analysis. Also, data related to operation analysis is inserted and extracted, into Microsoft Excel modules. These specifications' data is as follows: (1) Equipment horse power; (2) Rated capacity; (3) Maximum weight; (4) Load distribution; and (5) Performance charts. Some of these data had been tabulated in order to enhance the model's capability of interfacing data with information entered by the users. Furthermore, it is important to note that database information incorporated into excel modules possess a variety in equipment's' capacity, power, and maximum allowable weight which enables the developed model to be applied for any construction project regardless of the volume of materials involved.

7.2. Fundamentals of Earthmoving

The most important step in analyzing construction economic operations is to understand the characteristics of materials to be moved. Soil types and properties affect the type of equipment required to successfully complete a construction project. For this study, data pertaining to material properties is obtained from the Caterpillar (2013) [23].

7.3. Forces Affecting Motion of Equipment

Self-propelled equipment gets the power needed from the engine. However, there are certain parameters that need to be considered when conducting the operational analysis. These parameters are: (1) Total resistance force; (2) Traction; (3) Power; and (4) Effects of altitude, Day and Benjamin (1991) [26]. Prior to optimization, all of these factors were taken into consideration while conducting economic operation analysis of earthmoving equipment.

7.4. Estimating Productivity of Selected Equipment

Equipment productivity is a key factor that enables contractors to make a decision regarding project scheduling, equipment selection, and project costs. Most contractors depend on their historical data of previous projects to obtain the productivity of selected equipment Tavakoli (1985) [27]. In this study, the estimation of productivity rates is performed for each type of equipment individually. Fig. 2 illustrates the detailed methodology of estimating productivity.

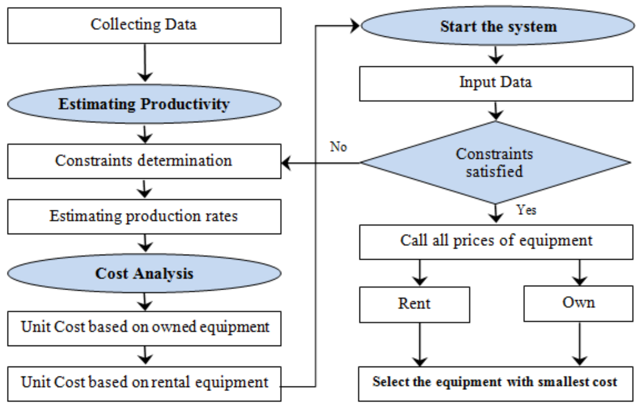

Figure 1. *Research Conceptual Model*

7.5. Cost Analysis

Construction projects cost analysis is a vital key for success. At this stage, simple cost analysis is conducted to illustrate the workability of developed model. Presently, a comprehensive owning and operating cost analysis is being implemented as a stand-alone module that is capable of being linked to any optimization module. In this paper, two main equations are used to obtain the equipment cost parameters. In order to obtain the time needed to complete a certain earthwork operation, refer to Equation (1):

$$\text{Duration (days)} = \text{Quantity (BCM)} \div \text{Daily productivity (BCM/day)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

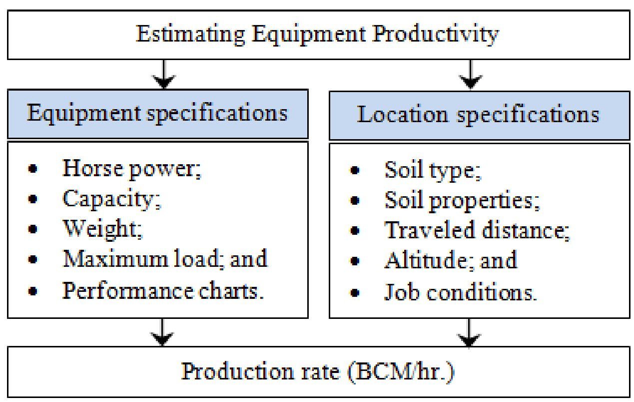

Figure 2. *Methodology of Estimating Productivity*

For equipment operating costs, Caterpillar (2013) [23] is used to obtain the operator's hourly wage. For renting costs, cost estimating handbook is used. In order to estimate the unit cost for the selected equipment, refer to Equation (2):

$$\text{Required equipment} = \text{Estimated completion time} \div \text{Required time} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

8. Optimization Process

Optimization is the process of maximizing or minimizing the objective function taking into consideration the prevailing constraints Belegundu and Chandrupatla (2002) [28]. To optimize equipment selection, one must understand all related constraints. Failure to do so may lead to erroneous results in the final output. In this study, all constraints obtained from the operation analysis are represented in a mathematical form. Then, the proposed model will select the optimum equipment that satisfies all constraints by using a linear programming approach. The constraints limit the degree to which objective function can be pursued Anderson et al. (2008) [29].

