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SIMULATION OF HOMOGENEOUS PRODUCTION PROCESSES

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Abstract
This paper is focused on streamlining the activity of the homogeneous production processes which form the production logistics of a particular extraction operation. The efficient extraction of millions of tonnes of raw materials presents a requirement for the correct use of the means of transport, machinery and equipment involved in the extraction of raw materials, with an economic, social, technical and ecological impact. The extraction operation studied is performed in a quarry for the extraction of limestone, which is used as input material for the production of various types of building materials. The extracted raw material gradually passes through the chain of extraction – loading – transport – unloading – crushing to the actual processing in the building materials plant. The results of the solution show that the maximum effective use of the operation of the defined system can be achieved with 27 means of transport and 4 loaders, while the utilization of workplaces in extraction operation workplaces is close to 100 % during the defined time of operation.
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Key Words: Homogeneous Production Processes, Manufacturing Logistics, Streamlining the Mining Industry, Simulation, ExtendSim, System

1. INTRODUCTION

The mining industry has a special position among industries. Its activities provide raw materials for other industrial sectors and it is therefore found at the very beginning of the chain of industries. The raw material extraction industry primarily serves as a supportive type of industry for other downstream industries. Mining and extraction processes are classed as homogeneous production processes.

Homogeneous production processes have a number of peculiarities that make it possible to characterize them as a peculiar class of management objects. Homogeneous production processes are typical for the production processes of mining operations in the extraction and preparing of raw materials, metallurgical production, production of construction materials, petrochemicals, etc. Non-homogeneous production processes, where the output is a wide range of products, are typical of engineering production and electrotechnical production. The characteristics of homogeneous production processes can be defined as follows [1]:

1. The output is one product or a narrow assortment of products such as metal sheets, oils, coal of varying quality.
2. Aggregates and equipment provide great power and productivity in production; they mostly operate continuously and downtime is not possible.
3. A system of homogeneous production processes requires high construction costs. To build a blast furnace, a sheet metal rolling mill, or to open a mine requires a large investment cost.
4. Homogeneous production processes are processes with a variable structure, the system is made up of a skeleton through which the flow of products and materials moves, forming connections.

5. Homogeneous production processes take place with continuous and discrete pieces of equipment. Equipment that performs individual production operations can operate in a continuous or discrete manner.
6. The material flow of homogeneous production processes varies from continuous to discrete or discrete to continuous.
7. Homogeneous production processes have a typical tree structure.
8. If, in the case of homogeneous production processes, the product does not correspond to the intended parameters, it is not in fact scrap, it can be sold in a different quality class, dimensions, etc.

The characteristics of homogeneous production processes complicate their modelling, simulation and management. From the point of view of computer simulation, one of the appropriate solutions for modelling and simulation of homogeneous production processes is their transformation into processes discretely. The problem described, examined and addressed in the contribution in question is related to the continuous streamlining of the activity of a particular mining operation. The aim of this paper is to highlight the new possibilities of using the ExtendSim simulation system for the needs of modelling and simulation of the homogeneous production processes of a particular mining operation, finding bottlenecks in the defined operation and pointing out the possibilities for setting up the system of homogeneous production processes efficiently while observing safety, operational and economic parameters and limitations.

2. LITERATURE REVIEW

The area of using computer simulation for the needs of streamlining the logistics of mining operations and providing solutions has been examined by experts and scientists all over the world. In professional journals, we meet with various designs of models and research that shows us the importance of simulation models for mining processes, optimization of transport for extraction of mineral resources, and also the impact of mining on the environment or economy, and many of them also offer solutions for practice [2].

According to the work of Kesek et al. [3] we can reasonably argue that by performing simulations and creating virtual models, it is possible to increase the efficiency of the processes analysed while minimising the costs of production, logistics and storage. In addition, simulation models enable the analysis of scenarios under different solutions and thereby enable us to make relevant decisions on the basis of the results obtained. They therefore become the basis for analysing various technological and procedural changes. Simulation and modelling tools are increasingly being used in extractive industries. The model of optimization of a production complex for planning the flow of quarry mining was designed by Straka et al. [4], while facilitating the planning and management of operations in the extraction, crushing and transformation of aggregates in the construction sector, taking into account the resources and constraints that make it possible to define effective strategies for the extraction plan.

