MATHEMATICAL AGGREGATION OPERATORS AND THEIR APPLICATION TO MECHANIZED EARTHWORK PROCESSES

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This contribution was prepared as a part of scientific research project VEGA N.1/0184/12.

Abstract: Equipment selection is a critical factor of many construction projects especially in the heavy construction projects where the equipment fleet may represent the largest portion of bidding price. Construction companies, developers and builders have a lot of things to consider before purchasing a right type of equipment. The importance of the criteria is expressed by weights, which are chosen by the experts or the decision makers. In this paper, a multi-criteria method based on weighting functions and aggregation operators was implemented into earthwork processes for comparing dozers which are available on the market. The key mathematical models for multi-criteria decision analysis are presented and the proposed model can be used like a tool for comparison of some types of mechanization.

Keywords: optimization, aggregation operators, mechanization, dozers

1 Introduction

Earthwork processes are involved in construction and in building process and they can be a fascinating part of a construction project because of powerful heavy equipment. The scope of these processes varies from a small amount of earth to moving millions of cubic meters of earth. The one thing that all soil processes have in common is that careful planning is the key to success. Traditionally, a project manager uses deterministic methods in analyzing soil processes, although real processes are stochastic. Considerable efforts have been made in development of efficient techniques and procedures for soil processes and many techniques have been developed so far.

The most of authors are interested in estimation of the actual field load spectrum which has to be designed properly. They aim to provide a new approach in estimating the minimum sample size of the transmission load of a wheel loader under multiple operating conditions. Zhang and Chu [9] studied the wheel loader and provided methods to estimate the sample size of load time history according to the extreme load values. Because the extreme load value poses a threat to structures by sometimes causing static failure, it is also studied in other fields. Naess and Gaidai [4] estimated the actual extreme values with the relationship between the extreme values and sample time series. Hence, the mean and standard deviation of the extreme load values are selected as other criteria for estimating the sample size of load signals. Wang et al. [8] focuses on determining the minimum sample size of the transmission load of a wheel loader under multiple operating conditions based on multi-criteria decision making technology. The weight values of the chosen criteria are determined, where the eigenvector and entropy information methods, together with linear combination weighting, are adopted. The optimal minimum sample size is estimated based on the feasible values determined by the three criteria and their corresponding weight values. Presently the majority of studies published in the literature focus on the optimization of equipment selection are based on diverse complex factors. Machine selection method and evaluation problem has been studied extensively. In contemporary equipment selection process for earthwork, the best alternative of machines is evaluated against multiple criteria rather than considering a single factor. Shapira and Goldenberg [7] developed a model which is based on an analytical hierarchy process which was developed by Thomas Saaty. The developed model is capable of providing users with results to compare with different alternatives based on several criterions for selection of equipment based on highest score. Its hierarchy was structured by dividing the problem into four criteria and eighteen sub-criteria, which were tackled in accordance to three perspectives: cost evaluation, benefit evaluation and total evaluation. Bascetin [1] have used Analytical Hierarchy Process approach for the equipment selection in final decision in the area of mining operations. The criteria for equipment selection are clearly identified what enables to decision makers to examines strength and weakness of loading-hauling systems by comparing them with the respect to appropriate criteria. In this study a computational example is provided to justify one of the multi-criteria methods. Applications of this method will increase effectiveness of building machines selection from the point of key criteria of optimizing, thus speeding up whole process of equipment selection.

2 The characteristic of dozers and the importance of selection the right piece of machine

In this study a computational example is provided to justify selected multi-criteria optimization method and method of scientific analysis and synthesis. These methods were implemented into are of earthwork processes, especially for comparing some alternatives of dozers like a main heavy equipment using for pushing earth, sand or rocks used in road building and construction. Dozer is classified like a tracked tractor that has an integral metal blade used to drive a significant magnitude of soil, sand, rocks, etc., generated during construction. Dozers are huge and robust tracked equipment and dozers weight is distributed by the wide tracks over vast area. They are designed preliminary for cutting and pushing material relatively for short distance (the tracked dozers for 60 meters, the wheeled dozers for 100 meters). The most economical application of dozers is their application mainly for the cutting of soil and for earthmoving at least, because with the increasing distance it has brought about losing soil and the performance of dozer is decreased. Selection of the right piece of dozers like main heavy equipment which can commonly be seen on the construction sites have to be based on a thorough analysis of the technological, economic and organizational aspects.

The choice of a particular type of dozer depends on the type and size of building, type and scope of work that the machine will perform during its operation and character of working activities which will be performed by the machine. Optimal choice of the machine also affects the composition of the soil type, the workability of soil, the groundwater level, the technical parameters of the machine, its performance, cost, estimated time for using the machine and also the nature of other mechanization that will work in the machine fleet. The first equipment selection step involves matching the right machine to the work physical task. Each piece of construction equipment is specifically designed by the manufacturer to perform certain mechanical operations that accomplish the work activity. Two types of failure can occur for all equipment. Structural or mechanical failure occurs when the machine is overloaded or stressed beyond the physical capabilities of its components. Stability failure occurs when the machine is overloaded or placed in a situation where it cannot remain balanced and upright. Using machines matched to the task will greatly increase the chance of avoiding failures and should be a primary goal of equipment selection. One of the most important considerations when selecting a piece of equipment is the availability of the right machine with proper and timely service, maintenance, and repair.

