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Dissertation Thesis Abstract

Optimization and Evaluation of Mechanized Earth Processes Effectiveness

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Content

Abstract

The optimal selection of machine or machine group for construction processes is very important role of building planner during the process of construction planning. In my thesis there are analyzed: ability of machines to realize designed construction earth process (quality aspect), duration of mechanized process (time aspect), minimizing of consumption fuel (environmental aspect) and minimizing of total costs (economical aspect. Chapter 1 analyzes all key factors that affect the quality, environment and economics of mechanized earth processes. This chapter also presents approaches in this area in Slovakia and abroad and existing mathematical models for the optimal design of earthmoving machinery.. The main goals of my thesis are the proposal of method of machine and machine groups selection for excavation including multi-criteria optimization method with software support and application and verification of this method into 3 kinds of excavation. 9 scientific methods applied in my thesis are analysed with description, in which part of thesis were implemented. The key results of the work in terms of the set goals are given in chapter no. 4, where the method of selection of construction machines for earth processes and its application for surface and deep excavations is proposed. The contribution to science, pedagogy and practice is presented in Chapter 5. At the end of the work, the achieved key results are summarized. This thesis was prepared as a part of scientific research project VEGA N. 1/0511/19.

Abstract in Slovak language

Optimálny výber strojov alebo strojových zostáv pre stavebné procesy je veľmi dôležitá úloha projektanta stavieb v procese plánovania výstavby. V mojej dizertačnej práci sú analyzované: schopnosť strojov realizovať navrhnutý stavebný zemný proces (kvalitatívny aspekt), trvanie mechanizovaného procesu (časový aspekt), minimalizácia spotreby pohonných hmôt (environmentálny aspekt) a minimalizácia celkových nákladov (ekonomický aspekt). V prvej kapitole sú analyzované všetky kľúčové faktory, ktoré ovplyvňujú kvalitu, životné prostredie a ekonomiku v oblasti mechanizovaných zemných procesov a zároveň sú v tejto kapitole uvedené aj prístupy na Slovensku a v zahraničí a jestvujúce matematické modely pre optimálny návrh zemných strojov. Cieľom mojej dizertačnej práce je návrh metódy výberu strojov a strojových pre vykopávky vrátane multi-kriteriálnej optimalizačnej metódy so softvérovou podporou a aplikácia

tejto metódy pre 3 druhy vykopávok. V mojej práci je analyzovaných 9 vedeckých metód s uvedením, v ktorých častiach práce boli použité i Kľúčové výsledky práce z hľadiska stanovených cieľov sú uvedené v kapitole 4, kde je navrhnutá metóda výberu stavebných strojov pre zemné procesy a ich aplikácia pre plošné a hĺbkové vykopávky. V závere práce sú zhrnuté dosiahnuté kľúčové výsledky. Táto práca bola realizovaná ako súčasť projektu vedeckého výskumu VEGA č. 1/0511/19.

Introduction

The optimal selection of machine or machine group for construction processes is very important role of building planner during the process of construction planning. In my thesis there are analyzed: ability of machines to realize designed construction earth process (quality aspect), duration of mechanized process (time aspect), minimizing of consumption fuel (environmental aspect) and minimizing of total costs (economical aspect). Earth processes are involved in construction and in construction process and they can be an important part of a construction project because of powerful heavy equipment. They involve repetitive work cycles, large volume of work, high fuel consumption and they need to be completed within deadline. 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 earth processes have in common is that careful planning is the key to success. Traditionally, a project manager uses deterministic methods in analyzing earth processes, although real processes are stochastic.

Considerable efforts have been made in development of efficient techniques and procedures for earth processes and many techniques have been developed so far. Recently, more researches are interested in earthwork operations and most of them use optimization and simulation as the methodologies that can be used for analyzing earth processes.

Chapter 1 analyzes all key factors that affect the quality, environment and economics of mechanized earth processes. This chapter also presents approaches in this area in Slovakia and abroad and existing mathematical models for the optimal design of earthmoving machinery.

The main and partial goals of my dissertation are defined in chapter no. 2. The main goals of my thesis are the proposal of method of machine and machine groups selection for excavation including multi-criteria optimization system with software support and application and verification of this method into 3 kinds of excavation.

Scientific methods applied in my thesis are analysed in chapter no. 3 with description, in which part of thesis were implemented.

The key results of the work in terms of the set goals are given in chapter no. 4, where the method of selection of construction machines for earth processes and its application for surface and deep excavations is proposed. The contribution to science, pedagogy and practice is presented in Chapter 5. At the end of the work, the achieved key results are summarized.

The aim of my work is to bring new knowledge in the subject area for science in the field of construction and to help construction practice to effectively select the optimal design of machines in terms of process duration, fuel consumption and total costs. As part of the work, another plan is to design suitable software that would increase these effects.

This thesis was prepared as a part of scientific research project VEGA N. 1/0511/19.

1. Analysis of the current state of problems in Slovakia and abroad

This chapter analyses the factors influencing mechanized earth processes and approaches of experts in Slovakia and abroad in this area. This analysis is important in order to find out what are the reserves in the field of mechanized earth process design and what are the possibilities to increase the efficiency of the selection of construction machinery for earth processes from several aspects (quality, process duration, energy consumption and total costs).

1.1 Analysis of factors and machine useful for earth processes – excavation

The earth processes consist of a varied complex of activities which resulted on earth structures. The standard of activities are STN 73 3050, Earth works, common regulations. As for the earth processes structure includes preparatory works, excavations, and manipulation with excavate products. The manipulations of products are loading, transport, and unloading. Furthermore, the earth process structure includes embankments and earth construction buildings which go into transport and spread of excavating product and compacting of embankments. Basic processes we can divide into [13]:

- transport and spread of excavating product,
- compacting of embankments,
- loading,
- transport,
- unloading.

Helping and assurance works includes site drainage, sloping, and bordering of excavation product wall. Finally, the finishing works includes surface areas modification of surface areas of earth construction. Soil Rock is which of consolidated or unconsolidated mixture of grains of one or more minerals and fragments of older rocks; consolidated earth which is characterized by strength for rock and semi-rock soils according to STN 73 10 01 Building foundation. Earth of frictional or binding unconsolidated easy disconnected earth. The technological properties of soils include:

- the mineability and disconnecting,
- natural gradient,
- bulk density,
- bulkage,
- moisture.

Soil mine-ability is the property of which expresses hardness of earth disconnection and removal has cumulative characteristics which involve earth strength, bulk density, grain size, porosity, water content, and natural gradient.

The 7th classes of soils from the point of its mine-ability include:

1. bulk soils taking by shovel or loader,
2. bulk soils disconnected by spade or loader.
3. pit soils disconnected by picker, excavator,
4. crumbly soils disconnected by wedge, excavator,
5. easy demolition consolidated soils disconnected by ripper, large excavator, demolitions,
6. hard demolition consolidated soils disconnected by hard ripper, demolitions
7. very hard demolition consolidated soils disconnected by demolitions

Excavation is the process in which the product is cutting earth subject with new created walls which are known as slopes, ground and possible curbing. The two types of excavation are excavation place where it is realized, excavation product where earth is disconnected by excavation. According to shape of excavation we can divide deepening excavation into [10]: shaft, ditch, deepening cutting and groove (line).

The place and position in terrain is working, spading, and deepening. As for the shape of deepen excavation product which involves ditch, deepening cutting, groove (line), and shaft. To go more in depth, excavation is the process of earth disconnecting, removal of excavation product; it's dropping or loading into means of transport. Working excavation above the level of horizontal place of earth removal, and finally spading which is working across the terrain wave. Excavation shaft is defined as the deepening excavation product, which area does not reach over $36m^2$, the largest dimension is deeply measured at it axis as a vertical distance from ground up to cutting point with horizontal removal of earth. Excavation ditch is the deepening excavation product which is not shaft and which floor plan has width bigger than 2 m, and value of relation of length to width of ground is less than 6, excavation deepening cutting is the product of which is not shaft and which floor plan has the width bigger than 2 m and value of relation of length to width of ground is minimum and excavation groove (line) is the deepening excavation product, which is not shaft and which floor plan has the width of maximum 2m, except for road and railway trenches.

The factors that influence the excavation realization are:

- soft and properties of disconnecting earth,
- type, shape, and range of excavation,
- the climatic and hydro-geological conditions affect excavation,
- health and safety requirement,
- environment requirements as well.

1.1.1 Analysis of factors influencing machine selection for earth processes

For effective machine selection for earth processes we must take into account these factors [6]:

- characteristics of earth material (Table 1.1),
- type of excavation (Table 1.2)

- location of excavation area (Table 1.3)

Legend to Table 1.1:

1. Excavator with black shoe
2. Excavator with front shovel
3. Excavator with loading shovel
4. Excavator with towed buckets
5. Excavator with grapple
6. Bucket excavator
7. Wheel excavator
8. Wheel loader
9. Crawler loader
10. Wheel dozer
11. Crawler dozer
12. Grader
13. Scraper

1.1.2 Analysis of construction machines for excavation and transport

Construction machines foe excavation and transport we can divide into:

- cyclical working,
- continual working.

Building machines are determined according to the style of work this can be based on cyclical working or continual working [10]. In my work I will deal mainly with cyclically working machines for earth processes. The most commonly used earthmoving machinery are: dozers, excavators, scrapers, dumpers (trucks), loaders, graders.

The dissertation defines the principles of the above construction machines, work schemes, use and calculation of production rate.

Table 1.1 Choice of machines suitable for ground works according to the categorization of earth and type and location of the excavation [6].

Type of machine / **Conditions**	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
Characteristics of minerals, category of workability (Slovak standard STN 73 30 50)													
Watery earth	CS			S	S	CS							CS
Modest workability, category no. 1-2	S	S	S	S	S	S	S	S	S	S	S	S	S
Moderate workability, category no. 3-4	S	S	CS	CS	S	S	S	CS	S	S	S	CS	CS
Hard workability, category no.4-5	S	S			CS	CS	CS		CS	S	S		
Modest workability, rock, category no.5-6	CS	CS									CS		
Hard workability, rock, category no.6-7											CS		
Types of excavations													
Grading	CS	S	S	CS	CS		CS	S	S	S	S		CS
Construction pit	S	S	S	S	S			S	S				CS
Dig products	S	S	S	S	CS			S	S				CS
Construction furrow	S				S	S	S						
Construction shaft					S								
Surface grading, depth 0,5 m				S			CS	CS	CS	S	S	S	S
Overburden	S	S	S	S		S	S	S	S	CS			S
Leveling, flattening	CS	CS	CS					CS	CS	V	S	CS	
Exact flattening										CS	CS	V	
Sloping			S							CS	S	S	
Location of excavation area													
Open	S	S	S	S	S	S	S	S	S	S	S	S	S
Cramped	S			S	S								
Under water	S			S	S	S					+		

Notes: S - suitable type of machine CS - conditionally suitable type of machine

Table 1. 2 shows effective transport distance for basic machines for earth processes

Table 1.2 Choice of machinery for excavation removal according to the transport distance [6]

Type of machine	**Convenient transportation distance in meter**
Crawler loader	30 - 50
Dozer	60 - 100
Wheel loader	100 - 200
Scraper	300 - 1500
Dump truck	More then 1000

Table 1.3 illustrates useful selection of machines for earth processes according to conducted operation process.

Table 1.3 Selection of machines for earth processes according to conducted operation process [10]

Production operations / **Types of machines**	01.	02.	03.	04.	05.	06.	07.	08.	09
Excavators									
Dozers									
Front-end loaders									
Scrapers									
Graders									
Dumpers									
Dump trucks									
Hydro mechanization									
Compacting machines									

Legend to Table 03:
01. Soil disconnecting 02 . Soil scooping 03. Soil transporting 04. Soil foisting
05. Soil loading 06. Soil unloading and storage 07. Soil grading 08. Soil compaction
09. Spray

1.2 Mathematical models for determination of production rate, time, costs and consumption of energy of mechanized earth processes

Production rate, duration of mechanized process, costs and consumption of fuel are the most important optimization criteria for effective proposal od earth machines or machine groups.