The digital mine is likened by the authors Lin et al. [5] to the “logistical supply chain”, the basic characteristic of which is a high-speed network with broadband and a two-way communication system, which is used as a “road map” to ensure the rapid delivery of all data to all the relevant enterprises in the country. Checinski and Witt examine the application of 3D simulation analysis to modelling production processes in surface mining [6]. Among the problems they focus on are the possibilities of creating a representation of mining elements in a three-dimensional environment, and also a description of the impact of the spatial characteristics of surface mines in simulation processes.

Research by Shah and Ur Rehman [7] consists of modelling and optimization, which not only point to significant cost reductions, but also help to achieve better coordination in the quarry. Using a simulation and optimization approach for short-term planning in mines, experts Upadhyay and Askari-Nasab [8] point out the complexity of open quarry mining operations. Bascetin et al. also discuss optimizing the quarry through programming. [9], based on the fact that the aggregates extracted are not always homogeneous and therefore optimization was carried out using linear programming in order to mix aggregates of different qualities. Zarubin et al. [10] analyse possibilities to improve the efficiency of the functioning of mining enterprises and to develop a software module to solve problems in the design and operational management of mining activities. Straka and Hricko [11] designed a practically applicable software system for determining the efficient arrangement of material for production and logistics needs. A simulation model focused on distribution in operations where a narrow location (critical node) is created in providing optimal service levels in the supply chain network is brought by Urzúa et al., Kot et al. and Nguyen et al. [12-14].

Saderova and Bindzar [15] worked on the creation of a matrix model to approach the loading and unloading process of quarry mining, where they took into account that the fulfilment of daily capacity depends on specific mining conditions, quantity of material, performance of loading and transport equipment, transport distance, work organization, duration of change and other factors. Assad [16] proposed a heuristic approach to planning long-term production in quarries. The aim of the quarry planning model was to design the extraction of core raw material blocks in such an order that the requirements be met for quantity and quality in subsequent production in the cement plant. The publication by Janic et al. is also focused on streamlining mining activities in an operation [17], and the main benefit of that article is the design of a mining planning model in the MATLAB/Simulink environment. Blistan et al. [18] focused on the application of selected geodetic methods in an opencast quarry using their 3D model of the quarry at Sedlice. Martinelli et al presented a mixed integer programming model to address the problem of long-term planning of extraction at a mine [19].

Mohtasham et al. [20], carried out an interesting case study relating to mining transport aimed at optimising the distribution of trucks in order to increase productivity and reduce costs at the Sungun copper mine. Souza et al. [21] propose a hybrid heuristic algorithm for dynamic deployment of mining equipment in open quarries. The objective is to optimise mineral extraction in the mines by minimizing the number of mining trucks used to meet production goals and quality requirements. The aim of their study is the development of a mixed integer programming model for scheduling production at iron-ore mines.

Okolnishnikov et al. [22] propose simulation models that have been developed for use as a quality and reliability assurance tool for new process management systems in coal mining. Deb and Islavath [23] consider time and motion aspects in a model that improves the efficiency of dumpers and a shovel deployed at a shallow depth mine. Savenko and Lisenko [24] also developed another dynamic mathematical model for the complex of mining and transport work that provides a solution for several optimization tasks for operational management in a mine. Computer modelling and design tools can assist in environmental management, as researched by Hancock et al. in their article [25]. Kim and Choi [26] worked with a modelling program to analyse and visualize groundwater recovery in abandoned mines to prevent water and soil contamination from draining acid mines. Samanta and Samaddar [27] created an innovative document based on computer programming with realistic data on environmental burdens related to mining activity. A large-scale study, evaluating the mining strategy at Camargo et al. [28] propose an integrated process simulation method that takes into account the dynamic, stochastic and systemic characteristics of mining operations to support investment decisions in the sector. The main challenge in evaluating a mining project is how to address the uncertainty associated with capital investments, said Pastor et al. [29]. A study by Akkoyun [30] also draws attention to the fact that simulation programmes can be used to make decisions about potential investments in natural stone deposits.

3. METHODOLOGY

The homogeneous production processes in the particular mining operation examined form the logistics of production, in which not only the sequence of processes but also the planning of activities on individual mines is important. The sequence of activities on five faces must be planned in such a way that the operations at individual faces are not endangered during the time of preparation and implementation of the raw material blasts. The overall operating system of the mining operation studied is shown in Fig. 1.

The mining operation examined consists of five P1-P5 faces on which there are places for drilling and blasting raw material, and loading prepared raw material onto trucks after blasting. Another separate workplace is the crusher for extracted raw material, which crushes the raw material into smaller fractions, which move on a conveyor belt to the site for the production of building materials. In terms of a comprehensive description of the activities of the mining operation examined, it is necessary to emphasize that the transport of material between the individual faces and the crusher requires time and in terms of computer simulation it can be modelled as a discrete activity [31].