8.1. Determination of the Number of Required Equipment

Each piece of equipment can perform the task within its corresponding capability and maximum productivity. However, sometimes contractors are required to achieve certain production rate to complete the job within a specific period of time. This rate is usually higher than the rate achieved by one piece of equipment. To determine the required equipment, refer to Equation (3):

Unit cost (EGP/BCM) = Equipment hourly cost (EGP/hr.) ÷ Hourly productivity (BCM/hr.) ……………… (3)

8.2. Optimization Equations and Constraints

The main objective of the optimization model is to minimize the unit cost and select the equipment that has the smallest unit cost. Economic operation analysis selects the pieces of equipment that was carried out to determine the two main constraints that must be satisfied by each piece of equipment. The first constraint was defined as the loaded weight. The loaded weight must not exceed the maximum allowable weight set by the manufacture. To identify this constraint, refer to Equation (4):

$$LW \leq RW \quad \text{………………} \quad (4)$$

Where,

LW is the loaded weight; and RW is the rated weight.

The second constraint is defined as the total resistance. The total resistance must not exceed the allowable rim-pull. To identify this constraint, refer to Equation (5):

$$TR \leq AR \quad \text{………………} \quad (5)$$

Where,

TR is the total resistance and AR is the allowable rim-pull.

If any of the abovementioned constraints was not satisfied, the model will automatically eliminate the equipment from the optimization process. All the aforementioned calculations were organized in different forms based on equipment's type to ease the development of the model using Java Application. Figure 3 was established in order to identify and organize the model's components and to achieve a better understanding of the relationship that exists between the different components. This step much assisted in visualizing the entire optimization process.

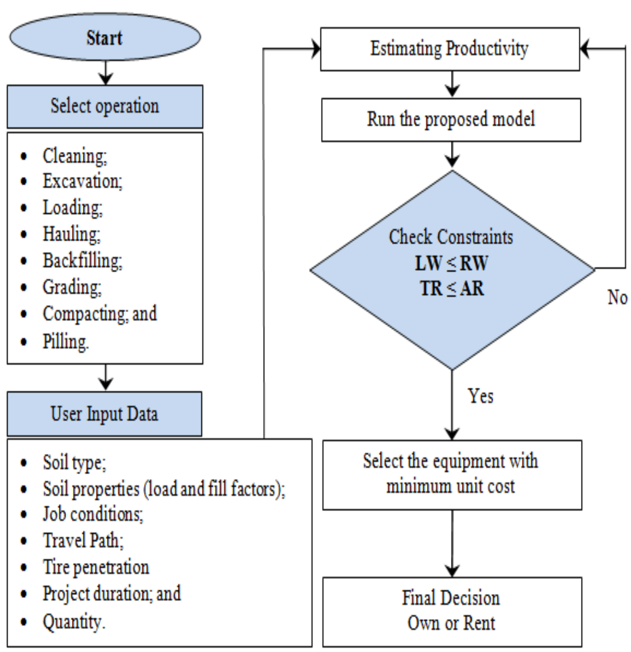

Figure 3. *Optimization Flowchart*

9. Model Development

The model is developed by using Java programming code. The main goal is to facilitate the interface between operation analyses, user input data, and optimization functions. The modules were already organized by activity names. For each activity, two more modules were created. The first module is the optimization form where optimization results will be displayed and the second module is the optimization report which contains printable tables that summarize results in the optimization form. Fig. 4 presents welcome form. Fig. 5 illustrates the main switchboard of the proposed model. Once the user select the desired activity, the corresponding form will be displayed. Then, the user will be required to enter the necessary data. Fig. 6 presents excavating activity module prior entering the data. Most importantly, if the constraints set by the model are not satisfied, an error message will appear to inform the user that some equipment will not be considered in the optimization process. Once the user finish reviewing operation analysis calculations, the optimization button will need to be clicked on for optimum equipment selection. Fig. 7 illustrates the excavating report which summarizes optimization results.