The right machine must not only match mechanical functions, but also power, capacity, and control requirements. Dealer or rental agency location proximity and staff competency will influence downtime and turnaround for service. The physical properties of clay, gravel, organic matter, rock, sand, or silt to be moved or excavated has a direct influence on the type and capacity of equipment selected for a specific work activity. The ease or difficulty of removing and handling soil or any material directly influences the amount of machine productivity. The composition of the soil and the amount of moisture in the soil influence the heaped capacity that the bucket can hold or the blade can push. Soil type and stability are also important to the engineer because the size of the particles, physical properties, and behavior when the moisture content is changed greatly influences the site and foundation design. Sometimes the soil must even be replaced or stabilized using other types of soils or additives. These decisions influence the types and capacities of the equipment needed by the contractor for the site work and ultimate construction of the foundation system.

Desired productivity is also a major influence on earth machines selection. Meeting the schedule for the quantity of work to be accomplished is the goal. The required hourly production of a piece of machinery is primarily determined by the amount of work to be done and how fast it has to be done. The amount of time the contractor wants to spend or has to spend on excavation or earthmoving will greatly influence the size of machinery chosen for the work. If there is a large volume of dirt that needs to be moved quickly, a large piece of machinery will probably be most efficient. If there is a small amount of dirt to be excavated, a smaller piece of machinery makes more sense. Equipment selection is typically company-specific and directly influenced by specific project and financial considerations. Equipment needs are further influenced by the complexity and uniqueness of a specific work activity. Contractors typically stretch the versatility of a piece of equipment by using it for multiple types of work. The goal is always to match the best hourly cost to the required production for the work activity. Each piece of equipment is specifically designed to perform certain mechanical tasks. Therefore, base the equipment selection on efficient operation and availability.

3 The selection of dozers and the choice of the normalization procedure

Selection of the right piece of machines for earthwork processes, like the right man for the job, affects field productivity. Productivity directly influences profitability. Using a machine that does not have enough capacity will slow down productivity. Using a machine with too large capacity might increase productivity to some extent, but will ultimately negatively affect profitability, because of the cost of operation of the oversized machine. This contribution illustrated the comparison of some types of the dozers like main heavy equipment with application multi-criteria optimization. The first step of comparing options for selected track-types dozers is the set of dozers and their characteristic submitted for analysis in the introductory phase – see Table 1. It is necessary to determine the criteria which are the most important in the process of the multi-criteria optimization. It is necessary to determine the criteria which are the most important in the process of the multi-criteria optimization.

Table 1: The selected types of dozers and their characteristics available on the market

THE TYPES OF THE DOZERS	Transport weight (kg)	Number of units (m^2)	Performance (m^2/h)	The price of machine (EUR)
D3K XL (LRC)	7 795,000	2,640	1 584,000	64 702,071
D3K2 XL	7 958,000	2,640	1 900,000	64 702,071
D4K LGP	8 510,000	3,150	2 835,000	84 563,929
D5K2 XL	9 314,000	2,780	3 336,000	96 431,571
D8T	38 488,000	4,990	5 988,000	463 195,750
D6N LGP	17 997,000	4,080	4 896,000	199 154,107
D7E STD	25 996,000	3,900	4 980,000	391 412,929

In the Table 1 they are selected track-type dozers and their parameters which have to be minimized or maximized to choose the most appropriate dozer in case of our criteria. The caterpillar was the main resource used to get information and characteristic of selected dozers which was determined like criteria which are important in the multi-decision making process. However, as shown in Table 2 below, some of the criteria have to be minimized and some of them have to be maximized to reach the optimal dozer with selected criteria of optimality. The comparison of alternatives depends on the choice of the normalization procedure at first, secondly on aggregation method. In order to compare values for selected criteria we choose normalization of data to the scale [0,1]. The point of linear normalization is to make variables comparable to each other. The reason this is a problem is that measurements made using such scales of measurement as nominal, ordinal, interval and ratio are not unique. Instead, you need to reduce the measurements to the same scale, and then compare. Normalization is the process of reducing measurements to a "neutral" or "standard" scale. In the Table 2 we can see normalized outputs for selected type of dozers.