The activity of the studied mining operation begins and ends in the parking lot, where heavy trucks, 5 of them, gradually move within 30 seconds to the faces where the extracted material is prepared. The sequence of activities on individual faces progresses in a cycle in order that drilling into the wall of the material for extraction and blasting of the material be safe for other activities such as loading, transport and unloading of raw material. For the safe loading, transport and unloading of raw materials, working days on individual faces follow a cycle: on the first working day – face P1, second working day – face P3, third working day – face P5, fourth working day – face P2 and fifth working day – face P4. The activity is repeated over time. If necessary, there may also be changes in the progress of the operation on the faces, but for the purposes of simulation we will stick to a defined schedule and progress of work (see Table I.).

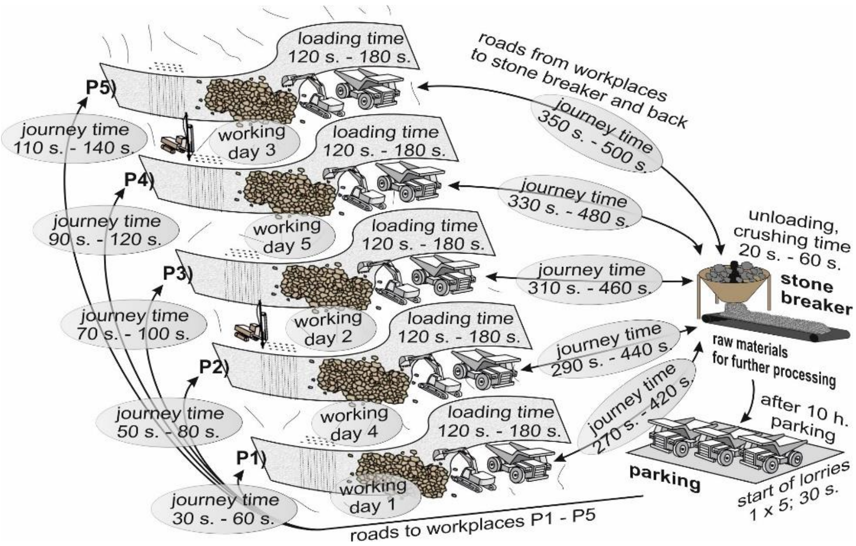

Figure 1: Activity, processes and parameters of the specific mining operation studied.

Within the framework of the examined production system, the main aim is to identify bottlenecks, to explore possibilities of streamlining the production logistics of the particular operation with homogeneous production processes, to design more efficient activity for the needs of increasing the processing of extracted raw material, with the maximum effective use of the available time and work resources. From the description it is possible to define the research problem and the goal for solving the task. The problem is related to continuous streamlining of the activity of a particular mining operation. The aim of this paper is to highlight the possibilities for using the ExtendSim simulation system for the needs of modelling and simulation of the homogeneous production processes of a particular mining operation, finding bottlenecks in the specified operation and pointing out the possibilities for efficiently defining the system of homogeneous production processes while observing safety, operational and economic parameters and limitations.

Table I: Timeline of works on individual faces.

Working day	Mining	Transportation parking - face (s)	Loading (s)	Transportation face - crusher = crusher - face (s)	Unloading (s)
1	Face P1	30 - 60	120 - 180	270 - 420	20 - 60
2	Face P3	70 - 100	120 - 180	310 - 460	20 - 60
3	Face P5	110 - 140	120 - 180	350 - 500	20 - 60
4	Face P2	50 - 80	120 - 180	290 - 440	20 - 60
5	Face P4	90 - 120	120 - 180	330 - 480	20 - 60

