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COMPUTER SIMULATION AS ONE OF THE TOOLS FOR MODELLING OF THE WORK CYCLE OF LOADING AND TRANSPORT OF THE RAW MATERIAL AT A QUARRY

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Abstract: The article deals with the modelling of the technological process at a quarry. The process modelling was carried out applying the simulation. The analysis of the operations performed within the technological process was used as the basis for the creation of the simulation model in the ExtendSim simulation software. The model simulation consisted of two parts. The first part represented the work cycle of a lorry – loading the lorry, a journey with the loaded material, emptying the load and a journey back to the loading station. The second part represented the work cycle of a loader that loads the material onto the lorry. The designed model was used to carry out several experiments. The article presents the results of two experiments. The simulation experiments were carried out for two different simulated times; the simulated time of 1 hour and the simulated time of 7.5 hours, representing 1 work shift. The results of the simulation comprised several parameters of time- and operation-related indicators. The presented simulation model is an appropriate accessory tool for the decision-making process when designing new systems or assessing the existing ones.

Keywords: *modelling, simulation, process, work cycle, loading, transport*

1. INTRODUCTION

Modelling is the process of replacing a dynamic system with a model thereof. The issues related to the modelling and model creation have been discussed by many au-

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thors in connection with various technological (Malindžáková at al. 2015), transporting (Akıncılar 2017), manipulation or economic processes (Sremac at al. 2018) while using various models – mathematical, graphical, simulation, heuristic, etc. Šaderová and Bindzár present the mathematical and graphical models of loading and unloading processes of mining output at a quarry (Šaderová, Bindzár 2014). Fedorko et al. present the simulation model for solving the urban traffic problems (Fedorko at al. 2014). Siderska presents the modelling of production and logistics processes by the computer simulation (Siderska 2016). Malindžák et al. present the basic principles and rules for the heuristic model creation in metallurgy (Malindžák et al. 2019). Coloured Petri nets were used for modelling a process of chemical production by authors Trebuňa et al. (2016). Janekova et al. present the possibility of using the Monte Carlo simulations when optimizing the production plan and in the project risk management (Janeková et al. 2018).

The above listed brief summary shows that modelling and models are applied in various forms and in multiple research areas.

The research discussed in this article is focused on the modelling of the work cycle of loading and transport of the raw material at a quarry facility using the lorries. This process represents a technological process that is typical for quarries and determines the smoothness of the operations performed using other technology units (e.g., a crushing line).

The modelling of the process was carried out using the computer simulation. The simulation is a research method based on replacing the examined dynamic system with a model thereof, a simulator, which is then used to perform experiments aimed at obtaining the information on the original examined status. The simulation is conducted out of the real objects, without affecting the real operations or without the existence of a real examined system. The result of the simulation comprises the information on the examined system and its components according to the defined parameters (Straka 2017). Several simulation tools are currently used for the computer simulation, such as Witness (Onofrejova et al. 2020), Technomatics Plan Simulation (Marasová et al. 2020; Siderska 2016), ExtendSim (Kazmierczak, Sawicka 2017; Kopytov and Muravjovs 2019) and others (Bardzinski at al 2019; Hashemi, Sattarvand 2014).

The main objective of this article is to describe the creation of a computer simulation model for the selected technological process in the ExtendSim8 simulation software. This simulation system combines the possibilities of the discrete and continuous simulations and is a widely used simulation tool for the computers with PC_MS Windows as well as Macintosh operating systems.

2. ANALYSIS OF THE TECHNOLOGICAL PROCESS

The application of the simulation and the creation of the simulation model of the technological process require a thorough analysis of the activities performed within the process. In this case, the subject of the analysis was the process of loading the material excavated by mining at a quarry using a shovel loader and the transport of the material by lorries.

The selected technological process at the quarry consisted of four main activities (Fig. 1): loading the material onto the lorry using the shovel loader (Loading), a journey of the loaded lorry from the loading station to the unloading station (Transport 1), unloading the material from the lorry (Unloading) and a journey of the empty lorry back to the loading station (Transport 2).

