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Multi-objective simulation-optimization for earthmoving operations

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ABSTRACT

This paper presents an integrated framework of multi-objective simulation-optimization for optimizing equipment-configurations of earthmoving operations. The earthmoving operations are modeled through simulation and the performances associated with equipment-configurations are evaluated in terms of multiple attribute utility reflecting the preference of decision-makers to multiple criteria. A modified two-stage ranking-selection procedure, a statistical method, is equipped to help compare the alternatives that have random performances and thus reduce unnecessary number of simulation replications. In addition, particle swarm optimization is incorporated to search for the potential equipment-configurations to be examined through simulation, thus speeding up the evaluation process and avoiding exhaustive simulation experiments of all the alternatives. The architecture of the integrated framework is developed. A computational example is provided to justify the proposed methodology. The study will provide an alternative means to help plan earthmoving operations by considering multiple criteria and combining multiple methodologies.

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1. Introduction

Earthmoving operations are commonly involved in construction engineering and are often performed under conditions that may give rise to uncertainty and randomness. In most cases, earthmoving operations need to be completed within deadline and limited cost. Various methodologies have been proposed to help plan earthmoving operations [1–3]. Simulation is one of the methodologies that can be applied to analyze earthmoving operations by modeling uncertainties and randomness. CYCLONE [4] and STRBOSCOPE [5] are the commonly used simulation tools specified for construction.

In consideration of the drawback of simulation that requires exhaustive experiments of all the alternative inputs to achieve “What if” or sensitivity analysis, combination of simulation and optimization, namely simulation–optimization, has been proposed to answer not only “What if” but also “How to” questions [6], which is becoming a mainstream in the simulation field [7]. Some efforts have been made with respect to simulation–optimization in construction. Abourizk and Shi [8] and Shi and Abourizk [9] considered constraints on inputs to guide simulation experiments for seeking near-optimal resource quantities. Hegazy and Kassab [10], Cheng and Feng [11], Marzouk and Moselhi [3,12] and Cheng et al. [13] proposed simulation–optimization by combining genetic algorithm (GA) with CYCLONE or other simulation techniques.

Most of these construction-specified simulation–optimizations focused on single objective optimization rather than multiple criteria. The simulation–optimization of Marzouk and Moselhi [3,12] considered multi-objectives for selecting near-optimal fleet configuration for earthmoving operations, but could not select any potential combinations of various types of equipment in a fleet. Moreover, these simulation–optimizations did not address the randomness in the performances produced from simulation, so that the performance differences related to stochastic natures or input variances could not be differentiated when ranking the alternatives.

In this study a framework of multi-objective simulation–optimization (MOSO) for optimizing equipment-configurations of earthmoving operations is proposed by integrating an activity object-oriented simulation (AOOS) [14], multiple attribute utility (MAU) theory [15], a statistical approach like the two-stage ranking and selection (R&S) procedure [16] and particle swarm optimization (PSO) algorithm [17,37]. The MAU theory is applied to evaluate the performances generated through simulation by considering multiple criteria and the preference of decision-makers. A modified two-stage R&S method will be incorporated to handle randomness in the performances when ranking and selecting best alternative equipment-configurations. Reasonable number of simulation replications for examining each alternative will be determined during two-stage R&S, and thus reducing unnecessary simulation experiments. PSO that is similar to Genetic Algorithm (GA) is used to help search for potential alternatives so as to avoid exhaustive simulation experiments of all available equipment-configurations, enhancing the efficiency of the proposed methodology.

2. Activity object-oriented simulation (AOOS)

Due to the availability of activity object-oriented simulation (AOOS) [14] and its extendable feature, AOOS is utilized as the

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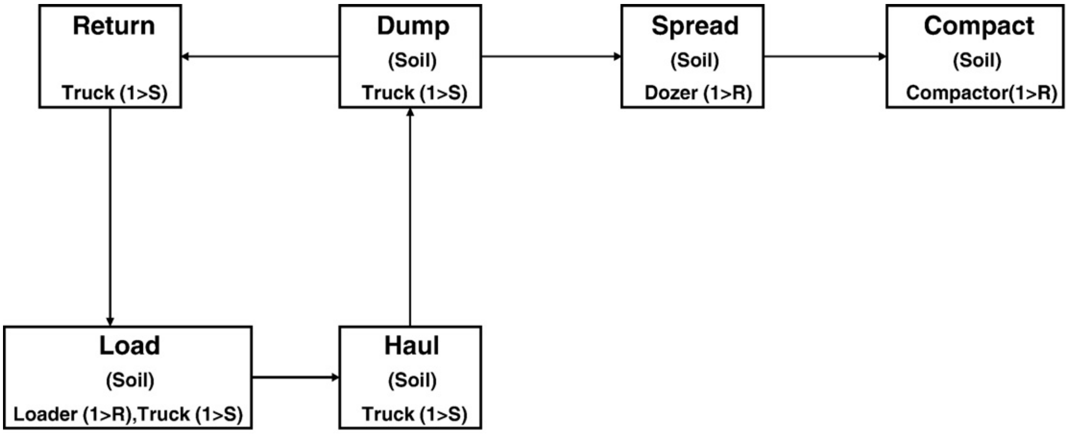