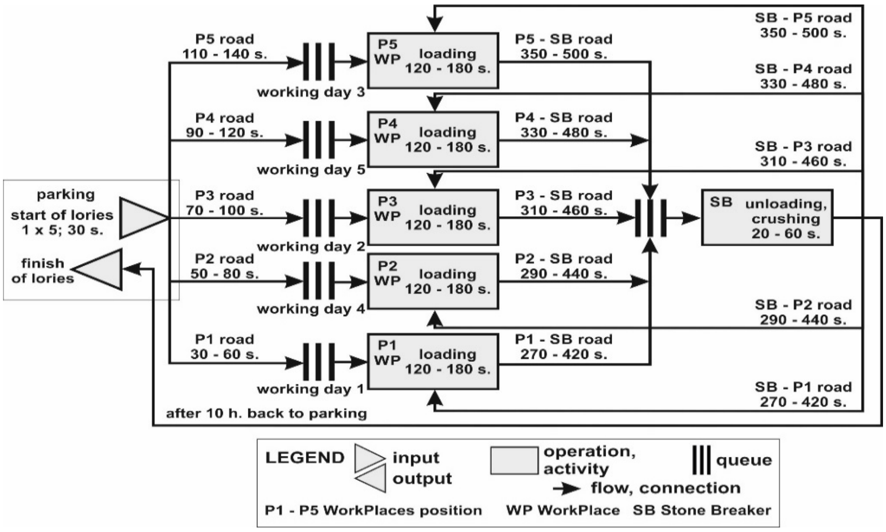

Figure 2: Formalized schema of the production logistics of the mining operation studied.

Since the means of transport perform transport from individual faces based on the timetable, the transport time they need on a given working day also varies. The further the face is from the parking lot, the more time is needed for transportation. The same applies to transfer of extracted raw material from the faces to the crushing station (see Table I). In the operation studied, one loader is available for loading, which moves between the faces in accordance with the plan of work on the faces. Loading one truck using the loader takes the same 120 to 180 seconds on each face. After loading, the means of transport moves to the raw material crusher. The time for transport depends on the position on what loading, and transport of the extracted raw material takes place on the given working day (see Table I). For crushing, the mine operation uses one crusher, and unloading one vehicle and crushing the raw material takes from 20 to 60 seconds. The crushed material is moved on a belt conveyor for further preparation at the site. We will not examine that activity in this paper. After unloading, the means of transport are moved again to the face where loading is taking place. The activity is repeated for the entire work shift, in this case 10 hours. After working hours, the means of transport is moved again to the parking lot, from which work starts again the following day.

From the above it is possible to assemble an exact formalized schema (see Fig. 2), which forms the basis for the creation of a simulation model for any simulation system, in our case ExtendSim. A formalized schema can be understood as the Esperanto of computer simulation. From a formalized schema, the programmer can create a specific computer simulation model in any simulation system.

Creating a computer simulation model in ExtendSim consists of two stages. The first part consists of a block schema of the given simulation system (see Fig. 3) and the second part is creating a computer simulation model for the purpose of conducting research into production logistics for the homogeneous production processes of a particular mining operation (see Fig. 4).

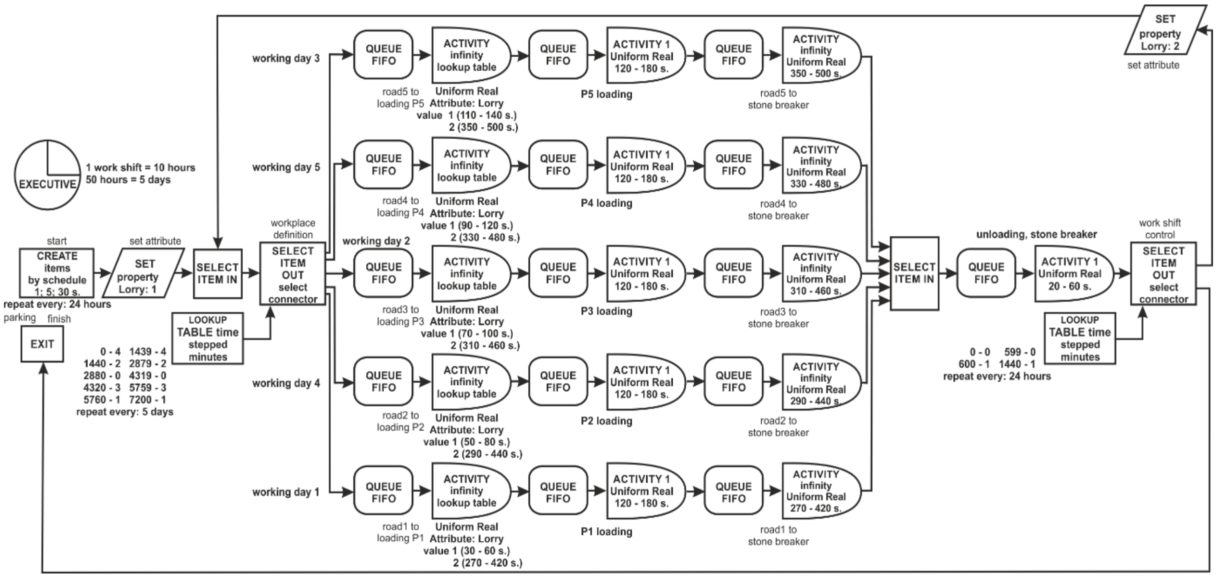

Figure 3: Block schema of the production logistics of the mining operation studied.