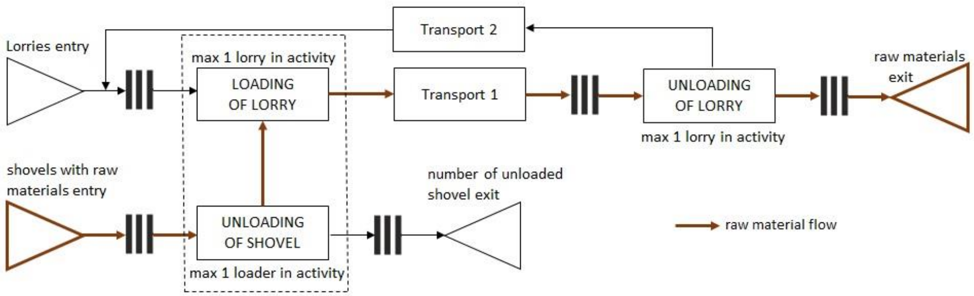


Fig. 1. Technological process at a quarry

The material is loaded using the loading equipment (a shovel loader) which loads the material onto the lorries. The main parameters that affect the efficiency of this activity include the size and capacity of the loader shovel (m^3, tones), the time of one work cycle of the loader (s) and the lorry capacity. The time of the loader work cycle affects the time of loading the quarry lorry. During this activity, certain loader-related delays may occur – the time of the loader waiting for a lorry, or the lorry-related delays – the time of the lorry waiting for the loading. Such delays affect the efficiency of the entire process. They are caused by an insufficient amount of lorries for particular operating conditions, insufficient capacity of the loader or insufficient capacity of the lorry. Therefore, this activity also depends on the parameter of the ratio of the volume (carrying capacity) of the lorry to the volume of the loading equipment (Šaderová, Ristovic 2018).

The transport of the raw material from the loading station to the unloading station is carried out using one of more lorries. The main parameters of this activity include the length of the transport journey and the travel time. The transport may be carried out using one or more routes. During this activity, certain transport delays may occur.

Unloading is an activity that comprises the unloading of the material from the lorry at the unloading station. The unloading is carried out after the lorry arrives to the unloading station and the bed is lifted. The unloading station may be, for example, a crusher feeder (the entry device of the line processing the material) or a material stock. The main parameter is the time of the lorry arrival and the time of emptying the lorry bed while and after it is lifted. During this activity, certain delays may occur when the lorry must wait for unloading because another lorry is currently being unloaded.

The empty lorry usually travels from the unloading station to the loading station along the same route as the transport of the loaded material.

The analyzed process was characterized by the following basic parameters (Marasová 2018):

1. Type of the raw material and its properties;
2. Loader parameters (shovel size and capacity, loader work cycle time which considerably depends on Parameter 1);
3. Parameters of the quarry lorry (carrying capacity and speed);
4. Ratio of the shovel volume (capacity) to the lorry bed volume;
5. Transportation route length; and
6. Number of quarry lorries.

3. DESIGN OF THE SIMULATION MODEL OF THE PROCESS

The simulation model of the selected process was created in the ExtendSim8 simulation environment by Imagine That, Inc. USA (Straka 2017). The simulation model is the model of the discrete simulation which was created using the blocks taken from the "Discreet Event" and "Plotter" libraries. Figure 2 shows the Print Screen of the created simulation model. The simulation model was created using the blocks which were connected with junctions determining the direction of the flows (the material flow and the flow of lorries). Each used block represented the part of the process or operation in the simulation model. The blocks had unique icons and names that expressed their basic functions within the model (Straka et al. 2018). The functions of the blocks used in the simulation model are listed in Table 1.

