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Metaheuristics, Data Mining and Geographic Information Systems for Earthworks Equipment Allocation

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Abstract
Optimal and sustainable allocation of equipment in earthwork tasks is a complex problem that requires the study of several different aspects, as well as the knowledge of a large number of factors. In truth, earthworks are comprised by a combination of repetitive, sequential, and interdependent activities based on heavy mechanical equipment (i.e., resources), such as excavators, dumper trucks, bulldozers and compactors. In order to optimally allocate the available resources, knowledge regarding their specifications (e.g., capacity, weight, horsepower) and the work conditions to which they will be subjected (e.g., material types, required and available volumes in embankment and excavation fronts, respectively) is essential. This knowledge can be translated into the productivity (i.e., work rate) of each piece of equipment when working under a specific set of conditions. Moreover, since earthwork tasks are inherently sequential and interdependent, the interaction between the allocated equipment must be taken into account. A typical example of this is the need for matching the work rate of an excavator team with the capacity of a truck team to haul the excavated material to the embankment fronts.
Given the non-trivial characteristics of the earthwork allocation problem, conventional Operation Research (e.g., linear programming) and blind search methods are infeasible. As such, a potential solution is to adopt metaheuristics – modern optimization methods capable of searching large search space regions under a reasonable use of computational resources. While this may address the issue of optimizing such a complex problem, the lack of knowledge regarding optimization parameters under different work conditions, such as equipment productivity, calls for a different approach. Bearing in mind the availability of large databases, including in the earthworks area, that have been gathered in recent years by construction companies, technologies like data mining (DM) come forward as ideal tools for solving this problem. Indeed, the learning capabilities of DM algorithms can be applied to databases embodying the productivity of several equipment types when subjected to different work

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conditions. The extracted knowledge can then be used to estimate the productivity of the available equipment under similar work conditions. Furthermore, as previously referred, since earthwork tasks include the material hauling from excavation to embankment fronts, it also becomes imperative to analyze and optimize the possible transportation networks. In this context, the use of geographic information systems (GIS) provides an easy method to study the possible trajectories for transportation equipment in a construction site, ultimately allowing for a choice of the best paths to improve the workflow.
This paper explores the advantages of integrating the referred technologies, among others, in order to allow for a sustainable management of earthworks. This is translated in the form of an evolutionary multi-criteria optimization system, capable of searching for the best allocation of the available equipment that minimizes a set of goals (e.g., cost, duration, environmental impact). Results stemming from the validation of the resulting system using real-world data from a Portuguese construction site demonstrate the potential and importance of using this kind of technologies for a sustainable management and optimization of earthworks.

Keywords: earthworks, optimization, sustainability, metaheuristics, data mining, geographic information systems

1 Introduction

Following the current research and innovation trends, including the EU 2020 Horizon goals, sustainable construction has been the subject of increased attention in recent years. Aspects like identifying and using environmentally and socially responsible materials, minimizing carbon and particle emissions, optimizing water use, reuse and recycling, and optimizing waste generation, reuse and recycling are now being given focus during design and execution of construction projects. At the same time, the pressure for lower cost and duration in these projects is also increasing, calling for a maximization of productivity and optimization of available resources.

It can be easily inferred that, in projects involving high amount of earthworks, carbon emissions are of critical relevance. In fact, given the reliance on heavy mechanical machinery for the completion of earthwork tasks, recent large-dimension construction projects (i.e., London Olympics Stadium) have undertaken strict mitigation measures in order to minimize these emissions. Reducing the number of vehicle movements through better planning, guaranteeing that no vehicles or plant are left idle unnecessarily or setting an appropriate speed limit on haul routes are some examples of mitigation measures. While they are designed to limit emissions, these restrictions also help developers reduce fuel costs, which take up a significant percentage of earthworks costs. This hints at two practical approaches for achieving a higher level of sustainability in earthworks constructions: either indirectly, as a consequence of optimizing the usage of available mechanical resources (i.e. maximizing productivity; minimizing fuel costs); or directly, as an actual quantifiable variable which must be minimized.

In this work, the focus is given to the first approach. The adopted solution translates into an earthworks optimization system, which, leveraging on several different technologies, aims to improve the sustainability of resource allocation solutions, as an indirect consequence of minimizing both execution costs and duration. This is achieved by improving material management, optimizing the resource usage potential (i.e. mechanical equipment is used to their maximum capacity, while preventing any idle activity), and minimizing material transportation trajectories. In order to accomplish this, it is necessary to breakdown earthworks into a series of interdependent activities, in the form of production lines, based on different types of resources. The activities comprise the tasks associated with earthworks, ranging from excavation and transport to spreading and compaction, while the available resources correspond to the associated mechanical equipment necessary for each task (e.g., excavators, dumper trucks, bulldozers, rollers). Moreover, earthworks feature a series of specific characteristics, which define them as an optimization problem centered on sequential, interdependent