The different parts of the computer simulation model are characterized by a sequence of blocks that are connected using connectors that uniquely determine the route of flows. The basic characteristics of individual blocks of the model are defined by the position, icon and name of the blocks, block connectors, connectors, dialogues with operands and flows [31].

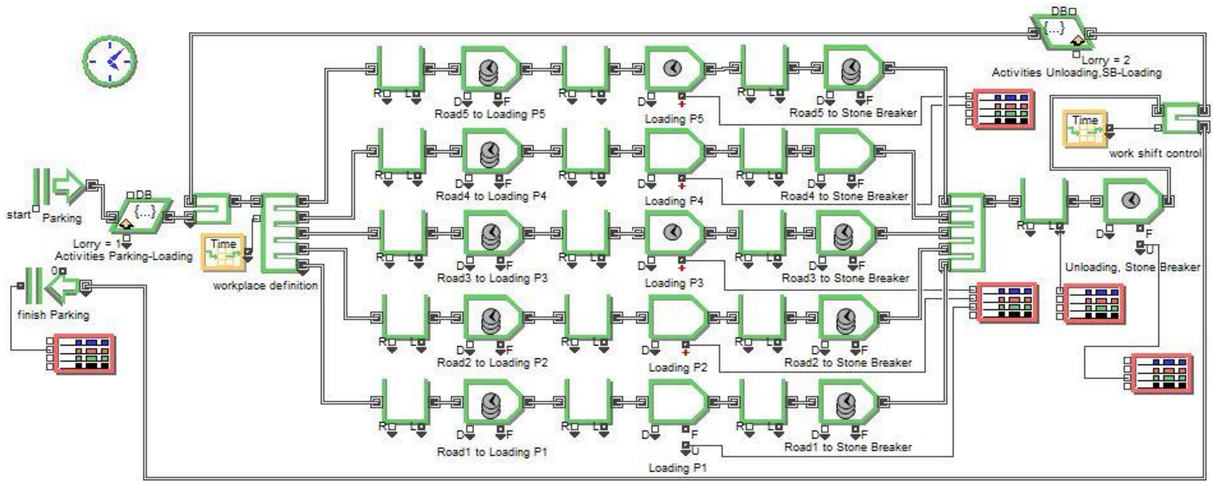

Figure 4: Computer simulation model of the production logistics of the mining operation studied using the ExtendSim simulation system.

As regards setting up the computer simulation model in ExtendSim, the dynamic element is the means of transport, the mining tipper, without which it is not possible to move the extracted raw material. The capacity of the mining tipper is several tens of tons of raw material; the number of transports carried out will indicate the amount of raw material transported. In the computer simulation model, the entry of the means of transport from the parking lot to the workplace is performed by the "*Create*" block. The "*Create*" block is set up using the parameter "*Create items by schedule*" and every 30 seconds the block releases, into the system, one dynamic element, one request, one means of transport. Under current conditions, 5 means of transport are placed in the system. The input generation status is repeated every 24 hours (see Fig. 5 "*Create*").

This is followed by the transfer of the means of transport to the P1-P5 face depending on the working day. In the system under examination for a given working day, the means of transport perform transport only from that place during the whole working shift.

The transfer of the means of transport from the parking lot to the place of loading is defined by the duration of the transfer, which depends on the working day. The journey times are shown in Table I. The principle of modelling the journey as a service device is described in more detail by the authors in [31]. In our case, a model with a multichannel service device was used, which represents the connection of "Queue - Activity" blocks with setting the value for request processing to "Infinity" (see Fig. 5 "*Activity*").

In order to identify, in the created computer model, whether the means of transport starts from the parking lot or is on a circuit between the face and the crusher, it carries a label in the attribute variable, the value of either 1 – start from the parking lot, or 2 – circuit between the face and the crusher (see Fig. 5 "*Activity*"). Depending on the value of the processed request, the system generates the length of delay time accordingly, representing the delay time of the means of transport on the road. When moving from the parking lot, the value of attribute 1 generates delay values on the road in the range of 30-140 seconds (see Table I) and when moving from the face to the crusher, attribute value 2, generates delay values on the road in the range of 270-500 seconds (see Table I). The transfer of the means of transport is followed by loading onto the means of transport or unloading and crushing the raw material. Both activities are represented in the simulation model by a pair of blocks: "Queue - Activity". The loading time of the extracted raw material per means of transport is the same at each workplace with a delay of 120-180 seconds. Loading is followed by transfer of the means of transport to the crusher, which in the simulation model is modelled the same way as the transfer of the means of transport from the parking lot. The unloading and crushing time of the extracted raw material from one means of transport is the same with a delay of 20-60 seconds. The unloaded means of transport is moved back to the face for loading additional raw material. The action is repeated for 10 hours. After 10 hours, the means of transport is moved again to the parking lot, which in the simulation model is represented by the "Exit" block.