Table 2: Normalized outputs for selected type of dozers

THE TYPES OF THE DOZERS	Transport weight (kg)	Number of units (m^2)	Performance (m^2/h)	The price of machine (EUR)
D3K XL (LRC)	0,000	1,000	1,000	0,000
D3K2 XL	0,005	1,000	0,928	0,000
D4K LGP	0,023	0,783	0,716	0,050
D5K2 XL	0,049	0,940	0,602	0,080
D8T	1,000	0,000	0,000	1,000
D6N LGP	0,332	0,387	0,248	0,337
D7E STD	0,593	0,464	0,229	0,820
	MIN	**MAX**	**MAX**	**MIN**

For the brevity, the normalization description notation $x_i = U_j(a_i)$ has been used. Thus $x_1, \ldots, x_n$ are the input values and the values $v_1, \ldots, v_n$ are normalized outputs. We apply a linear normalization which is performed according to the formula:

$$v_i = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}, \quad (1)$$

where normalized vector fulfills the following conditions $0 \le v_i \le 1$, while minimum $v_i = 0$ and maximum $v_i = 1$.

3 The evaluation of selected dozers by weighting functions and aggregation operators

In this paper the evaluation of selected dozers is presented by weighting functions and aggregation operators. Weights in aggregation reflect the different importance of single inputs to be processed. For the comparison of selected dozers the evaluation by mixture operators has to be chosen. For an interval $I \subset R$, let $D: I^2 \to R$ be given by $D(x,y) = (x-y)^2$. Then for any weighting functions $g: I \to [0,\infty]$, the operator $A_{g,D}$ is a mixture operator given by a mathematical model:

$$A_{g,D}(x_1, \ldots x_n) = \frac{\sum_{i=1}^{1} g(x_i).x_i}{\sum_{i=1}^{1} g(x_i)}. \quad (2)$$

In multi decision making process the expression has to be minimized:

$$h(r) = \sum_{i=1}^{n} g(x_i).(x_i - r)^2, \ r \ I \quad (3)$$

The function h is differentiable and:

$$h'(r) = -2.\left(\sum_{i=1}^{n} g(x_i).x_i - r.\sum_{i=1}^{n} g(x_i)\right) \quad (4)$$

$A_{g,D}$ need not be monotone increasing, in general. Ribeiro and Pereira have shown that any non - decreasing piecewise differentiable weighting function $g : [0; 1] \to [0;1]$ such that

$$g \ \ge g' \quad (5)$$

More general, for a non-decreasing differentiable weighting function $g : [a; b] \to [0,\infty]$, if

$$g(x) \ge g'(x).(b - x), x \in [a, b], \quad (6)$$

then $A_{g,D}$ is an aggregation operator.

In our case study after normalization, we have to determine the global ranking $r^{A}_{norm} : A \rightarrow [1;\infty]$ based on an aggregation function $A : [0;1]^n \rightarrow [0;1]$. The normalized inputs will be aggregated by a mixture operator $A:[0;1]^4 \rightarrow [0;1]$ with a weighting function $g : [0;1] \rightarrow [0;1]$ given by:

$$g(x) = x + 2,$$

$$Ag, D(x_1,\ldots x_4) = \frac{\sum_{i=1}^{1} g(x_i).x_i}{\sum_{i=1}^{1} g(x_i)} = \frac{(x_1+2).x_1+(x_2+2).x_2+(x_3+2).x_3+(x_4+2).x_4}{x_1+2+x_2+2+x_3+2+x_4+2} \quad (7)$$

The results of aggregation normalized inputs and resulting global ranking are summarized in the next Table 3.

Table 3: Aggregation normalized inputs and resulting global ranking

THE TYPES OF THE DOZERS	g (x) = x + 2	Ranking
D3K XL (LRC)	0,700	**7**
D3K2 XL	0,684	**6**
D4K LGP	0,602	**3**
D5K2 XL	0,619	**4**
D8T	0,500	**2**
D6N LGP	0,493	**1**
D7E STD	0,635	**5**

Table 3 shows us which alternatives were the best and which were the worst with application of weighting functions and aggregation operators. So with this application the track-type dozer D6N LGP is the best solution in terms for our optimal criteria.

4 Conclusions

Multicriteria optimization is a key factor to achieve success in any discipline, especially in a field which requires handling large amounts of information and knowledge base. The application of multi-criteria methods proved as an effective methodology thanks to its ability to combine various criteria in order to select the best alternative in terms of our key criteria of optimality. It is a reasoning process and the model of multi-criteria analysis is based on the set of possible alternatives and the number of the criteria which can be qualitative, quantitative or mixed. The importance of the criteria is expressed by weights, which are chosen by the experts or the decision makers and can be normalized real numbers or weighting functions. In this paper, a multi-criteria method based on weighting functions and aggregation operators were implemented into earthwork processes for comparing dozers which are available on the market. The key mathematical formulas for multi-criteria decision analysis are presented and the proposed model can be used like a tool for comparison of some type of machines. The comparison of alternatives depends on the choice of the normalization procedure at first, secondly on aggregation method. Recall that all of the multicriteria methods which were developed so far are only a support for a decision maker in the process of decision making because they are almost subjective and the chosen method depends always on the decision maker.

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Primary Paper Section: J

Secondary Paper Section: JN, JQ, JR