Intelligent Earthworks Optimization System

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1 Introduction

Earthworks involve the use of heavy machinery in performing repetitive ground leveling activities, which can represent up to 30 to 50% of total construction costs in road and railway infrastructure projects. Although the importance of optimizing earthworks activities has been increasingly documented over the years, effective solutions for this problem have yet to be established. Thus, this work presents an integrated optimization system for earthmoving tasks, aiming to minimize multiple objectives simultaneously, namely construction cost and duration. For this purpose, it is necessary to integrate a wide variety of technologies, such as Soft Computing and geographical information systems, in order to allow for a proper adjustment to reality. The system was validated using a real earthworks data base from a road construction site in Portugal, yielding competitive results.

2 System Arquitecture

Following previous work by Gomes Correia & Magnan (2012), and Parente *et al.* (2014), the developed system consists of two modules, one based on *data mining* (DM) techniques and another based on geographic information systems (GIS), which support a third module, responsible for performing the multi-objective optimization of equipment throughout earthwork tasks. This translates into three integrated modules (equipment, spatial, and optimization modules) with the capacity to acquire and manipulate data in each phase of an earthworks project. Table 1 summarizes the modules and their functions.

Table 1: System modules and functions

Module	Technology	Function
Equipment	*Data mining*	• User inputs • Estimate mechanical equipment productivity
Spatial	Geographic information systems	• Construction site modelling • Optimization of transport equipment trajectories
Optimization	Evolutionary computation	• Optimal selection and allocation of the available mechanical equipment • Return output to the user

3 Case Study

The developed system was validated by using a real earthworks database stemming from a road construction site in Portugal. The purpose of this application was not only to determine the solution that minimizes both the cost and time for the earthmoving construction process, but also to ensure a greater degree of sustainability in terms of minimizing carbon emissions and optimizing resource usage. Additionally, since the productivity of the equipment allocated to a specific task is always conditioned by the productivity of the equipment allocated to previous tasks, optimal allocation solutions must take into account the need to synchronize the productivity of teams throughout the earthworks production lines. This allows for a constant flow of material from excavation to embankment fronts, thus ensuring the use of the available equipment at maximum efficiency, and reducing equipment idle time.

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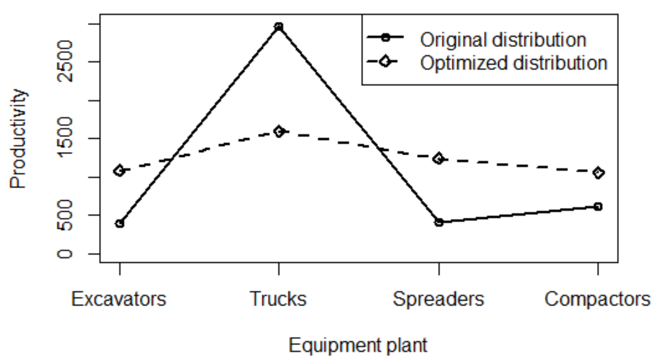
This is clearly shown in Figure 1a, in which a comparison is made between the production lines corresponding to the original distribution, obtained by conventional design methods, and the optimized distribution, obtained by the system. From the analysis of this figure, it is easy to infer that, in the original distribution, the productivity in each earthwork task is not properly synchronized. Consequently, the production line is limited by the productivity of the excavation team, which acts as a bottleneck. Contrariwise, the production lines of the optimized solution, obtained from the optimization system, are as homogeneous as possible in terms of the productivity of the teams in each task. As a result, besides reducing the cost and duration of the work, the system additionally improves the sustainability of the allocation solutions, as optimal management of resources and minimal carbon emissions are ensured.

By following this methodology, the system yields competitive results regarding the reduction of cost and duration of earthworks in this case study, when compared to the originally adopted solution. Figure 1b illustrates the multi-objective output of the system (i.e., in terms of cost and duration), in the form of a Pareto-optimal front of solutions, obtained by using a Non-dominated Sorting Genetic Algorithm II (NSGA-II) (Deb *et al*., 2002). In this figure, each dot corresponds to a viable distribution solution, represented in terms of its associated duration (in hours) and cost (in €). These multiple solutions correspond to optimal compromises between the optimization goals (Pareto front), in which maximum sustainability is guaranteed as a result of the aforementioned methodologies.



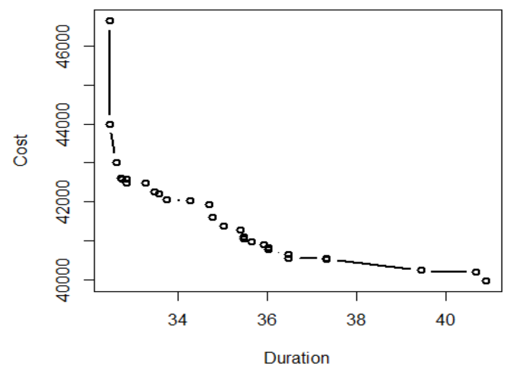


Figure 1: a.) Comparison between the allocated equipment productivity (in m^3/h) for the original and the optimized solutions; b.) Output of the system for the case study problem (*xx* axis in hours, *yy* axis in €)

4 Conclusions

The proposed system was validated in a case study using real data originating from a road construction site in Portugal. Results show that, in ideal conditions, a considerable reduction in total costs and durations of earthwork tasks (up to 50%) can be achieved, when compared to the originally adopted solution. Additionally, the type of output chosen (Pareto-optimal front of solutions) features the required flexibility to allow for the selection of the solution that best fits the project constraints (e.g., budget and deadline), representing an additional advantage in comparison with conventional design methodologies.

References

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