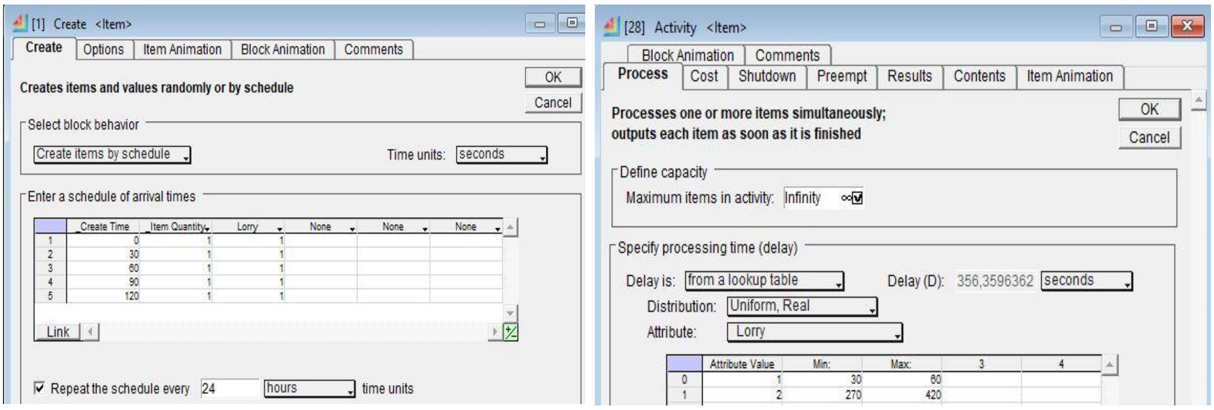

Figure 5: Setup of the *"Create"* block representing the parking lot for means of transport and setting the *"Activity"* block representing the journey of the means of transport.

From the point of view of the interesting creation of the computer simulation model, a separate description of the model forms part of the simulation model, where the means of transport are divided among the faces based on the working day and the part where the work shift ends after 10 hours and the means of transport are moved back to the parking lot.

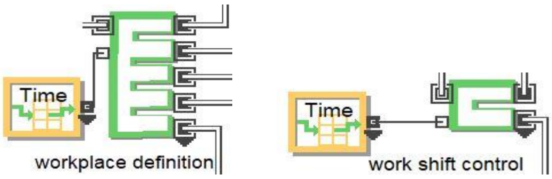

Figure 6: The pair of blocks "*Select Item Out"* and "*Lookup Table"* manage the transfer of means of transport.

For the purpose of modelling precise control of vehicles on individual work faces on a given working day, the "*Select Item Out*" and "*Lookup Table*" (see Fig. 6) blocks are used in the ExtendSim simulation system. The same pair of blocks ensures the management of the activity of, after 10 hours, moving the means of transport to the parking lot from which the new work shift will begin (see Fig. 6). The "*Select Item Out*" block serves as a junction with one input and several outputs. In our case, there are 5 outputs, one for each face. The "*Lookup Table*" block serves as an administrator of defined time intervals in which the corresponding output opens and other outputs are closed. Since in reality the means of transport carry extracted raw materials from only one face for one whole working shift, which is determined by the working day schedule procedure, it is necessary to model the situation in the simulation system too. In order for the means of transport to change stations progressively based on the set workday schedule, the faces need to be managed. Traffic control is provided by the "*Select Item Out*" block, which opens and closes the output connectors of the block based on the "*select connector*" parameter (see Fig. 7). The values that are fed into the "*select connector*" are generated by the "*Lookup Table*" block according to the defined table of values (see Fig. 7).