1.2.1 Production rate of mechanized processes

Production rate of cycling working construction machines, which are excavators, dozers, scrapers, and dumpers can be calculated according to this formula [10,12]:

$$Q_c = n_c \; . \; V \; .k_o \; .k_{pú} \qquad (m^3.h^{-1}) \tag{1.1}$$

where:

Q_c- production rate of cyclic working machine ... ($m^3.h^{-1}$),

n_c- number of machine cycles per one hour ... (h^{-1}),

$n_c = 3600 \; . \; t_c^{-1}$ ... t_c - time of working cycle in second,

V-mass of product realized in one cycle ... (m^3),

k_o- bulk coefficient of earth,

k_{we} - coefficient of work effectiveness of machine.

Production rate of continual working building machines which are bucket excavators and transport belts can be calculated according to this formula [10]:

$$Q_k = 3600 \; . \; S_z \; .v \; .k_o \; .k_{we} \quad (m^3 \, h^{-1}) \tag{1.2}$$

where:

Q_z- production of continual working machine ... ($m^3 \, h^{-1}$),

S_z- area of working equipment, bucket capacity ... (m^2 , m^3),

V - speed of motion of working equipment ... ($m.s^{-1}$),

k_o- bulk coefficient of earth,

k_{we}- coefficient of work effectiveness of machine.

1.2.2 Time (duration of mechanized work)

Duration of mechanized cycling working building machines can be calculated by mathematical model:

$$T = MP \cdot Q_c^{-1} (h) \qquad (1.3)$$

where

T - duration of machine work (h),

Q_c - production rate of cyclic working machine ... ($m^{3.} h^{-1}$),

MP – total mass of product realized by machine (m^3).

1.2.3 Cost of mechanized work

The costs of mechanized building processes include cost incurred which is the finance expression of total work (live and materialized) which is being spent in production, and an indicator of economical production effectiveness. The total costs are fixed costs and variable costs. Fixed costs: N_1not depending on site conditions can be calculated as [10,12]:

$$N_1 = S \cdot Q^{-1} \; (€ \cdot j^{-1}) \qquad (1.4)$$

where:

S – operating costs per 1 hour of machine work (€ . h^{-1}),

Q – production rate of machine ($m^3 \cdot h^{-1}$).

The operating costs are the salary of machine service, installation, removal, repair, depreciation and amortization of machine Oil and grease and clean material and overhead.

Variable costs: N_2 depend on site conditions and can be calculated as [10,12]:

$$N_2 = (N_{ZS} + N_{ps} + N_{pp} + \ldots) \cdot MP^{-1} (€ \cdot j^{-1}) \qquad (1.5)$$

where:

N_{ZS} – costs of site facilities (€),

N_{ps}– costs for machine removal (€),

N_{pp}– costs due to necessary interval in work (Climatic conditions) .. (€),

MP – total mass of product realized by one or more machines (unit).

Total costs for unit: N_{tc} (€ . unit^{-1}) is calculated as:

$$N_{tc} = N_1 + N_2 \qquad (1.6)$$

where:

N_1 - fixed costs in €,

N_2 - variable costs in €.

K. Prokopčáková analysed the issue of costs in more depth [23]. The total costs divided into :

- current costs,
- occasional costs,
- one-off costs.

Current costs are essentially constant costs that are related to the normal operation of the machine and accrue even when the machine is not running. Examples are the costs of depreciation, insurance, tax, wages, fuel and lubricants, the annual work fund of the machine, etc.

Occasional costs arise when the machine is operated at certain intervals. Examples are the costs of repair and maintenance, replacement of tires and belts, etc.

One-off costs of the machine represent its costs for transport and relocation, assembly and disassembly, as well as unforeseen costs related to the operation of the machine (auxiliary equipment)

1.2.4 Energy consumption

Total consumption of fuel of machine groups- excavator-trucks: TC (l) is calculated according to mathematical model [6]:

$$TC = N \left(\sum_{i=1}^{n} Tw_i \,.\, Sw_i + \sum_{i=1}^{n} Two_i \,.\, Swo_i + \sum_{i=1}^{n} Tt_i \,.\, St_i \right) \quad (\,l\,) \tag{1.7}$$

where:

N – number of working shifts (shift)

Tw_i– time of waiting regime of „i“ machine during engine work (min.shift^{-1})

Two_i– time of working regime „i“ machine (min.shift^{-1})

Tt_i–time of transport „i“ machine (min.shift^{-1})

Sw_i– consumption of fuel of „i“ machine during waiting regime (l . min^{-1})

Swo_i– consumption of fuel of „i“ machine during working regime (l . min^{-1})

St_i– consumption of fuel of „i“ machine during transport regime (l . min^{-1})

n -number of machines in machine group

1.3 Knowledge of the topic in Slovakia and abroad

There are several authors in Slovakia and abroad, who developed optimal selection of construction machines for earth processes. Slovakian authors I. Zapletal, B. Kintly, J. Kolárik, I. Juríček, J. Gašparík, A. Gron and K. Prokopčáková developed in [6,7,8,9,1012,1323,29] the issue of the use of construction machinery in earthmoving processes, comprehensive care for construction machinery and calculations of performance and cost of construction machinery.

Czech autors Č. Jarský and I, Vávra and Slovak autors I.Zapletal and Z. Hulínová in [28,29] developed mathematically the quering theory in machine group excavator-trucks and the method of polyoptimization [29]. J. Gašparík in [6,7,9] developed and described selection of machines foe excavation using machine group excavator-trucks with software support form the point of earth process duration and from the point of minimization of consumption of fuel. At his research work he implemented theory of systems [26] and optimization theory of the process [20]. The research work of L. Paulovičovej [7,9] was focused on the modelling of mechanized earth processes using multi-criterion optimization from the point of time, cost, fuel consumption and emissions of CO_2. Her work was implemented into deep excavation using machine group excavator-transport means.she prepared for students and practice an interactive Web site for optimal machine selection. Considerable efforts have been made in development of efficient techniques and procedures for earth processes and many techniques have been developed so far. Recently, more researches are interested in earthwork operations and most of them use optimization and simulation as the methodologies that can be used for analyzing earth processes. CYCLONE and STROBOSCOPE are the commonly used simulation tools specified for construction (Zhang, 2008 [31]). These tools for construction modeling, such as STROBOSCOPE enable accurate and detailed modeling of any complex situation but these tools demand a level of training (Martinez, 1996 [15]). In the context of STROBOSCOPE Martinez developed an EarthMover, which is a discrete-event special-purpose simulation modeling tool for earthwork planning. This tool includes STROBOSCOPE as a simulation engine, Visio for the graphical and interactive model definition, Excel for tabular and graphical output and Proof Animation for dynamic output (Martinez, 1998 [16]). Halphin developed CYCLONE methodology for modeling and simulating repetitive construction processes (Halphin, 1977 [11]). Shi and AbouRizk [25] introduced the resource-based modeling (RBM) methodology in order to automate the modeling process and by using this methodology can the project manager construct a simulation model for a project in a few minutes, but it consisted of only eight basic atomic models and is connected only with earthmoving operations (Shi & AbouRizk, 2002). Marzouk and Moselhi [17] analyzed earthmoving operations by combining genetic algorithm (GA) with CYCLONE and other simulation techniques. Their simulation and optimization considered multi-objectives for selecting near-optimal fleet configuration for earthmoving processes, but could not select any potential combination of various type of equipment which are in the fleet (Marzouk & Moselhi, 2004). The work of Zhang formed a framework of multi-objective simulation-optimization for optimizing equipment-configurations of earthmoving operations and it is proposed by integrating an activity object-oriented simulation, multiple attribute utility theory, a statistical approach like the two-stage ranking and selection procedure and particle swarm optimization algorithm. His procedure is equipped to help compare the alternatives that have random performances and thus reduce unnecessary number of simulation replications. It can speed up the evaluation process, but this integrated framework is still developed (Zhang, 2008).

In my country Saudi Arabia there also using similar machines for excavation like in Slovakia (dozers, excavators, scrapers, dumpers, loaders) from all of the world and also the mathematical models are similar as they are using in Slovak Republic but for our country it is the most important criterion time (Saudi Arabian Road establishment, because always they would like to finish very quickly the earth process and use the building to have the money back.

Although many authors deal with the issue, I feel the possibilities of further progress in the topic, such as extending the application to excavations with the use of dozers and scrapers, focusing on the criteria of optimality: quality of machine selection, time, fuel consumption and costs, software development for quick decisions and determining the weighting factor according to the requirements of investors.

2. Aim and thesis of dissertation work

The main aims of my dissertation thesis are:

1. Proposal of method of machine and machine groups selection for excavation including multi-criteria optimization system with software support
2. Application and verification of this method into 3 kinds of excavation

The partial aims of my thesis are:

1. Analysis of existing approaches to the topic in Slovakia and abroad
2. Analysis of factors influencing technology and proposal of mechanized earth processes for excavation

3. Proposal of method of machine and machine groups selection for excavation including multi-criteria optimization system (time, energy and cost)
3. Application of this method into 3 model example
4. Definition of mathematical variables and models for calculation of outputs like: production rates, duration of process, fuel consumption and total cost. for selected excavation
5. Verification of thesis results
6. Proposal of software support for optimization criteria
7. Synthesis of new knowledge
8. The effects of dissertation theses results for science, education and practice

3. Used scientific methods

In my work were used these scientific methods and theories:

- method of scientific analysis,
- method of scientific synthesis,
- method of induction,
- method of deduction,
- method of comparison,
- method of abstraction,
- method of generalization,
- queuing theory,
- multi criteria optimization.

Scientific analysis was used to investigate issues in Slovakia and abroad, factors influencing mechanized earth processes, parameters of construction machinery for earthworks, criteria for the selection of construction machinery for earthworks, efficiency of use of construction machines for earth process.

Scientific synthesis was used to in:

- proposal of a method for selecting construction machinery for mechanized construction processes,

- creation of mathematical models for determining the performance of construction machinery, the duration of mechanized construction work, fuel consumption and total costs,
- creation of software for the selection of construction machinery in terms of efficiency and investor requirements,
- formulating benefits for science, practice and pedagogy and overall conclusions.

Method of inductionis used to draw general scientific conclusions, the theorem, based on the evaluation of basic scientific data. In my work was implemented for formulating general research outputs on the base of research results [24].

Method of deduction, unlike induction, is based on general assumptions and applies them to individual general or partial conclusions. In my work was implemented for formulating benefits for science, practice and pedagogy and overall conclusions [24].

Method of comparison was implemented in the process of comparison of different variants of machines and machine groups realized earth processes from the point of production rate, cast, duration of process and fuel consumption.

Method of abstraction was implemented in the process of the selection of important input data for creation mathematical models.

Method of generalization was implemented in the process of creation method of optimal machine selection according to proposed criteria.

The queuing theory was applied in my work in model example N.. 3 when applying the machine group excavator-transport means (trucks).

The multi criteria optimization was applied in my work in model examples in 4th chapter.

4. Solution of work according to set goals

This chapter is the most important from the point of view of my research work. It is aimed at meeting the objectives defined in Chapter 2. The basis is the proposal of method of machine and machine groups selection for excavation including multi-criteria optimization system with software support and application and verification of this method into 3 kinds of excavation

4.1 Proposal of method of machine and machine groups selection for excavation including multi-criteria optimization system with software support

The optimal selection of machine or machine group for earth processes is very important role of building planner during the process of construction planning. During this process building planner have to analyze several factors influencing the final effective decision concerning this problem. There are several factors and criteria for effective selection of construction machines. In my work there are analyzed: ability of machines to realize earth processes (quality aspect), duration of mechanized process (time aspect), minimizing of energy consumption (environmental aspect) and minimizing of total cost of mechanized processes (cost aspect).