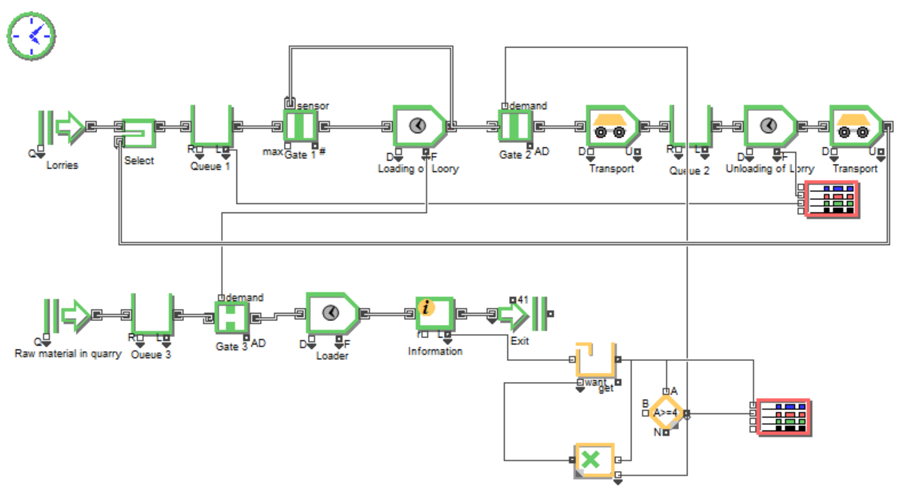
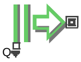
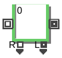
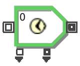
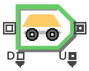
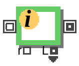
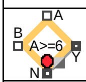
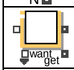


Fig. 2. Simulation model in ExtendSim

Table 1 Functions of the used blocks

	*Create* generates entries of requests. *Lorries Entry* generates the input units; in this case, it generated lorries. *Shovel Entry* generates the input unit requests; in this case, it generated loader shovels with the material and imitated the arrival of the material, with the loader shovel capacity.
	*Select In* splits the connection so that the returned empty lorries can pass the entire cycle.
	*Queue 1* represents a queue of the lorries waiting in a queue for loading. *Queue 2* represents a queue of the lorries waiting in a queue for unloading. *Queue 3* represents a queue of shovels filled with the material waiting in a queue for unloading.
	*Gate 1* ensures the request entry into the process at the moment when the previous request completes the "Activity" block; in this case, it stopped the lorry before loading while another lorry was being loaded. *Gate 2* checks whether the lorry has been fully loaded. If the lorry is not yet full, the "Gate 2" block will not allow the next operation (Transport). If the lorry is fully loaded, the "Gate 2" block will let the lorry exit the loading activity. The "Gate 2" obtains the information on the fully loaded lorry via the "Decision" block provided that the lorry received at least "A" portions of loading shovels, representing a release of one fully loaded lorry for the next activity. *Gate 3* checks whether an empty lorry is available. If such lorry is available, the "Gate 3" block will allow unloading the next shovel of the materials onto the lorry. If the lorry is not available, the "Gate 3" block will not allow unloading the next shovel.
	*Activity:* *Lorry Loading* represents loading the lorry while no other lorry can be loaded at the same time. *Lorry Unloading* represents unloading the material from the lorry while no other lorry can be unloaded at the same time. *Shovel Unloading* represents unloading the material from the loader shovel onto the lorry; this represents one work cycle of the loader.
	*Transport:* The block represents the travel of the multi-channel servicing equipment. *Transport 1* is the journey from the loading station to the unloading station. *Transport 2* is the journey from the unloading station back to the loading station. Any number of lorries may travel at the same time.
	*Information* provides the information whether the required number "A" of shovels has been loaded with the material to fill up one lorry and sends such information to the Holding Tank block. This provides the information on how many shovels of material have been loaded onto the lorry.
	*Decision* compares the number of work cycles of the loader (emptied shovels) with the "A" value that represents the number of shovels with the material required to fill up one lorry.
	*Holding Tank* counts the cycle of loading one shovel of the material onto the lorry via the Information block.
	*Math* performs the selected mathematical operation at the entries and the result is at the exit.

	*Exit* represents the exit of requests, how many work cycles the loader have performed, how many shovels have been emptied onto the lorry.
	*Discrete Event* block uses the input data to plot the simulation graphs and puts the values of the monitored inputs in the table.

The simulation model consisted of two parts. The first part represented the work cycle of the lorry – loading, a journey with the material, unloading the material and a journey back to the loading station. The second part represented the work cycle of the loader which was loading the material onto the lorries.

The inputs for the simulation model must be determined using, for example, the technical documentation, calculations or measurements carried out directly in the operation.

The results of the simulation include the following parameters: the number of loaded lorries, the number of unloaded shovels, the loader capacity utilization, the number of lorries waiting for loading, the number of lorries waiting for unloading, etc.