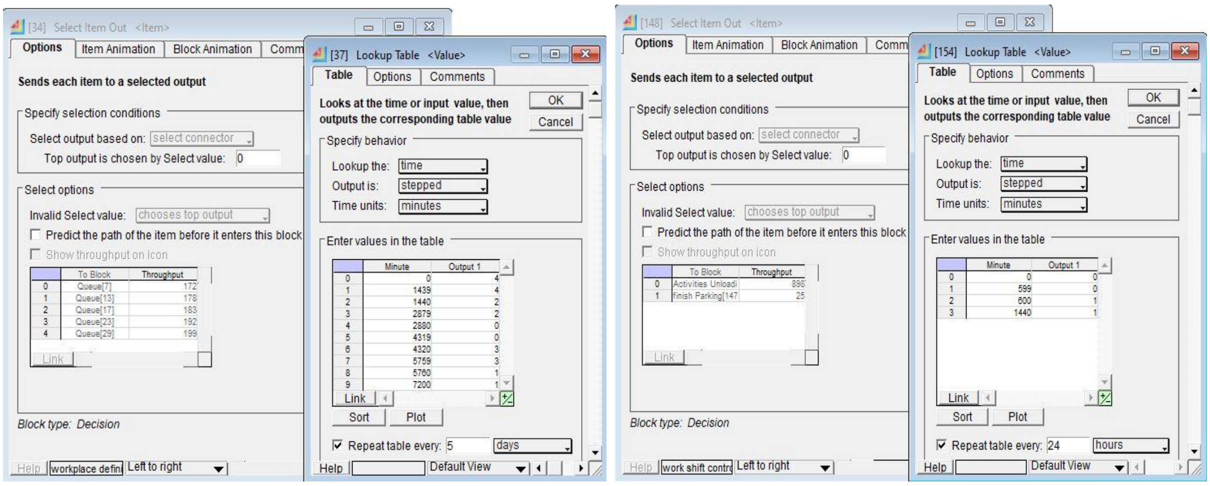

Figure 7: Setting up the "*Select Item Out"* and "*Lookup Table"* blocks, which manage the transfer of the means of transport to the appropriate connector.

The "Lookup Table" block (see Fig. 7) generates a value of 4 on the output connector between 0 and 1439 minutes (face 1 in reality), generates a value of 2 to the output connector between 1440 and 2879 minutes (in reality face 3), from 2880 to 4319 minutes it generates a value of 0 to the output connector (in reality face 5), between 4320 and 5759 minutes generates a value of 3 per output connector (face 2 in reality), between 5760 and 7200 minutes it generates a value of 1 per output connector (face 4 in reality). The entire procedure of generating values over time is repeated once every 5 days, which is 7200 minutes. The "*Select Item Out*" and "*Lookup Table*" blocks work on a similar principle, controlling the return of vehicles to the parking lot after a 10-hour work shift (see Fig. 7). The "Lookup Table" block (see Fig. 7) generates a value of 0 per output connector between 0 and 599 minutes (in reality the work shift is active), between 600 and 1440 minutes it generates a value of 1 on the output connector (in reality there is no active shift, so the means of transport moves to the parking lot). The entire procedure for generating values over time is repeated once every 24 hours, which is 1440 minutes.

4. RESULTS AND DISCUSSION

The setting up of the simulation model is followed by its use for the needs of research and the efficiency of production logistics for the homogeneous production processes of the particular mining operation. Within the defined simulation, the operation of the system is studied with several options: 10 hours (1 working shift), over a five-day cycle and over 30 days.

The results of the simulation for 1 working shift of 10 hours, which captures the current state of one working day at the mining operation, show that the bottleneck of the whole system is the loading process. The results of the simulation show that the loader is used at approx. 80 % and the unloading and crushing processes show a usage factor of only about 20 %. If we move the simulation time to 24 hours, the utilization of the devices decreases, but this is due to the fact that after ten hours of work the system is already idle, which does not correspond to the actual load of the devices when the whole system is in operation. From this point on, we can assume that when the system is set with an effective percentage of equipment load during one work shift, it should be used with the same percentages of workload during the operation of the system during the other working days. The reserve for further increasing the performance of the various working stations is the available time, i.e. to switch to continuous 24-hour operations, which would require additional new staff. If 6 means of transport are sent into the system, the utilization rate of the loading site will increase to 95 % during one work shift and for 7 means of transport the usage will increase to 100 %, while the system will already have a capacity reserve in the means of transport. The utilization of the unloading and crushing site of the extracted raw material will increase to 26 % under the given conditions. It follows from this that a maximum of 7 means of transport must be used for the operation of the whole system for one work shift and the given settings, with alternating working days. If it is necessary to increase the usage of the station for unloading and crushing extracted raw material during one working shift, it is necessary to use several loaders in the system and in proportion to the means of transport. To increase the utilization of the unloading and crushing station of the extracted raw material to approx. 70 %, it is necessary to use 17 means of transport and 3 loaders for the operation of the system. 4 loaders and 27 mining tippers are required for 95 % usage of the loading workplace and 99 % usage of the station for unloading and crushing of the extracted raw material.