The "Machine Selection Optimizing Method" (MSO Method) consists of these steps (Figure 4.1):

1. **Definition of construction problem and the final product of the construction processes**:

Description of activities: At this phase is key definition of construction problem and final product of mechanized construction processes, for example the type of construction works, characterization of the final product of the mechanized construction process, input information necessary for solving of the problem and so on.

2. **Selection of a suitable machines or machines groups**

Description of activities: At this phase is main activity the selection of a suitable machines or machines groups for a given type of construction works. The criterion (aspect of quality) is the usefulness of the machines or machines groups for the realization of the final product of the construction process. Basic processes at this step are:

- analysis of the resulting product of the construction process,
- analysis of a useful machines or machine groups for a given type of construction process and its final product,
- the collation of all the information including the performance data of the machines for their incorporation into a model of the mechanized construction process.

The output of this step will be set of the machines suitable for realization of the final product of the construction process.

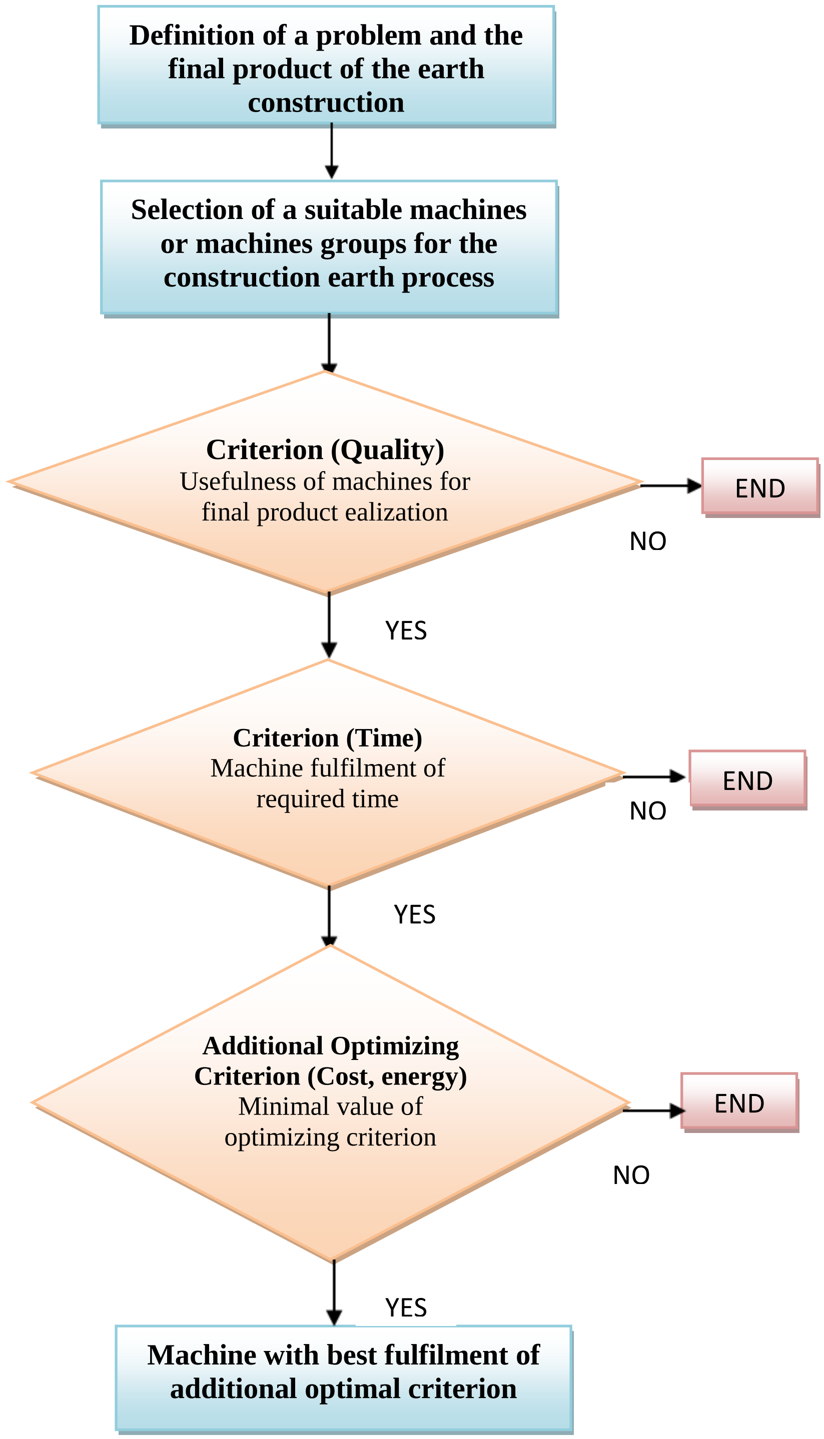


Figure 4.1. Machine Selection Optimizing (MSO) Method

3. Assessment of machines in terms of required time

Description of activities: At this phase are all proposed machines or machine groups evaluated according to time criterion. The first are calculated production rates of all proposed and useful machines or machine groups and then is calculated duration of the process. Time is one of the key requirements of the most of investors. Basic processes at this step are:

- the construction of the verbal – graphic model of the real system,
- the choice of the variants of the machines, let us say of the machine groups for realization of the final product of defined construction process,
- the selection and the choice of the mathematical model variables, their definition, symbol, dimension, quantification with the source of the quantification,
- the formulation of the particular mathematical relations of the model,
- the construction of the mathematical model for determination duration of the final product realization,
- the verification, quantification, numerical solution using software, interpretation
- and implementation of the created mathematical model concerning the criterion of time.

The output of this step will be set of the machines performing the time requirements for realization of the final product.

4. Assessment of machines in terms of additional optimizing criterion

Description of activities: At this phase are all machines or machine groups, which fulfill time criterion evaluated according to additional optimizing criterion, for example cost or energy aspect). Minimizing of cost and consumption of fuel of machines are very serious requirement of investors and also construction process supplier. Basic processes at this step are:

- the selection and choice of the decision variables, their definition, symbol, dimension, quantification with giving of the source of the quantification,
- the construction of the mathematical model of the criterion of the optimization,
- the verification, quantification, numerical solution using software, interpretation and implementation of the mathematical model of the criterion of the optimization.

The output of this step and the optimal solution is the machine, let us say the machine group with the minimal cost or energy consumption for realization of the final product of the construction process.

4.2 Application and verification of this optimal method into 3 model examples of earth excavation

The “Machine Selection Optimizing Method” (MSO Method) were applicate and verified in three model example, in which were evaluate three different excavation and construction machines: dozers, scrapers and machine group excavators + transport means

4.2.1 Model example N. 1

1. **Definition of a problem and the final product of the earth construction**

The problem concerns the implementation of surface excavation, specifically the levelling of the sloping terrain. The total volume of earthworks is 5000 m^3. The average distance between the centre of gravity of the excavation and the centre of gravity of the hopper is 100 m.
Basic input data:

- final product of construction earth process – surface excavation,
- total volume of earth work: 20 000 m^3
- soil type and class – sandy earth, the 2nd class of cohesion (according to Slovak National Standard STN 733050),
- the average distance of earth transport L=100 m
- season of year of realization of works – April, May,

2. **Selection of a suitable machines or machines groups for the construction earth process**

Based on the information given in Tables 1.1 to 1.3 in Chapter 1 of the work, a dozer appears to be a suitable machine for the implementation of this excavation. In my model example, I chose 5 types of dozers to implement the leveling of the terrain:

- D1 (Model CAT D5K2 Trac Type Tractor)

- D2 (Model Komatsu D65EX-18)
- D3 (Model Liebherr PR 736
- D4 (Model CAT D6R Track Type Tractor)
- D5 (Model CAT D10T Track Type Tractor)

In this work, I deliberately chose different types of dozers with different parameters to better assess their resulting parameters in the optimization.

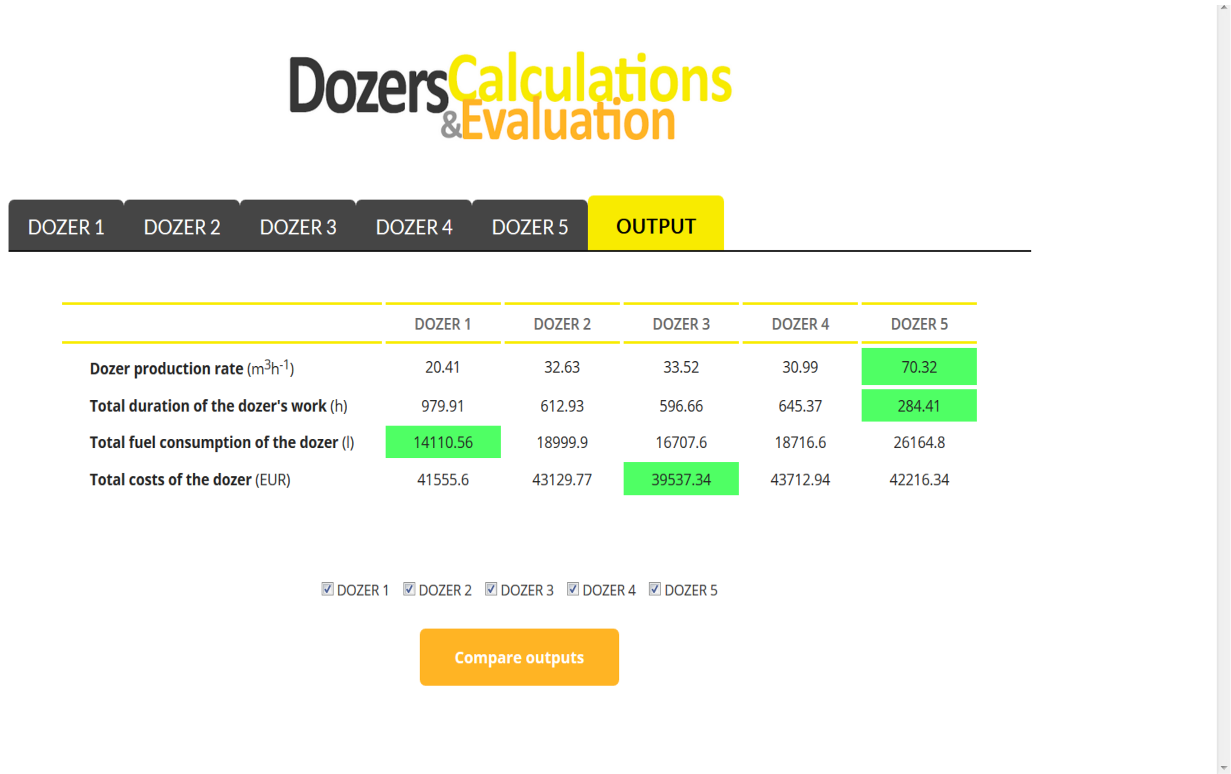
3. Assessment of machines in terms of required time and additional optimizing criterion

In this part it is necessary to define all input data on the final product of earthworks, the earth itself, technical parameters of selected dozers and to design mathematical models for determining the selected optimality criteria: duration of work (TIME), fuel consumption (ENERGY) and total costs (COST). All necessary inputs, mathematical quantities and mathematical models for determining the time, fuel consumption and costs for individual dozer variants are involved by table form in my dissertation thesis.