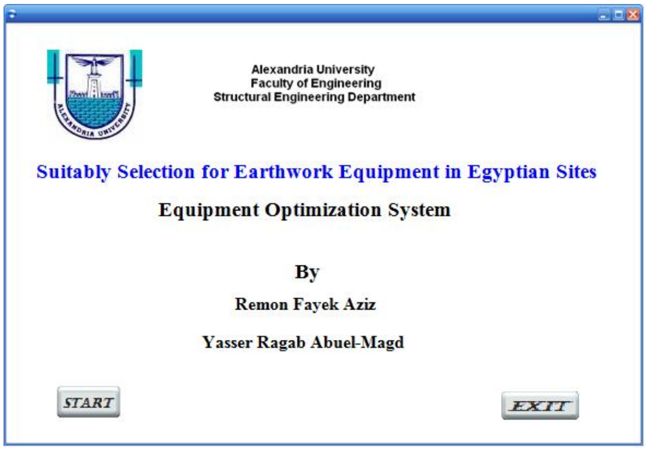

Figure 4. *Welcome Form.*

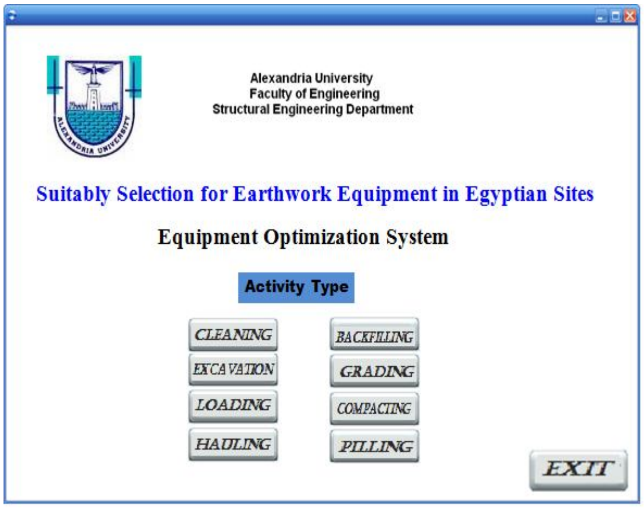

Figure 5. *Switchboard Form.*

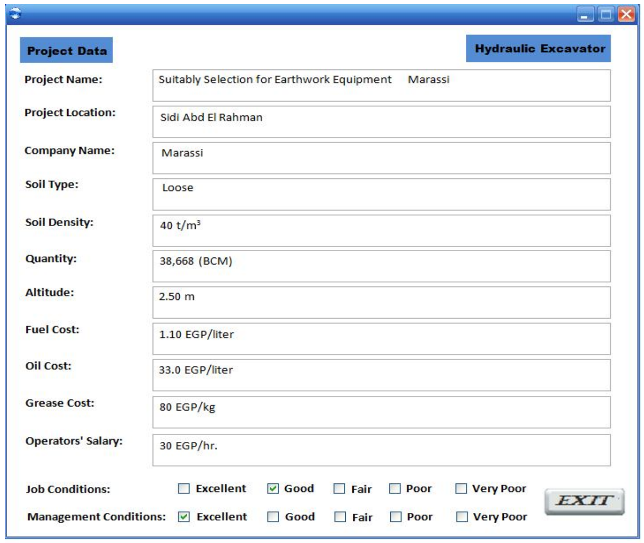

Figure 6. *Data Entry Form.*

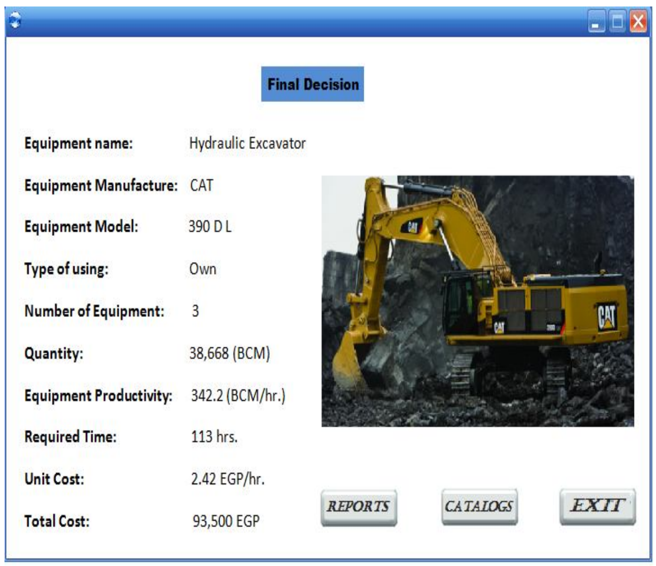

Figure 7. *Results Form.*

10. Model Validation

To validate the model, an actual construction project is selected. This project is considered to illustrate the use of developed framework in selecting near-optimum minimum duration with minimum cost from a set of excavator's models. It also demonstrates the ability of the framework in conducting time–cost tradeoff analysis. The project, being considered in this paper, involves excavating 239,970 m3 bank volume of common and loose soils from a real case study of large-scale project which is called "Marassi Resort" in Sidi Abd El Rahman that consists of more clusters zones. Selected cluster with area 521,185 meter square. Table 1 summarizes the scope of earthwork in terms of soil type and material volume. The challenge was to select the optimum excavator equipment necessary to execute the construction. The developed model was capable of selecting the optimum equipment model.

Table 1. *Scope of Excavation Earthwork in (BCM).*

Soil Type	Stage 1	Stage 2	Stage 3	Total
Common	42,424	28,938	34,813	**106,175**
Loose	38,668	50,795	44,332	**133,795**
Total	**81,092**	**79,733**	**79,145**	**239,970**

11. Comparison of Results

For comparing the results, the optimizer needs to understand the differences between the two results in order to understand model limitations. The obtained results were compared with actual project data and were found in good agreement with a percentage difference ranging between 5% - 21%. It should be noted that the model eliminated the CAT-390 D L Hydraulic Excavator from the optimization process because the limitation of constraints, while actual action in studied project selected CAT-365 C L Hydraulic Excavator. Comparison of results is illustrated in Table 2.

Table 2. *Time-Cost Comparison.*

Scenario	Soil Type	Stage 1		Stage 2		Stage 3		Total	
		Time Hrs.	Cost EGP	Time Hrs.	Cost EGP	Time Hrs.	Cost EGP	Time Hrs.	Cost EGP
Model Data	Common	120	96,000	87	69,600	123	100,000	**330**	**265,600**
	Loose	113	93,500	131	104,900	124	99,200	**368**	**297,600**
	Total	**233**	**189,500**	**218**	**174,500**	**247**	**199,200**	**698**	**563,200**
Actual Data	Common	141	112,800	96	76,800	116	92,800	**353**	**282,400**
	Loose	110	88,800	145	116,000	127	101,600	**382**	**306,400**