Fig. 1. AOOS graphic model for an earthmoving operation.

platform to model earthmoving operations. AOOS was developed based on activity cycle diagram (ACD) [18], "Micro-Saint" simulation [19], and ABC [20,21], as well as the object-oriented approach. One of the main characteristics of AOOS is its resemblance of graphical model form to the CPM activity-on-node network. Unlike CYCLONE and STRBOSCOPE that use two kinds of activity modeling elements (i.e., conditional or unconditional activities) and queue elements for entities flow, AOOS uses only one kind of activity modeling elements. Detailed descriptions of AOOS can be found in Zhang et al. [14]. Fig. 1 is the AOOS graphic model for an earthmoving operation, where six activities and four kinds of resources are involved.

The resources-configurations for an earthmoving operation contain quantitative and qualitative variables inputs for the simulation model. For example, the qualitative variables include the properties of resources and the routes of the resources among multiple activities, while the quantity variables include the numbers, cost and capacity of various resources. Through simulation the outcome performances such as project duration and total cost of an earthmoving operation can be observed to evaluate the associated equipment-configuration.

3. Multiple attribute utility (MAU) for multiple criteria evaluation

Multiple attribute utility (MAU) theory was originated from the eighteenth century, and has been developed by Keeney and Raiffa [22]. MAU theory is an analytical method for decision-making based on multiple criteria. Applications of MAU in construction include the approaches for procurement route selection [23] and performance assessing of construction engineering [24].

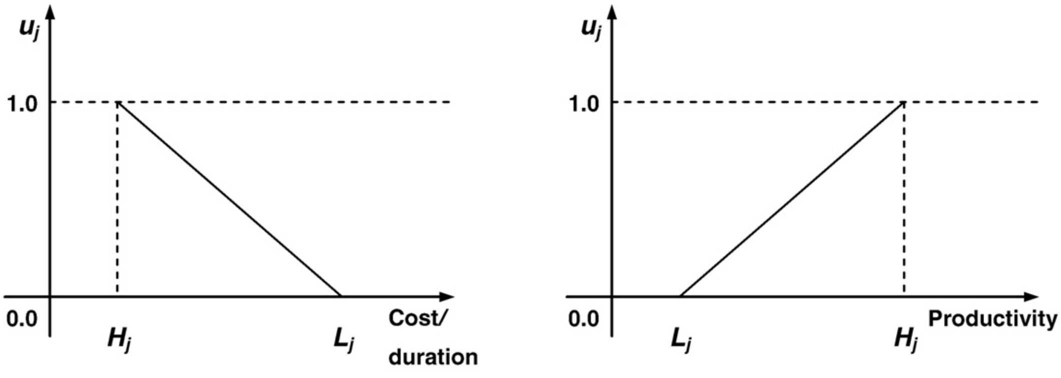
Attribute utility means a measure of the desirability of outcomes associated with an alternative action. An alternative may be chosen according to the preference of decision-makers or the importance of each single criterion or performance. According to the MAU technique, each alternative to be evaluated is measured through multiple attribute functions that reflectively reflect each single criterion and are then composed using a series of weight; the weights reflect the preference of decision-makers or the importance of each performance. If there are $J \geq 1$criteria for each alternative, then let $Y=(y_1,\ldots,y_J)$denote a vector of performances for an alternative, then the total attribute utility for measuring this alternative can be obtained as follows:

$$Y = U(Y) = \sum_{j=1}^{J} w_j u_j(y_j) \tag{1}$$

where $u_j(y_j)$ $(j=1,\ldots,J)$ is a single attribute utility function over the performance j and is scaled from 0 to 1. w_j is the weight for the performance j and the sum of all the weights is equal to 1, i.e., $\sum_{j=1}^{J} w_j = 1$. The single utility functions can be one of the three types: risk prone, risk aversion, and risk neutral. The risk neutral utility function is commonly used and is defined as:

$$u_j(Y) = a_j y_j + b_j \tag{2}$$

where a_j and b_j are the constants, and can be determined through $u_j(L_j)=0.0$ and $u_j(H_j)=1.0$. L_j and H_j represent the performances where their measure levels reach the lowest value 0.0 and the highest value 1.0 respectively. Fig. 2 illustrates the single attribute utility



(a) Attribute utility function for cost/duration (b) Attribute utility function for productivity

Fig. 2. Linear single attribute utility functions for two cases.

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