Calculation according to the proposed mathematical models and evaluation of dozers was performed using the software Dozers calculation & evaluation developed in the Quality Management Centre in Construction (CEMAKS) at the Department of Building Technology in Civil Dozers Calculations & Evaluation is an application based on Javascript and HTML. Its purpose is to provide automatic calculation of key mathematical outputs of specific dozers' work and also to evaluate and identify the best dozer vehicle based on these main criteria: dozer production rate, total duration of the dozer's work, total fuel consumption of the dozer, total costs of the dozer.

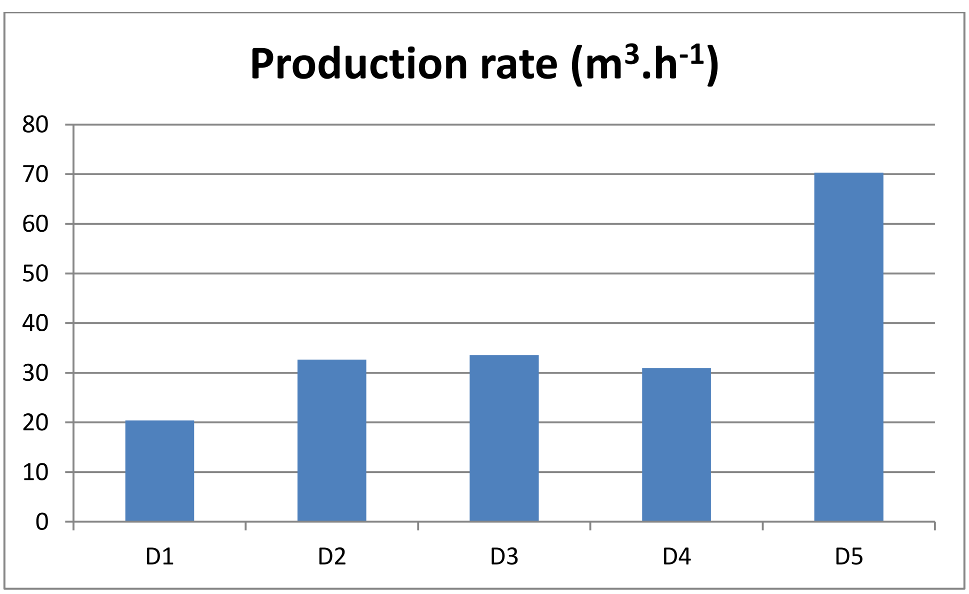
User enters the inputs for a maximum five dozers. On an output screen, the user choose which dozers to compare (minimum 2, maximum 5). Optimal solution based on the mentioned 4 criteria will be clearly marked on the output screen's result table. Figure 4.1 shows the overall evaluation of dozers in terms of production rate, time, fuel consumption and total cost.

Graphical interpretations of dozer variants evaluation from the point of view - production rate, duration of process, fuel consumption and total cost are in Figure 4.2-4.5.



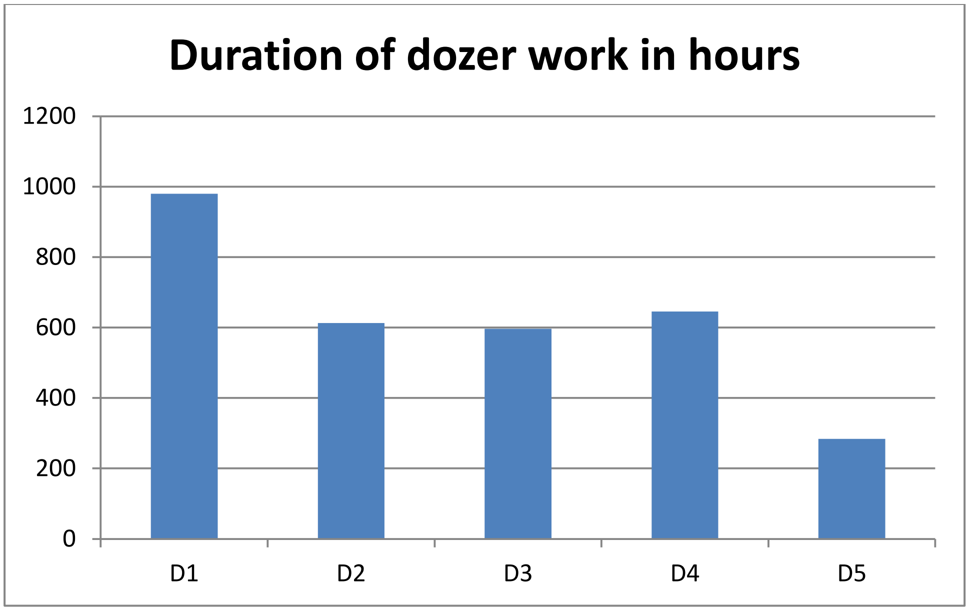
	DOZER 1	DOZER 2	DOZER 3	DOZER 4	DOZER 5
Dozer production rate (m^3h^{-1})	20.41	32.63	33.52	30.99	70.32
Total duration of the dozer's work (h)	979.91	612.93	596.66	645.37	284.41
Total fuel consumption of the dozer (l)	14110.56	18999.9	16707.6	18716.6	26164.8
Total costs of the dozer (EUR)	41555.6	43129.77	39537.34	43712.94	42216.34

Figure 4.1 Overall evaluation of dozer variants from the point of view - production rate, duration of process, fuel consumption and total cost in software Dozer Calculation & Evaluation



D - DOZER VARIANT

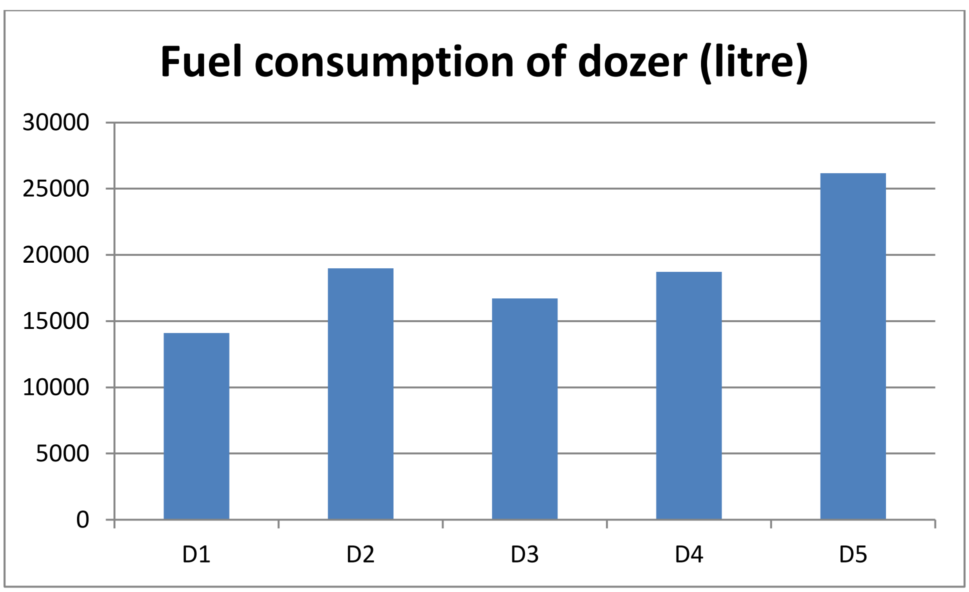
Figure 4.2 Evaluation of dozer variants from the point of production rate



D - DOZER VARIANT

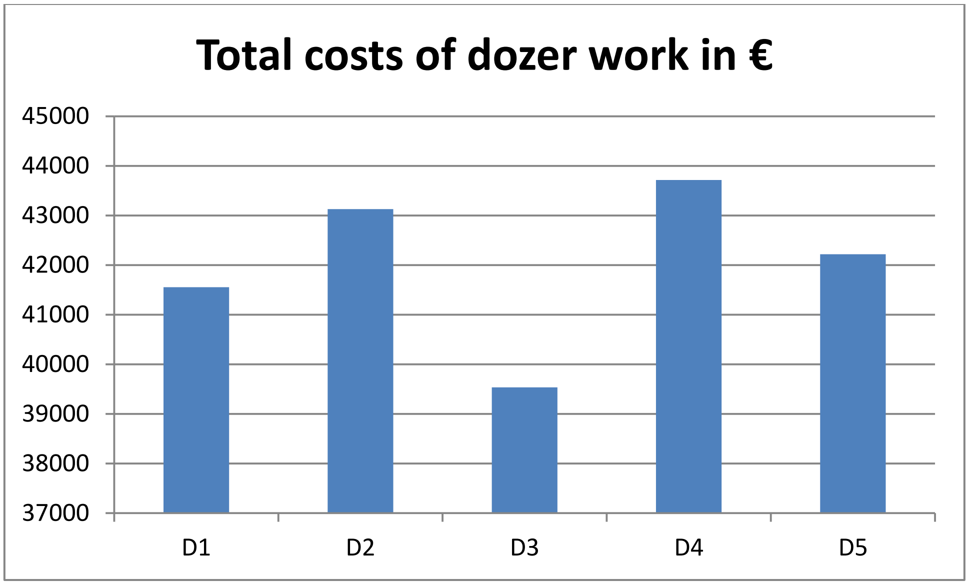
Figure 4.3 Evaluation of dozer variants from the point of duration of work

(TIME CRITERION)



D - DOZER VARIANT

Figure 4.4 Evaluation of dozer variants from the point of fuel consumption in liters (ENERGY CRITERION))



D - DOZER VARIANT

Figure 4.5 Evaluation of dozer variants from the point of total costs

(COST CRITERION))

4.2.2 Model example N. 2

1. Definition of a problem and the final product of the earth construction

The problem concerns the implementation of surface excavation, specifically the levelling of the sloping terrain. The total volume of earthworks is 20 000 m^3. The average distance between the centre of gravity of the excavation and the centre of gravity of the hopper is 1000 m.

Basic input data:

- final product of construction earth process – surface excavation,
- total volume of earth work: 20 000 m^3
- oil type and class – sandy earth, the 2nd class of cohesion (according to Slovak National Standard STN 733050),
- the average distance of earth transport L=1000 m
- season of year of realization of works – April, May.

2. Selection of a suitable machines or machines groups for the construction earth process

Based on the information given in Tables 1.1 to 1.3 in Chapter 1 of the work, a scraper appears to be a suitable machine for the implementation of this excavation. In my model example, I chose 5 types of scrapers to implement the leveling of the terrain:

- S1 (Model CAT 621K)
- S2 (Model Komatsu WS23S-1)
- S3 (Model TEREX TS 14 G)
- S4 (Model CAT 627G Auger)
- S5 (Model CAT 637G)

In this work, I deliberately chose different types of dozers with different parameters to better assess their resulting parameters in the optimization.

3. Assessment of scrapers in terms of required time and additional optimizing criterion

In this part it is necessary to define all input data on the final product of earthworks, the earth itself, technical parameters of selected scrapers and to design mathematical models for determining the selected optimality criteria: duration of work (TIME), fuel consumption (ENERGY) and total costs (COST). All necessary inputs, mathematical quantities and mathematical models for determining the time, fuel consumption and costs for individual dozer variants are involved by table form in my dissertation thesis.

Calculation according to the proposed mathematical models and evaluation of scrapers was performed using the software Scrapers Calculation & Evaluation developed in the Center for Quality Management in Construction (CEMAKS) at the Department of Building Technology in Civil Engineering during my research work. Software has 2 parts:

Scrapers Calculations & Evaluation is an application based on Javascript and HTML. Its purpose is to provide automatic calculation of key mathematical outputs of specific scrapers' work and also to evaluate and identify the best scraper vehicle based on these main criteria: scraper production rate, total duration of the scraper's work, total fuel consumption of the scraper and total costs of the scraper.