	Total	**251**	**201,600**	**241**	**192,800**	**243**	**194,400**	**735**	**588,800**

12. Conclusion

Optimizing equipment selection in heavy earthwork operations is a critical key in the success of any construction project. The objective of this paper incentive was geared towards developing a computer model to assist contractors and construction managers in estimating the cost of heavy earthwork operations. Economical operation analysis was conducted for an equipment taking into consideration the owning and operating costs involved in earthwork operations. The model is developed by using Java programming code and is capable of integrating with other estimation and optimization modules. The implementation of the model shall give optimum selection of equipment, not only based on cost effectiveness, but also in terms of versatility. For more accurate results, data should always be obtained from the actual site and historical data. The overall results showed that the accuracy of the model varies depending on soil type, altitude, cycle time, and temperature. Also, the model results may be improved by implementing a comprehensive owning and operating costs module. The results of this study are anticipated to be of major significance to owners, general contractors, and construction managers. Furthermore, the proposed model will contribute with database of earthwork equipment management system by including a computer-coded model that is developed by Java programming code to integrate earthwork equipment operational analysis with its corresponding economical analysis.

References

[1] Peurifoy, L., Schexnayder, J., and Shapira, A. (2006). "Construction planning, equipment, and methods", 7th Ed., McGraw-Hill, Boston.

[2] Nunnally, S. (1977). "Managing construction equipment", Englewood Cliffs, NJ: Prentice-Hall.

[3] Moselhi, O. and Marzouk, M. (2000). "Automated system for cost estimating of earthmoving operations", Proceedings of the 17th International Symposium on Automation and Robotics in Construction (ISARC), Taipei, Taiwan, 1053-1058.

[4] Marzouk, M. and Moselhi, O. (2003). "Object-oriented simulation model for earthmoving operations" Journal of Construction Engineering and Management, 129 (2), 173-181.

[5] Alkass, S. and Harris, F. (1988). "Expert system for earthmoving equipment selection in road construction", Journal of Construction Engineering and Management, 114 (3), 426-440.

[6] Amirkhanian, S. and Baker, N. (1992). "Expert system for equipment selection for earthmoving operations", Journal of Construction Engineering and Management, 118 (2), 318-331.