4. RESULTS AND DISCUSSION

The designed model was used in several experiments. Entering the values in the blocks and settings of the simulation model were carried out applying the method described in paper (Straka 2018).

This article presents the results of the simulation of loading and transport of the raw material for the input values listed in Table 2.

Table 2. Functions of the used blocks

Parameter	Value	
	Experiment 1	Experiment 2
Time of the loader work cycle [min]	1.2	1.2
Number of loader shovels required to fill up one lorry	4	5
Time of the lorry travel to the unloading station [min]	10	10
Time of unloading the lorry [min]	5	5
Time of the lorry travel back to the loading station [min]	10	10
Number of used lorries [min]	2, 3, 4	2, 3, 4

Experiment 1 represented the simulation of loading the material onto the lorries; in order to fill up one lorry, the loader had to make 4 work cycles. The value set in the Decision block was 4.

Experiment 1A simulated the process of 2 lorries engaged in the transport. During the simulated time of 60 minutes, the loader made 16 work cycles, filled up 4 lorries and the time utilization was 33%. 67% of the simulated time represented the loader idle times when the loader was not loading the material, but waiting for the lorry.

Experiment 1B simulated the process of 3 lorries engaged in the transport. During the simulated time of 60 minutes, the loader made 24 work cycles, filled up 6 lorries and the time utilization was 49%. The idle times of the loader represented 51% of the simulated time.

Experiment 1C simulated the process of 4 lorries engaged in the transport. During the simulated time of 60 minutes, the loader made 32 work cycles, filled up 8 lorries, as shown in Fig. 3, and the time utilization was 65%. The idle times of the loader represented 35% of the simulated time.

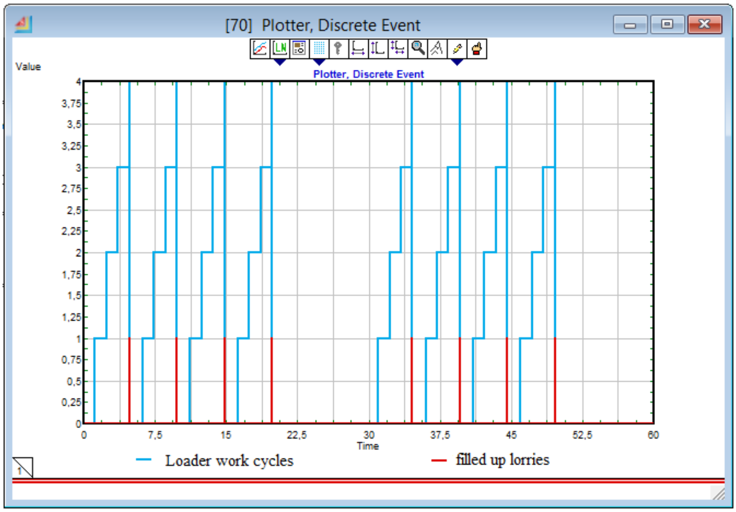


Fig. 3. Loading the lorries by the loader in EXP 1C

Experiment 2 simulated loading the material onto the lorries, but in this case the loader had to make 5 work cycles to fill up one lorry. The value set in the Decision block was 5. Experiment 2 was carried out for alternatives A (2 lorries), B (3 lorries) and C (4 lorries). The results of the simulations were similar to those obtained in Experiment 1.

Experiment 2A simulated the process of 2 lorries engaged in the transport. During the simulated time of 60 minutes, the loader made 20 work cycles, filled up 4 lorries and the time utilization was 40%. 60% of the simulated time represented the loader idle times when the loader was not loading the material, but waiting for the lorry.

Experiment 2B simulated the process of 3 lorries engaged in the transport. During the simulated time of 60 minutes, the loader made 30 work cycles, filled up 6 lorries and the time utilization was 60%. The idle times of the loader represented 40% of the simulated time.

Experiment 2C simulated the process of 4 lorries engaged in the transport. During the simulated time of 60 minutes, the loader made 40 work cycles, filled up 8 lorries, as shown in Fig. 3, and the time utilization was 80%. The idle times of the loader represented 20% of the simulated time.