User enters the inputs for a maximum five scrapers. On an output screen, the user choose which scrapers to compare (minimum 2, maximum 5). Optimal solution based on the mentioned 4 criteria will be clearly marked on the output screen's result table.

Figure 4.6 shows the overall evaluation of scrapes in terms of production rate, time, fuel consumption and total cost. Graphical interpretations of scraper variants evaluation from the point of view - production rate, duration of process, fuel consumption and total cost are in Figure 4.7-4.10

Figure 4.6 Overall evaluation of scraper variants from the point of view - production rate, duration of process, fuel consumption and total cost in software Scraper Calculation & Evaluation

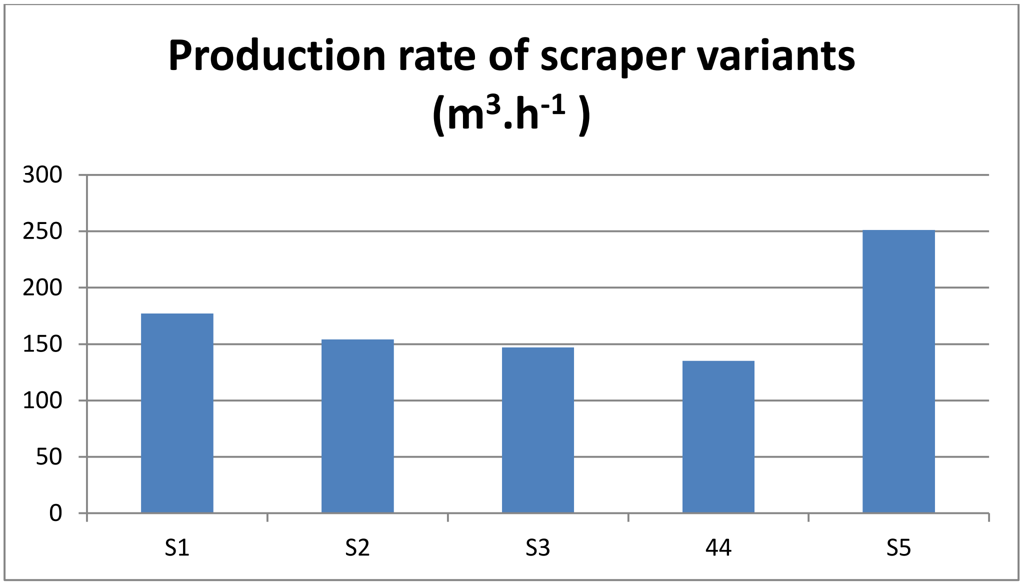


Figure 4.7 Evaluation of scraper variants from the point of view: production rate

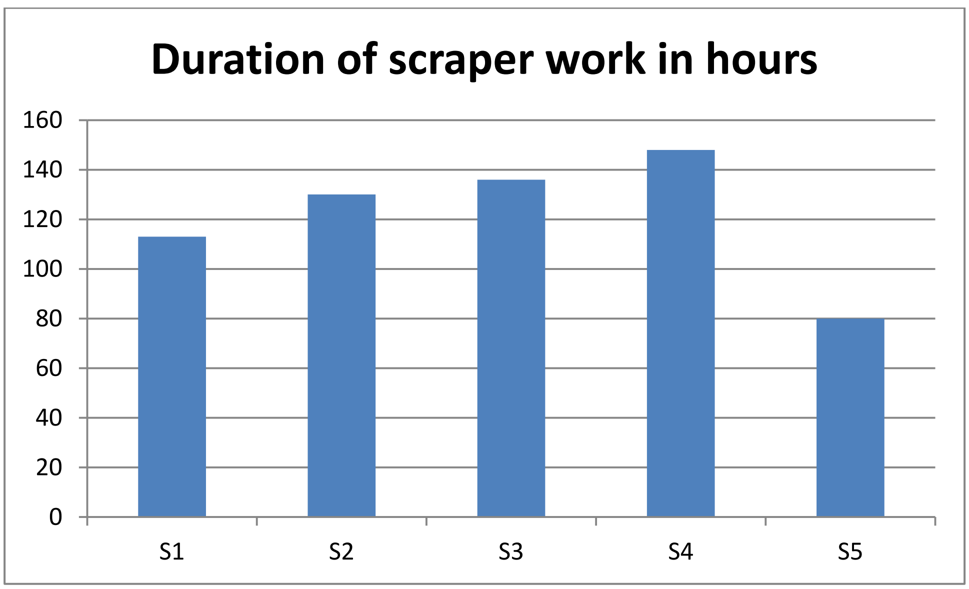


Figure 4.8 Evaluation of scraper variants from the point of duration of work

(TIME CRITERION)

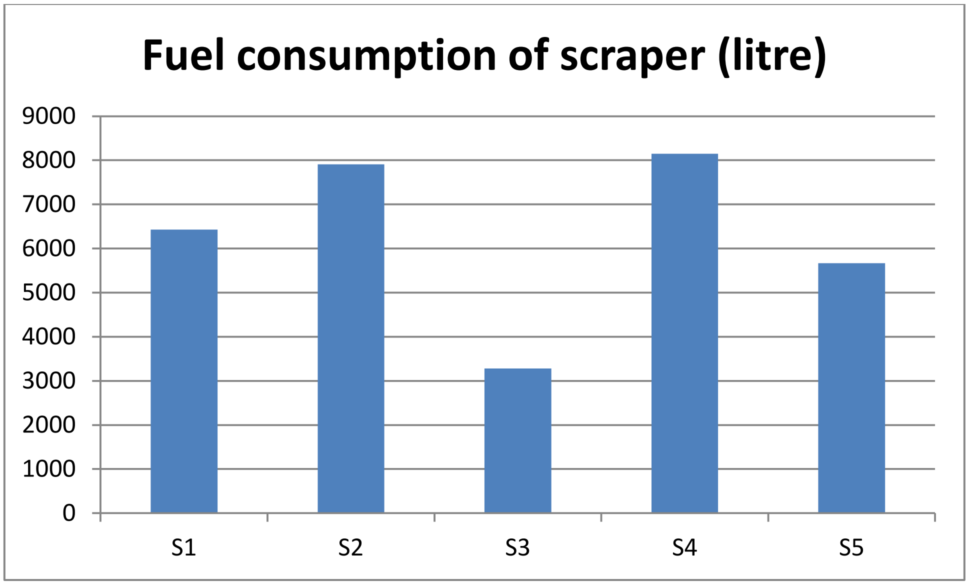


Figure 4.9 Evaluation of scraper variants from the point of view: fuel consumption in liters (ENERGY CRITERION))

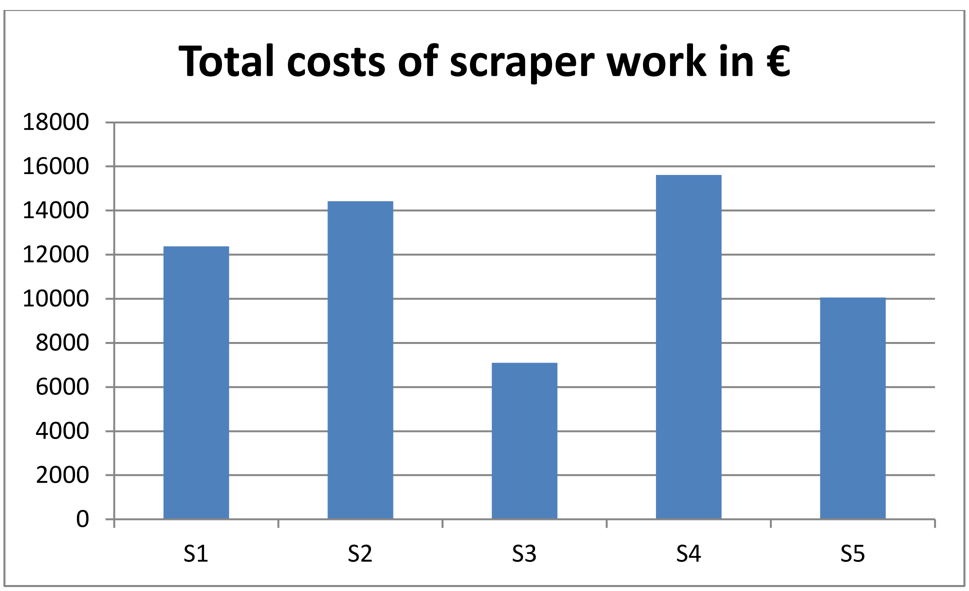


Figure 4.10 Evaluation of scraper variants from the point of view: total costs

(COST CRITERION))

4.2.3 Model example N. 3

1. **Definition of a problem and the final product of the earth construction**

This "MSO method" was applied at the model example N. 3 into the selection of machine group for the deep excavation and the removal of the earth at the given distance from the above mentioned criteria: time, energy and cost (Figure 4.11).

Figure 4.11 Building machine group: excavator + transport means (trucks)

Basic input data:

- final product of construction process – construction pit: width – 60 m, length – 90 m, depth – 3,55 m ,
- required work capacity $V_p = 16\ 000\ m^3$,
- oil type and class – sandy earth, the 2nd class of cohesion (according to Slovak National Standard STN 733050),
- transport distance L= 4 km,
- required time of duration of works T= 15 000 min. (31 shifts),
- season of year of realization of works – April, May,
- kind of road surface – mastic asphalt, plane on the whole length.

Comment: presupposition of approximate identical operation of machines during shifts, time for lunch and inspection of machines at the beginning and the end of shift have not being included in time of shift duration.

2. Selection of a suitable machines or machines groups for the construction earth process

Based on the information given in Tables 1.1 to 1.3 in Chapter 1 of the work, a excavator with depth bucket and trucks appear to be a suitable machine group for the implementation of this excavation and transport of earth to the distance 4 km. In my model example, I chose 9 variants of machine group excavator-trucks to realize depth excavation (see Table 4.1).

Table 4.1 Proposal of variants of machine groups: excavator + truck

Variant	Symbol	Machine group (excavator-truck)
A	E_1T_1	HITACHI ZX 210 LC-5 + IVEC0 AD 410T41
B	E_1T_2	HITACHI ZX 210 LC-5 +TATRA 815 S3
C	E_1T_3	HITACHI ZX 210 LC-5 +MERCEDES ACTROS 4043S
D	E_2T_1	LIEBHERR R 944C+ IVEC0 AD 410T41
E	E_2T_2	LIEBHERR R 944C + TATRA 815 S3
F	E_2T_3	LIEBHERR R 944C + MERCEDES ACTROS 4043S
G	E_3T_1	CAT 225 + IVEC0 AD 410T41
H	E_3T_2	CAT 225 + TATRA 815 S3
I	E_3T_3	CAT 225 + MERCEDES ACTROS 4043S

Legend to table 4.1:

A, B, C, D, E, F, G, H, I are symbols for machine group variant "excavator + trucks", E_i - type of excavator, where i = 1, 2, 3; T_j - type of truck, where j = 1, 2, 3.

In each variant there will be analyzed following machine set "excavator + 1 to 13 pcs of trucks".

3. **Assessment of machine groups (excavator-trucks) in terms of required time and additional optimizing criterion**

In this part it is necessary to define all input data on the final product of earthworks, the earth itself, technical parameters of selected excavators and trucks and to design mathematical models for determining the selected optimality criteria: duration of work (TIME), fuel consumption (ENERGY) and total costs (COST). All necessary inputs, mathematical quantities and mathematical models for determining the time, fuel consumption and costs for machine group excavator-trucks variants are involved by table form in my dissertation thesis.