[7] Haidar, A., Naoum, S., Howes, R. and Tah, J. (1999). "Genetic algorithms application and testing for equipment selection", Journal of Construction Engineering and Management, 125 (1), 32-38.

[8] Shapira, A. and Goldenberg, M. (2005). "AHP-based equipment selection model for construction projects", Journal of Construction Engineering and Management, 131 (12), 1263-1273.

[9] Marzouk, M. and Moselhi, O. (2004). "Multiobjective optimization of earthmoving operations" Journal of Construction Engineering and Management, 130 (1), 105-113.

[10] Feifei, C., Yaowu, W. and Xianzhang L. (2010). "Multi-Objective Dynamic Simulation-Optimization for Equipment Allocation of Earthmoving Operations", Construction Research Congress, 328-338.

[11] Lucko, G. (2011). "Modeling the Residual Market Value of Construction Equipment under Changed Economic Conditions" Journal of Construction Engineering and Management, 137 (10), 806-816.

[12] Anjaneyappa, V., Amarnath, M. and Srinivasamurthy B. (2014). "Compacting Characteristics of Light Compacting Equipment" Journal of Construction Engineering and Management, 140 (3), 1-8.

[13] Marks, E., Cheng, T., and Teizer, j. (2013). "Laser Scanning for Safe Equipment Design That Increases Operator Visibility by Measuring Blind Spots" Journal of Construction Engineering and Management, 139 (8), 1006-1014.

[14] Xu, J., Meng, J., Zeng, Z., Wu, S., and Shen, M. (2013). "Resource Sharing-Based Multiobjective Multistage Construction Equipment Allocation under Fuzzy Environment" Journal of Construction Engineering and Management, 139 (2), 161-173.

[15] Kim, B., Lee H., Park, H., and Hyoungkwan K. (2012). "Greenhouse Gas Emissions from Onsite Equipment Usage in Road Construction" Journal of Construction Engineering and Management, 138 (8), 982-990.

[16] Mitchell, Z., Hildreth, J., and Vorster, M. (2011). "Using the Cumulative Cost Model to Forecast Equipment Repair Costs: Two Different Methodologies" Journal of Construction Engineering and Management, 137 (10), 817-822.

[17] Kannan, G., (2011). "Field Studies in Construction Equipment Economics and Productivity" Journal of Construction Engineering and Management, 137 (10), 823-828.

[18] ElMisalami, T., (2010). “Construction Equipment Management using Capital Budgeting under A Multi-Period Uncertainty Model” Eighth Alexandria international conference on Structural and Geotechnical Engineering, "AICSGE7", Faculty of Engineering, Alexandria University, Alexandria, EGYPT. Pro. 8, No. MG, 17-26.

[19] Ng, S., Tang, Z., and Ekambaram, P. (2009). "Factors contributing to the success of equipment-intensive subcontractors in construction" International Journal of Project Management, (27), 736–744.

[20] Hammad, A., Zhang, C., Hussein, M., and Cardinal, G. (2007). "Equipment Workspace Analysis in Infrastructure Projects" Can. Journal of Civ. Eng., (34), 1247-1256.

[21] Tatum, C., Vorster, M., Klingler, M., and Paulson, B., (2006). "Systems Analysis of Technical Advancement in Earthmoving Equipment" Journal of Construction Engineering and Management, 137 (10), 976-986.

[22] Schaufelberger, J. (1999). "Construction equipment management", Upper Saddle River, NJ: Prentice-Hall.

[23] Caterpillar (2013). "Caterpillar performance handbook", Peoria: Caterpillar.

[24] Gransberg, D., Popescu, C. and Ryan, R. (2006). "Construction equipment management for engineers, estimators, and owners", Boca Raton, FL: Taylor & Francis Group.

[25] Tavakoli, A. and Taye, E. (1989). "Equipment policy of top 400 contractors: A survey", Journal of Construction Engineering and Management, 115 (2), 317-329.

[26] Day, D. and Benjamin, N. (1991). "Construction equipment guide", New York: John Wiley & Sons.

[27] Tavakoli, A. (1985). "Productivity analysis of construction operations", Journal of Construction Engineering and Management, 111 (1), 31-39.

[28] Belegundu, A. and Chandrupatla, T. (2002). "Optimization concepts and applications in engineering", Delhi: Pearson Education.

[29] Anderson, D., Sweeney, D., Williams, T. and Martin, K. (2008). "An introduction to management science quantitative approaches to decision making", Mason, OH: Thomson Higher Education.

Biography

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