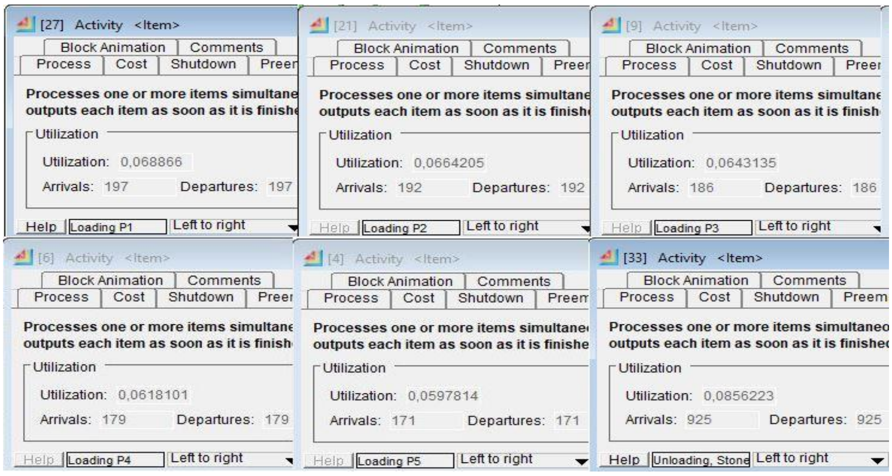

Figure 8: Usage of the stations for loading, unloading and crushing of extracted raw material over a 5-day working cycle.

The streamlining of the utilization of homogeneous production processes of the particular mining operation described above is performed for one working shift and one working day. Another task aims at detecting system workloads over the five working days and defining an effective system setup for full rotation of working days on all faces. Over five working days, five means of transport with one loader and planned rotation of work on the faces, the usage of individual workplaces is roughly the same, about 6 %, and the usage of the station for unloading and crushing the extracted raw material is 8.5 % (see Fig. 8). The percentage usage of the various stations has fallen compared to the previous survey with one working shift because with only one shift it is used for 10 hours, while the next 14 hours is downtime.

5. CONCLUSION

The many simulation experiments carried out show that increasing the number of loaders for a given activity while maintaining the number of means of transport will not lead to a significant increase in the performance of the unloading and crushing site of the extracted raw material. To increase the performance of the whole system, it is necessary to extend the active working hours from 10 hours to 24 hours of operation. For 7 means of transport and one loader, the load capacity of the loading site is almost 100 % and the station for unloading and crushing the extracted raw material is 26 %.

Table II: Usage of the stations for loading, unloading and crushing with various simulation research parameters.

Duration of work shift	The duration of the simulation	Number of lorries	Number of loaders	Utilization of loading workplaces [%]	Utilization of unloading and raw material crushing workplace [%]
10 hours	10 hours	5	1	80	20
10 hours	10 hours	7	1	100	26
10 hours	10 hours	27	4	96	100
10 hours	5 days	7	1	8	11
10 hours	5 days	27	1	9	12
10 hours	5 days	27	4	8	42
10 hours	5 days	102	16	2	45
24 hours	24 hours	7	1	100	26
24 hours	24 hours	27	4	92	98
24 hours	5 days	7	1	18	26
24 hours	5 days	27	1	21	28
24 hours	5 days	27	4	17	96
24 hours	5 days	120	4	19	100
24 hours	5 days	120	7	11	100
24 hours	5 days	120	10	8	100
24 hours	5 days	120	15	5	100
24 hours	5 days	120	20	4	100
24 hours	5 days	150	4	20	100
24 hours	30 days	30	4	18	98
24 hours	30 days	120	20	4	100
24 hours	30 days	150	4	20	100

The system would achieve maximum performance if it were possible to transport the extracted raw material simultaneously from all faces, which is not possible from a safety point of view. Under the defined operating conditions, the maximum usage of the whole system with one loader is when using 7 means of transport. For maximum usage of the unloading and crushing site for extracted raw material, 4 loaders and 27 means of transport are needed. With this setting, the load capacity of the stations for loading, unloading and crushing is almost 100 % (see Table II.). Other reserves are available only in the available time and in changing the organization of work to remove extracted raw material from several faces at the same time.

Future research will focus on the application of defined principles of simulation of homogeneous production processes to systems with a similar focus.

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