4. MSO method software support

The Machine Selection software was created at the Quality Management Centre in Construction (CEMAKS) at the Department of Building Technology (Faculty of Civil Engineering, Slovak University of Technology in Bratislava) as a software support for method described in this contribution. Machine Selection is a desktop application, built in Java. Therefore it is runnable on all operating systems that support Java Virtual Machine. Introduction screen (Figure 4.12) contains panels to enter input variables. User can choose number of excavator and trucks types. For both - one as minimum and three as maximum. It is enabled to save inputs into file and load inputs. User can also change excavator and truck names. Clicking “Check Inputs” button provides control of input variables values. Wrong values are marked as red, acceptable as green.

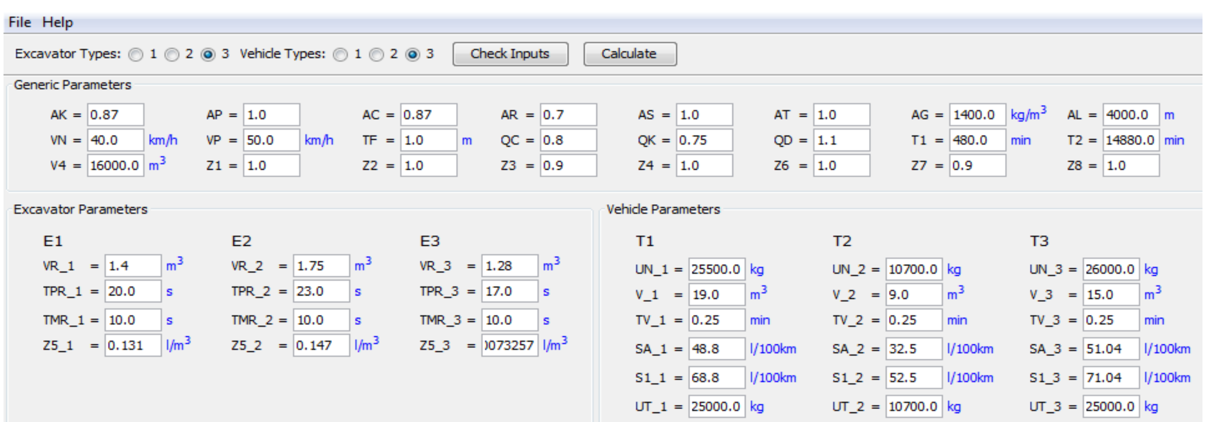


Figure 4.12 Input screen of Machine Selection software

Button called “Calculate” leads to result screen, which is divided into four sections:

1. Optimal Solutions(s),
2. Complete Work Time Table,
3. Complete Fuel Consumptions Table.

“Optimal Solution(s)” contains a list displaying all variants of excavator and trucks able to solve the task in desired time and volume of work. Best variant is marked as green. It is also possible, that task in desired volume with desired work time is not solvable with maximum number of vehicles 13. In this case, fuel consumption of variant is not calculated and this variant is marked as “out of range” error. This part of result screen is displayed on Figure 4.13. At this picture you can see, that from all variants (A ….I) , which fulfill criterion of work duration is the best variant G (CAT 225 + 4 pcs of IVECO TRAKKER AD 410T41 with min. consumption of fuel – 10 023,3 liter of Diesel. This is also result of all model example concerning the energy criterion.

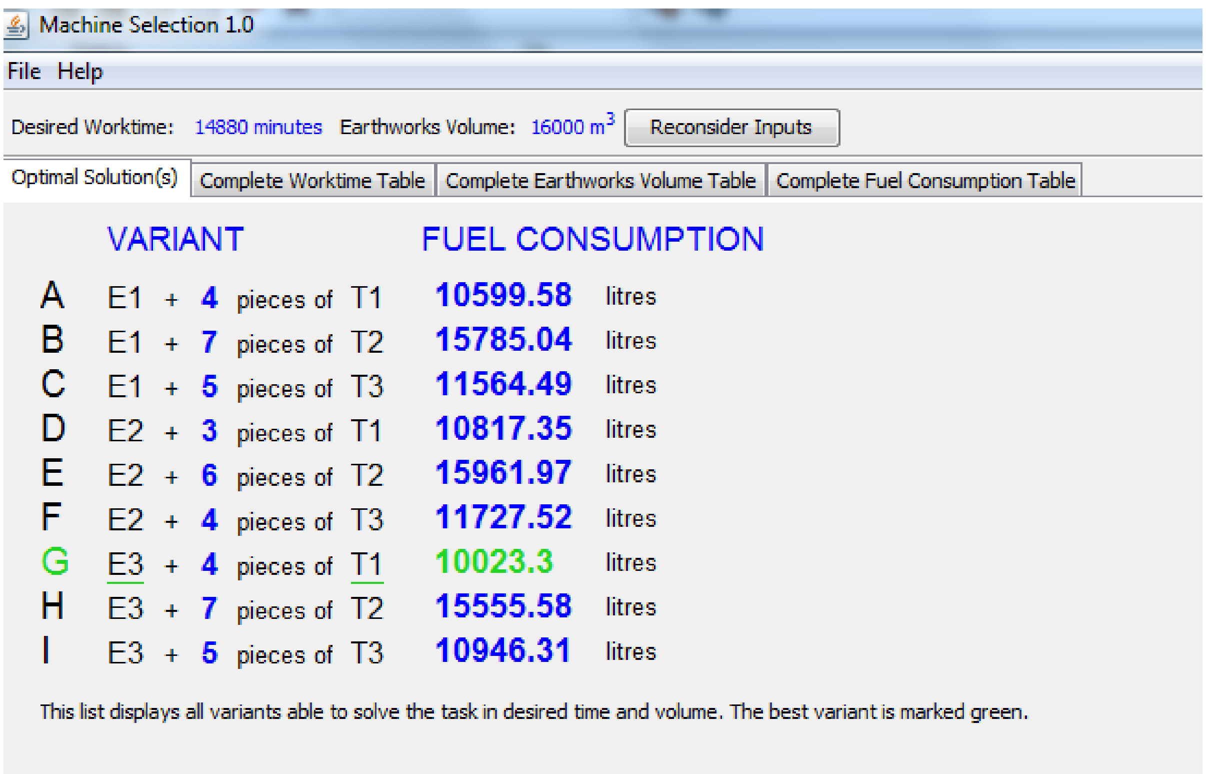
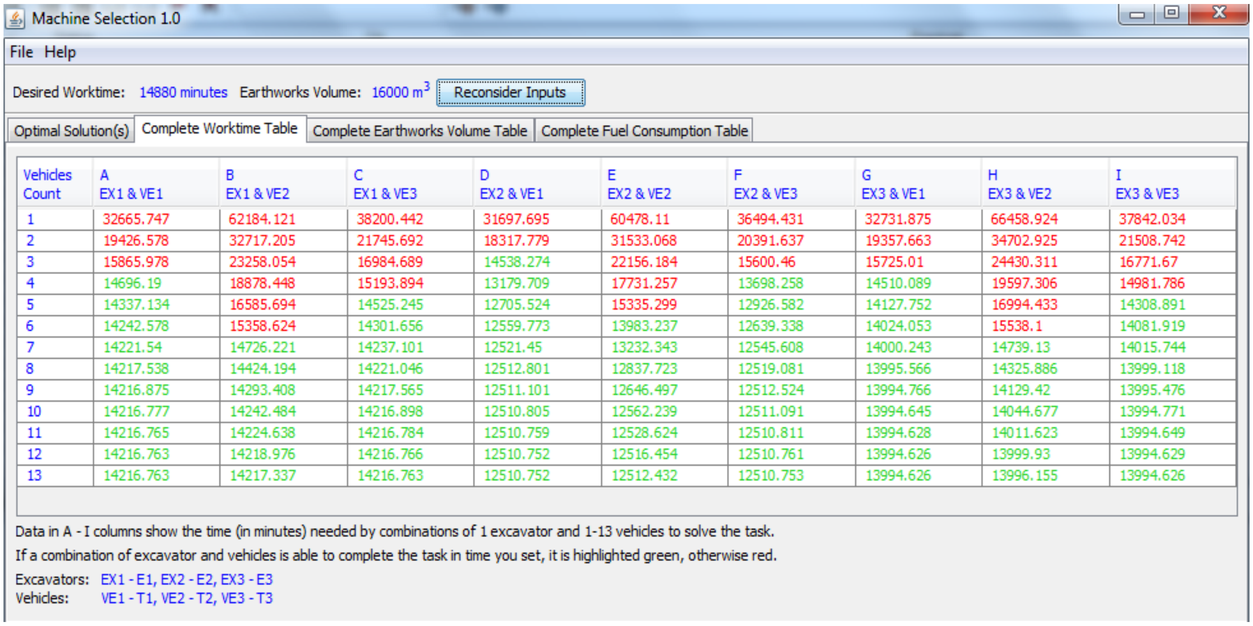


Figure 4.13 Result screen, Optimal Solution(s) section

“Complete Work Time Table” is a table created to display data for all combinations of excavator and truck types. Data show the time in minutes needed by combinations of 1 excavator and 1 to 13 vehicles to solve the task in desired volume. If a combination of excavator and vehicles is able to complete the task in time set by user, result time data is highlighted green, otherwise red. This part of result screen is displayed on figure 4.14.



Machine Selection 1.0

File Help

Desired Worktime: 14880 minutes Earthworks Volume: 16000 m^3 Reconsider Inputs

Optimal Solution(s) | Complete Worktime Table | Complete Earthworks Volume Table | Complete Fuel Consumption Table

Vehicles Count	A EX1 & VE1	B EX1 & VE2	C EX1 & VE3	D EX2 & VE1	E EX2 & VE2	F EX2 & VE3	G EX3 & VE1	H EX3 & VE2	I EX3 & VE3
1	32665.747	62184.121	38200.442	31697.695	60478.11	36494.431	32731.875	66458.924	37842.034
2	19426.578	32717.205	21745.692	18317.779	31533.068	20391.637	19357.663	34702.925	21508.742
3	15865.978	23258.054	16984.689	14538.274	22156.184	15600.46	15725.01	24430.311	16771.67
4	14696.19	18878.448	15193.894	13179.709	17731.257	13698.258	14510.089	19597.306	14981.786
5	14337.134	16585.694	14525.245	12705.524	15335.299	12926.582	14127.752	16994.433	14308.891
6	14242.578	15358.624	14301.656	12559.773	13983.237	12639.338	14024.053	15538.1	14081.919
7	14221.54	14726.221	14237.101	12521.45	13232.343	12545.608	14000.243	14739.13	14015.744
8	14217.538	14424.194	14221.046	12512.801	12837.723	12519.081	13995.566	14325.886	13999.118
9	14216.875	14293.408	14217.565	12511.101	12646.497	12512.524	13994.766	14129.42	13995.476
10	14216.777	14242.484	14216.898	12510.805	12562.239	12511.091	13994.645	14044.677	13994.771
11	14216.765	14224.638	14216.784	12510.759	12528.624	12510.811	13994.628	14011.623	13994.649
12	14216.763	14218.976	14216.766	12510.752	12516.454	12510.761	13994.626	13999.93	13994.629
13	14216.763	14217.337	14216.763	12510.752	12512.432	12510.753	13994.626	13996.155	13994.626

Data in A - I columns show the time (in minutes) needed by combinations of 1 excavator and 1-13 vehicles to solve the task.
If a combination of excavator and vehicles is able to complete the task in time you set, it is highlighted green, otherwise red.
Excavators: EX1 - E1, EX2 - E2, EX3 - E3
Vehicles: VE1 - T1, VE2 - T2, VE3 - T3

Figure 4. 14 Result screen, Complete Work Time Table section

Graphical interpretations of best variants (Excavator-Trucks) evaluation from the point of view - duration of process and total fuel consumption are in Figure 4.15-4.16. All this variants fulfilled required time 31 shifts.

