Computer simulation as a means of efficiency of transport processes of raw materials in relation to a cargo rail terminal: A case study

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The article deals with the use of computer simulation for the solution of a streamline of transport processes in relation to the cargo rail terminal. The case study is focused on the job sequence problem of transport processes at the rail terminal. The rail terminal serves as a means of the mineral resources delivery support with the necessity of scheduling a lot of means of transport. Unloading time of a wagon with a capacity of 60-70 t based on observations and measurements in practice varies on average from 30 to 45 minutes. Time for unloading the wagons affects their length of stay at the loading track as well as the waiting charges that affect operational efficiency. The problem is related to the utilization of concrete computer simulation system EXTENDSIM for the necessity of simulation and more effectivity of the whole transport system with his processes. The aim of the solution is the practical application of computer simulation for the needs of effective activities of concrete transport processes of a concrete company. The intention is to show the practical role of simulation systems and to use EXTENDSIM as concrete simulation system for the needs of a streamline of transport processes and activities of a concrete company. The objective of this study is to compare the several possibilities of alternative solutions of activity concrete system, which is created from unloading the mineral resources from railway wagons by cyclically working grab and the transport of mineral resources to places of storing. The simulation was performed for different variants of the unloading process. The simulations in this article simulate the process of unloading of ten railway wagons and one unloader by a different number of trucks (2, 3 and 4) providing a transfer of mineral resources. The simulation results show that the lowest unloading time is reached when unloading by one unloader working with three or four lorries; this represents a decrease of 10% when compared use two lorries. The simulation results show that the effective unloading time is reached in dependence on the number of working means of transport and scheduling of the whole system.

Keywords: *Computer Simulation, Transport Processes, EXTENDSIM, Rail Terminal, Efficiency of Processes, Case Study*

Introduction

Dynamic changes in the business environment require a well-organized supply chain, and this requires a proper organization of logistics processes within the enterprise (Groover, 2007; Kot, 2015; Oláh et al., 2018).

The transport of minerals is carried out by various types of vehicles. Most often, for on and off-site transport of bulk raw materials are used road trucks, wagons, ships, long-distance belt transport and other (Marasova et al., 2007). Choosing an appropriate means of transport depends on several factors. Besides the raw materials property, the factors include route length and the amount of transported material. For the transport of smaller amount of raw materials within company's premises (quarries) and short-distance transport (for example, construction, mining, agriculture, food industry) are mostly used trucks and various types of conveyors (belt, bulk-conveyor). For the horizontal transport in the mining conditions, mining rail transport and belt conveyors are used. Vertical mining transport uses transport cage towing equipment and conveyors (Marasova et al., 2009; Šimková et al., 2019). Wagons are used for transporting a huge amount of materials over long distances, and ships transport bulk material. Before the actual transportation takes place, it is necessary to load and unload the suitable means of transport at the intended destination. The method of loading and unloading is again dependent on the type of minerals, means of transport and unloading facilities available (Toomey, 1996).

Several authors deal with the loading and unloading process in the literature, and it is not only for the bulk materials. That issue is most elaborated for port terminals; articles are dedicated to modelling and simulation of bulk material or containers (Bugaric and Petrovic, 2007; Demirici, 2003; Carteni and de Luca, 2012; Kia et al., 2002; Janič et al., 2019). Wagon unloading is wide because this type of transportation uses various types of wagons for which different unloading equipment.

Literature review

The modelling process can serve as a basis for selecting unloading process or rationalization of the existing system, which has a significant impact on the evaluation of the performance of the transport system or the entire enterprise (Rosova and Balog, 2012; Ho et al., 2010; Pan et al., 2014; Markulik et al., 2018; Kovács and Kot, 2016).

The problem is related to the utilization of concrete simulation system EXTENDSIM for the necessity of simulation and more effectivity of the whole transport system with his processes. It is the product of the Imagine

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That, Inc. USA company. A simulation language that is used belongs to advanced simulation capabilities where the simulation model consists of blocks that are grouped in the libraries. Its use is simple and intuitive. System of implementation of transport processes is limited by a lack of suitable means of transport, creates a lot of downtime and restriction of planning for the needs of the efficient use of means of transport and of logistics ensuring. The aim is to streamline and configure the transport system to a level that would be effective as economically, technically and also by side the logistics. The aim of the solution is the practical application of computer simulation for the needs of effective activities of concrete transport processes of a concrete company. The intention is to show the practical side of simulation systems and to use EXTENDSIM as concrete simulation system for the needs of a streamline of transport processes and activities of a concrete company.

For the transport of mineral resources by rail, there are used the types of wagons marked by capital letters as follows:

E - Open Top (High wall) wagon of ordinary construction with a flat floor and the possibility of frontal or side tipping (wagons are designed to carry the bulk and general cargo goods that doesn't require the carriage of covered space and protection from the weather).

F - Open wagon of special construction (wagons are designed for the carriage of the bulk of powdered bulk goods like coal, limestone, gravel, etc.). Wagon construction enables double-sided gravity unloading of goods.