In the experiments described above, the simulation was also carried out for the simulated time of 7.5 hours, representing 1 work shift. The results obtained from the simulation are summarized in Table 3. If the weight of the material in one shovel is 2.8 tones, the results of the simulation may be used to identify the quantity of the loaded material *Q* (t).

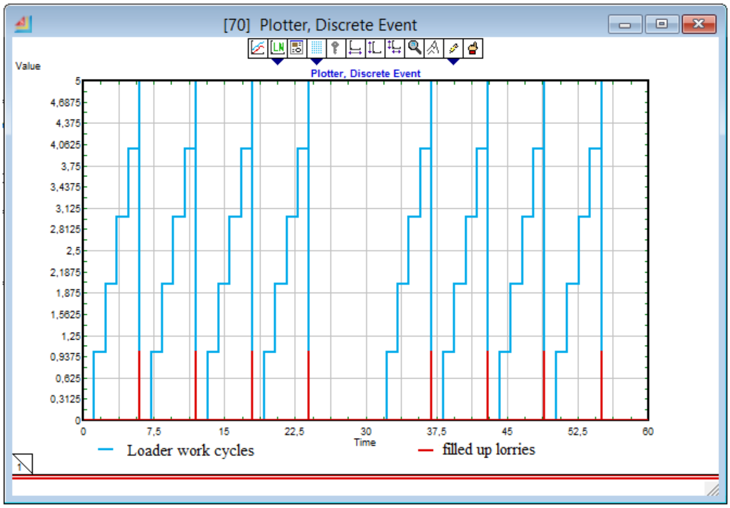


Fig. 4. Loading the lorries by the loader in EXP 2C

As indicated by Table 3, in Experiment 1, one lorry made 15 cycles in each alternative and each loaded lorry unloaded the material at the unloading station. This statement, however, does not apply to the alternatives of Experiment 2, because the numbers of loaded and unloaded lorries were different. This was caused by the fact that at the moment of the simulation completion the lorry was heading to the unloading station.

Table 3. Simulation results for the simulated time of 7.5 hours (one work shift)

	EXP 1A	EXP 1B	EXP 1C	EXP 2A	EXP 2B	EXP 2C
Number of loader cycles	122	182	242	150	223	293
Loader capacity utilisation (%)	33	49	65	40	60	78
Number of loaded lorries	30	45	60	30	44	58
Number of unloaded lorries	30	45	60	29	43	57
Q (tones)	341.6	509.6	677.6	420	624.4	820.4

The model described above may be used as an accessory tool within the decision-making regarding the issues such as:

– How many lorries of a particular carrying capacity must be engaged in the operation in order to fulfil the daily capacity required for the processing plant?
– How the number of engaged lorries changes with different lengths of the material transportation route etc.?
– What type of lorry to choose in terms of the carrying capacity?

The model described above may be used for the simulation of the designed system when choosing an appropriate loader-lorry combination. These experiments may be carried out for various types of loaders and lorries.

The model may also be used to verify the current situation at a facility in order to identify an insufficient width of the working space, idle times of the equipment, identify the limits of the existing systems, etc.

5. CONCLUSION

The article presents the analysis of the process of loading and transport of the material at a quarry and the basic operations in the process – loading, transport of the material, unloading the material and the lorry travel back to the loading station. The results of the analysis were then used to create a simulation model of the technological process in the selected simulation language, including the description of the characteristics of individual blocks. The simulation model was used in the experiments carried out with the operating conditions which are present in real facilities. The input data for the model included the number of lorries (2, 3, 4) and the loader, the number of work cycles required for the loader in order to fill up one lorry, the times of individual activities: the time of one work cycle of the loader, the time of the transport of the material, the time of unloading the material and the time of the lorry travel back to the loading station. The results of the experiments included the following parameters: the number of the work cycles of the loader representing the number of loader shovels emptied onto the lorries, the number of filled up lorries, the number of unloading operations and the time utilization of the loader.

The simulation model is an appropriate accessory tool for the decision-making process when designing new systems or assessing the existing ones.

The model may also be applied to other (similar) technological processes, not exclusively at quarries, or to a part of the company system. The model may also be supplemented with other activities, or it may also represent other activities which should be subjected to the investigation in future.

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