5. Evaluation of total cost of best variants (Excavator-Trucks)

In this part it is necessary to define all input data which are needed for calculation of total costs (COST criterion). All inputs, mathematical variables and mathematical models for determining the costs for individual machine group (Excavator-Trucks) variants are by table form involved in my dissertation thesis. Evaluation of total costs of machine groups is graphically illustrated on in Figure 4.17.

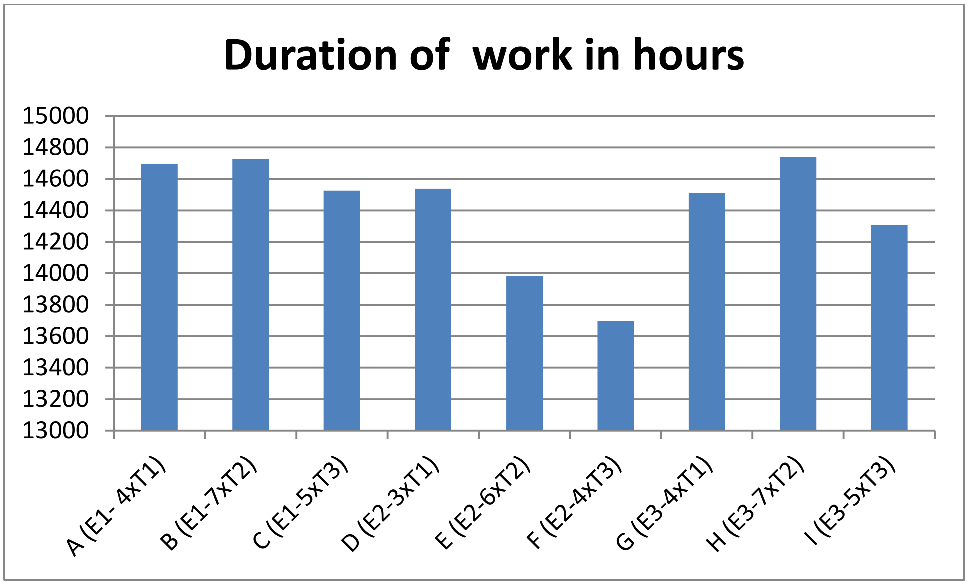


Figure 4.15 Evaluation of best variants (Excavator-Truck) from the point of duration of work (TIME CRITERION)

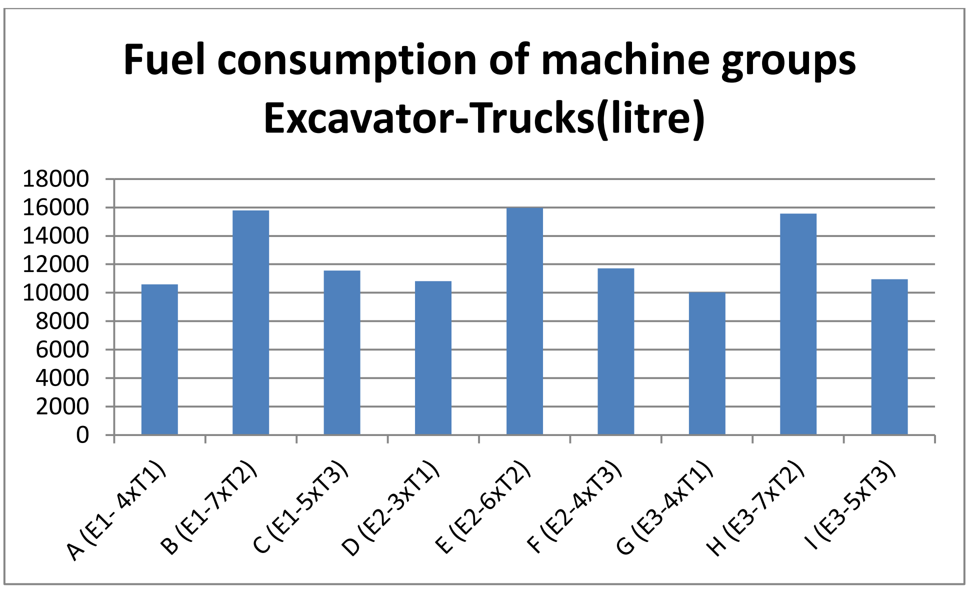
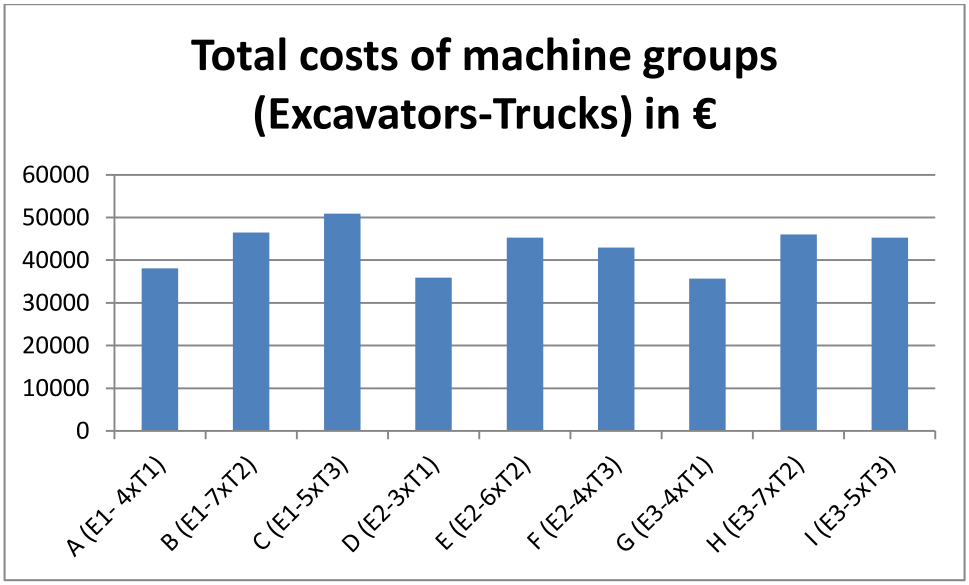


Figure 4.16 Evaluation of best variants (Excavator-Truck) from the point of fuel consumption minimum in liters (ENERGY CRITERION))



Machin groups (Excavator-Trucks) variants

Figure 4.17 Evaluation of machine groups (Excavator-Trucks) from the point of total cost of earthwork.

4.3 Multi-criteria optimization of mechanized earth processes

The principles of multi-criteria optimization are described in Chapter 3.9 of my dissertation thesis.. In my work I applied this method to all 3 model examples (dozers, scrapers and excavator-trucks). I used as optimality criteria: mechanized process duration (TIME criteria), fuel consumption of mechanized processes (ENERGY criteria) and total costs of mechanized processes (COST criteria). In table 4.2 are defined mathematical quantities and models to find optimal solution.

The calculation of the optimal solution is realized using software Machine Criteria Optimization developed within my research work at the Quality Management Centre in Construction (CEMAKS) at the Department of Building Technology (Faculty of Civil Engineering at the Slovak University of Technology in Bratislava). Machines Criteria Optimization is an application based on Javascript and HTML. Its purpose is to provide automatic calculation to compare machines work and to choose the best variant, based on the main criteria and the weight assigned for each criterion. User enters inputs for a maximum of nine machines or machine groups. Then he/she choose which machines to compare (minimum 2, maximum 9) and enters the weight for each

Table 4.2 Definition of mathematical quantities and models to find optimal solution

Multi criteria optimization

Machine (M), i=1,.... 10, i- number of machine variants

N.	Construction symbol	Software symbol	Mathematical variable	Unit of measure	Mathematical model	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
1.	T	T(i)	Total duration of the machine work	h											
2.	E	E(i)	Machine energy consumption	l (liters of diesel)											
3.	C	C(i)	Total cost of the machine work	€											
4.	TI	TI(i)	Time indicator	-	TI(i)= T(i)/SUM T(i) i=1...10										
5.	EI	E(i)	Energy Indicator	-	EI(i)= EI(i)/SUM EI(i) i=1...10										
6.	CI	C(i)	Cost Indicator		CI(i)= CI(i)/SUM CI(i) i=1...10										
7.	WT	WT	Weighting Factor of Time	-	Input (0-100)% the same for all variants										
8.	WE	WE	Weighting Factor of Energy	-	Input (0-100)% the same for all variants										
9.	WC	WC	Weighting Factor of Total Cost	-	Input (0-100)% the same for all variants										
10.	IMO(i)	IMO(i)	Indicator of multi optimizatiom	-	IMO(i)= (TI(i). WT + E(i). WE+ CI(i). WC).10^{-2} 10=(4.7+5.8+6.9). 10^{-2}										
11.	Best variant	BV			BV= min(IMO(i) i=1 ... 10 11= min(10)										

criterion. Calculated outputs will be shown in the main table. In this table also the optimal variant is clearly marked.

In Figure 4.18 are outputs of multi criteria optimization implemented into dozers, in Figure 4.19 into scrapers and in 4.20 into machine groups Excavator-Trucks. When the weighting factors change, new optimal solutions appear immediately.

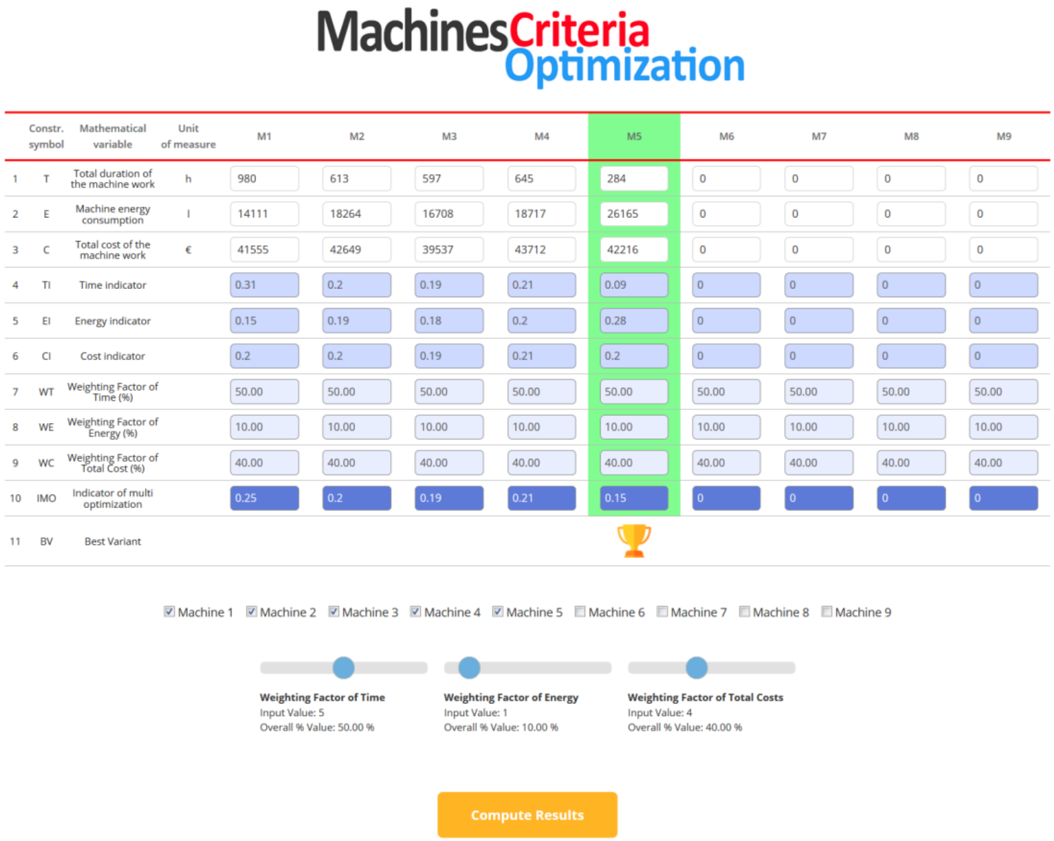
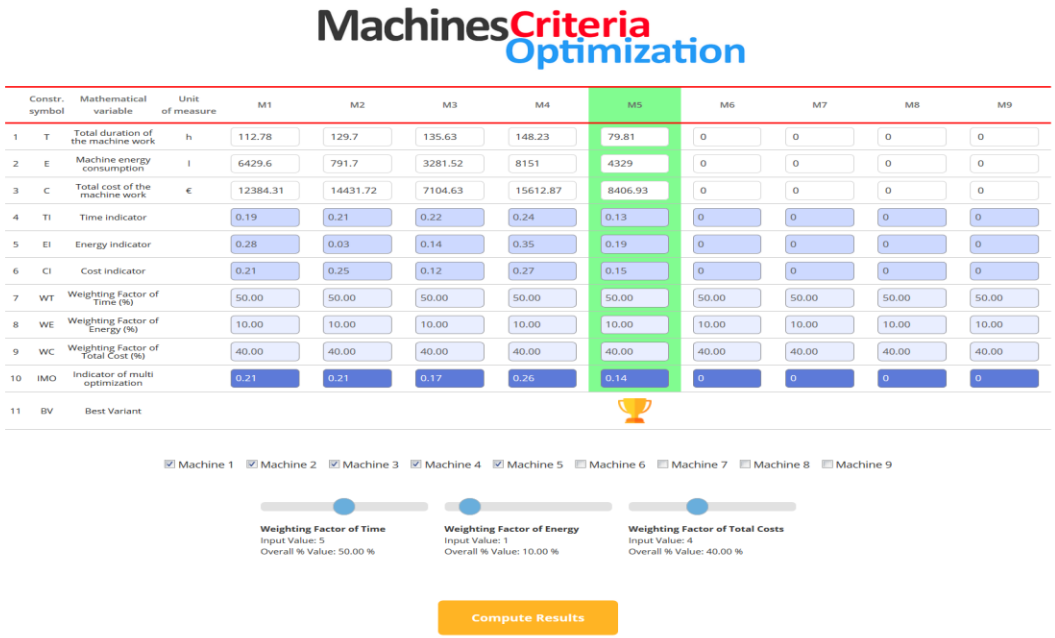
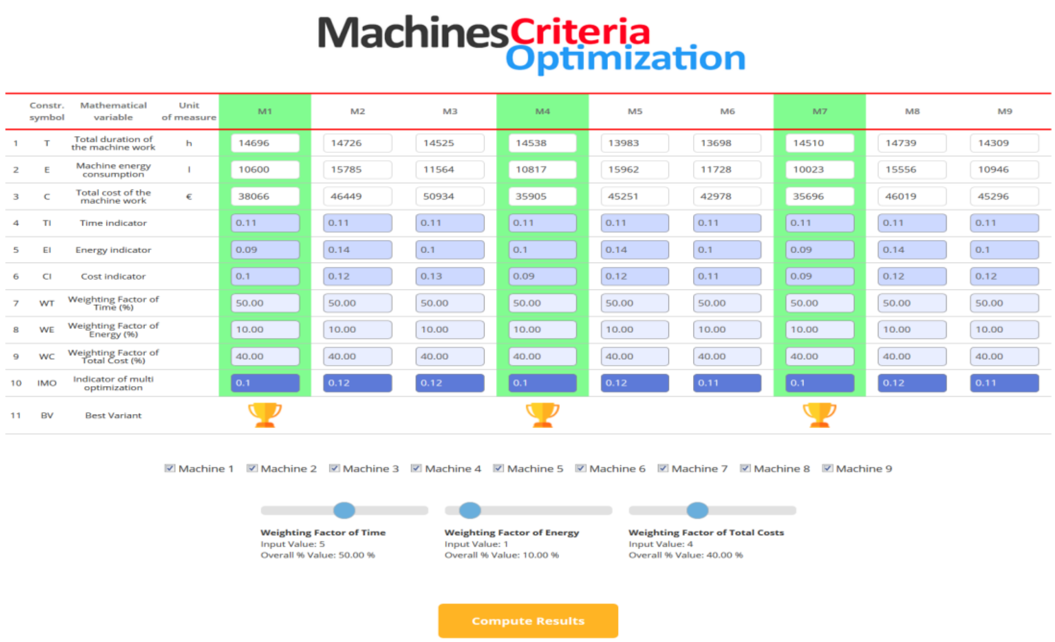


Figure 4.18 Outputs of multi criteria optimization implemented into dozers



	Constr. symbol	Mathematical variable	Unit of measure	M1	M2	M3	M4	M5	M6	M7	M8	M9
1	T	Total duration of the machine work	h	112.78	129.7	135.63	148.23	79.81	0	0	0	0
2	E	Machine energy consumption	l	6429.6	791.7	3281.52	8151	4329	0	0	0	0
3	C	Total cost of the machine work	€	12384.31	14431.72	7104.63	15612.87	8406.93	0	0	0	0
4	TI	Time indicator		0.19	0.21	0.22	0.24	0.13	0	0	0	0
5	EI	Energy indicator		0.28	0.03	0.14	0.35	0.19	0	0	0	0
6	CI	Cost indicator		0.21	0.25	0.12	0.27	0.15	0	0	0	0
7	WT	Weighting Factor of Time (%)		50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
8	WE	Weighting Factor of Energy (%)		10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
9	WC	Weighting Factor of Total Cost (%)		40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
10	IMO	Indicator of multi optimization		0.21	0.21	0.17	0.26	0.14	0	0	0	0
11	BV	Best Variant										

Figure 4.19 Outputs of multi criteria optimization implemented into scrapers



	Constr. symbol	Mathematical variable	Unit of measure	M1	M2	M3	M4	M5	M6	M7	M8	M9
1	T	Total duration of the machine work	h	14696	14726	14525	14538	13983	13698	14510	14739	14309
2	E	Machine energy consumption	l	10600	15785	11564	10817	15962	11728	10023	15556	10946
3	C	Total cost of the machine work	€	38066	46449	50934	35905	45251	42978	35696	46019	45296
4	TI	Time indicator		0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
5	EI	Energy indicator		0.09	0.14	0.1	0.1	0.14	0.1	0.09	0.14	0.1
6	CI	Cost indicator		0.1	0.12	0.13	0.09	0.12	0.11	0.09	0.12	0.12
7	WT	Weighting Factor of Time (%)		50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
8	WE	Weighting Factor of Energy (%)		10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
9	WC	Weighting Factor of Total Cost (%)		40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
10	IMO	Indicator of multi optimization		0.1	0.12	0.12	0.1	0.12	0.11	0.1	0.12	0.11
11	BV	Best Variant										

Figure 4.20 Outputs of multi criteria optimization implemented into machine groups Excavator-Trucks

5. The importance of dissertation work for science, pedagogy and practice

At this chapter are written effects of my research outputs into science, pedagogy in construction and construction practice.

5.1 The importance of dissertation work for science

I consider the following as my personal scientific contribution to the development of science in the field of construction:

- proposal of method of machine and machine groups selection for excavation including multi-criteria optimization system with software support,
- application and verification of this method into 3 kinds of excavation for main products of earth processes using dozers, scrapers and machine group excavator-trucks
- analysis of factors influencing technology and proposal of mechanized earth processes for excavation,
- definition of mathematical variables and models for calculation of outputs like: production rates, duration of process, fuel consumption and total cost for selected excavation,
- cooperation in a process of software creation and application for dozers, scrapers, excavator-trucks machine group and multi-criteria optimization of all these machines.

The optimal selection machine method for earthworks using an automated system of machine evaluation will also find effects in the BIM system (Building Information Modeling) application in the section time planning (4D), billing (5D) and technological procedures and quality (6D) My dissertation thesis was realized as a part of research project VEGA N. 1/0511/19.

5.2 The importance of dissertation work for pedagogy

The achieved results of my dissertation can be reflected in several subjects in the field of Construction, for example in the following subjects: technology of construction processes in civil engineering, realization of constructions, economics in construction, technological project for bachelors, technology project for graduates, bachelor thesis, thesis for 2nd and 3rd degree of study, research activities in the dissertation thesis.

5.3 The importance of dissertation work for practice

The results of the work can be of great importance for construction contractors in the process of construction preparation, who try to find the optimal selection of construction machinery in terms of minimizing time, fuel consumption and total costs in the implementation of earthworks. The software, which in the case of dozers and scrapers and in the case of multi-criteria optimization are original, will allow them to simulate various combinations of machines and in a short time to evaluate their effective deployment. In addition, they can vary the weighting factor for process duration, fuel consumption and total costs according to investor requirements. If, for example, time is the most important factor for the investor, then more weight is added for time, e.g. 70%. If another investor prefers low costs, the weighting factor for costs will increase and with the help of the software, the construction planner immediately has a new solution. Several organizations in Slovakia and abroad have shown interest in the results of the work, e.g. LECTURA company from Germany, which provides a database of construction machines and is interested in software designed in my dissertation. Several renting organizations for construction machinery are also interested in the results of my work. The biggest problem in carrying out the work was that many manufacturers of construction earthmoving machinery do not provide information on fuel consumption during working and transport modes, and it was also difficult to find information on the monthly rental of construction machinery. If construction machinery manufacturers were to provide this information in the technical data in the future, the importance of the work would increase even more.

Conclusion

Machine Selection Optimizing (MSO) method was during my research work implemented into earth processes and selected building group machines (dozers, scrapers and machine group-excavators and trucks), which are very often used in construction processes. In my thesis was presented the proposal of method of machine and machine groups selection for excavation including multi-criteria optimization system with software support, application and verification of this method into 3 kinds of excavation for main products of earth processes using dozers, scrapers and machine group excavator-trucks, analysis of factors influencing technology and proposal of mechanized earth processes for excavation, definition of mathematical variables and models for calculation of outputs like: production rates, duration of process, fuel consumption and total cost for selected excavation. Software for effective selection of dozers, scrapers and machine group excavator-truck were developed in Quality Management Centre in Construction (CEMAKS at the Department of Building Technology (Faculty of Civil Engineering at the Slovak University of Technology in Bratislava) according to my proposal of mathematical models and next important input dates.

Application of this method and software will increase the effectiveness of building machine selection from the point of key criteria of optimizing: time, energy consumption and total costs. The most important factor in MSO method is that it is able to eliminate energy and costly variants of the machines, during the design and preparation phase of construction. By using software it gives information about duration of work, energy and costs usage of machines when considering their use in the final product of the building process and gives the possibility to make fast decision for the choice of the optimal machine in a short time. The software, which in the case of dozers and scrapers and in the case of multi-criteria optimization are original, will allow to simulate various combinations of machines and in a short time to evaluate their effective deployment. In addition, construction planner can vary the weighting factor for process duration, fuel consumption and total costs according to investor requirements.

All the observed factors analyzing in thesis are influencing the duration of work, fuel consumption and costs. It is important to note that these factors cannot be ignored and disregarded. For a practical application of the proposed MSO method it is necessary to improve the quality of input data, especially consumption of fuel and rental system of machines. The volume of savings of the operating expenses possible to be obtained already in the preparation phase of construction process by this method are not negligible, vice versa, it shows the disclosure of reserves that are available in the choice of machines for building processes. This MSO method will find a full application only when these reservations will be removed.

The optimal selection machine method for earthworks using an automated system of machine evaluation will also find effects in the BIM system (Building Information Modeling) application in the section time planning (4D), billing (5D) and technological procedures and quality (6D) .This thesis was prepared as a part of scientific research project VEGA N. 1/0511/19.

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