G - Covered wagon of normal construction (wagons are designed to carry the palletized goods, general cargo, bulk grain or another bulk substrate like industrial salt that must be protected from the weather. The wagons allow the transport of live animals).

T - Wagon with an openable roof (Tds) - wagon of special construction with a convertible roof (wagon is designed to transport bulk goods requiring weather protection). The wagon construction enables double-sided gravity unloading of goods.

Conceptualization of traffic flow pattern is one of the influential factors on traffic simulation modeling (Kim, 2011; Bohács et al., 2018). The same idea is necessary for the creation of a simulation model of our transport system.

Unloading of minerals from railway wagons under real conditions can be carried out in various ways depending on the type of rail wagon, type of minerals, loading mechanisms to be available and forms of trans-loading. The Slovak Republic is specific in that its territory features normal and broad railway gauge, and besides classic wagon unloading also loading and unloading of minerals from normal to broad railway gauge takes place (Saderova and Bindzar, 2014). Thus there are three dimensions of the process:

1. Unloading of minerals from the standard gauge railway wagons using different types of unloading systems.
2. Unloading of minerals from broad gauge rail wagons using different types of unloading systems.
3. The transhipment mineral resources from railway wagons on a broad gauge to standard gauge railway wagons that may be realized as direct transhipment or indirect transhipment.

In the direct transhipment, minerals are directly transferred from broad gauge wagons to parallel wagons that are then shipped to customers. In the case of indirect transhipment, the minerals are not transferred directly from wagon to wagon, but minerals are firstly unloaded using unloading devices to another type of vehicle and moved to storage or to an open dump. Then, when the time comes, its loading is carried out in the required quantity.

Unloading of mineral resources in all forms can be realized in four ways – by shovelling, scooping, tipping or by self-unloading. Self-unloading requires the special construction of railway wagons allowing double-sided gravity discharge of raw material (series F and Tds). The first three forms are used for the unloading of mineral resources from high-wall opened or closed wagons (series E and G). It is important to use suitable unloaders depending on the form of unloading. There are 2 groups of unloaders for shovelling, scooping and tipping (Saderova and Bindzar, 2014):

- Means of "small mechanization" are considered as mechanisms where human effort remains an essential factor (mechanical shovel),
- Means of "complete mechanization" like mobile and bridge grab cranes, bucket unloaders, front and rotary tipplers.

Modelling and model creation is one of the basic cybernetic approaches to study, analysis, design and design of systems. The modelling is the process of replacing a dynamic system by its model. The model represents a simplified object or process and is created on a computer, physical or real object (Malindzak, 2009; Straka et al., 2016). Several authors deal with the modelling and model creation in various sectors across process technology, transport, handling, services, etc. (Vilamova et al., 2016; Gracanin et al., 2013; Šaderová et al., 2018; Pekarcikova et al., 2019; Urzúa et al., 2019).

Simulation is an experimental method in which the real system is replaced by a computer model. It is possible to make a number of experiments with such a model, to evaluate and to optimize it and then results can be applied to the real system. The first step in the simulation is to build a simulation model of the real system. The next step is to provide experiments with the simulation model by which there are achieved results, which need to be correctly interpreted and applied. Application possibilities of computer simulation can be applied in designing manufacturing processes and systems (Lu et al., 2015; Ba et al., 2016).

The modelling of unloading the mineral resources is composed of two subsequent parts. The first preparatory phase is targeted on creating the algorithm as a basis for the second part. The second modelling part consists of two types of model for a selected time period based on the algorithm graphic and simulation models.

Simulation is not a tool for getting the optimal solution, but it is a tool that allows you to test different outputs decision on simulation models. The model allows performing experiments to evaluate, analyse, and to optimize the results that can be subsequently used for the real system. Risk reduction can be examined in advance, by "replaying" the system run whilst observing the performance and behaviour of the system, then after applying the required changes, examine the future behaviour of the system, where any potential problems and bottlenecks can be removed in advance (Straka et al., 2019). Animations of manufacturing processes allow greater clarity and understanding of the production processes, thus allowing to prevent failures, which could exist in practice if a system is not testing on mistakes and deficiencies (Straka, 2007).

The simulation model created by EXTENDSIM is defined by a specific sequence of modelling blocks connected by lines representing the processing flow directions. The block position, icon and name, the connector blocks, the links as well as the user interface dialogues with operands and flows are the main properties of individual blocks. The blocks themselves represent individual processes or subsystems, thus creating the actual representation of the real-life system under examination. The icons and block names are the graphic representation of each block, with their exact unique name that describes their defined function and the primary purpose of the particular block within the model. The block labelled "create" represents the generation of input requirements while the model block labelled "queue" defines the creation of a series of demands, with the input to the queue and the subsequent output. The block labelled "exit" represents the simulation model output. The blocks connectors enable connecting each block with others in accordance with a rule that one connector can only connect the input with output slot. The connectors of two different blocks form a logical sequence of blocks, which reflects the real system and forms the basis for forcing the flows. The connected blocks form flows representing the real sequence of units and facilities within the examined system. User interface windows and operands represent specific items and the block properties characteristic for the particular blocks. By opening a user interface window, the parameters and properties of each block can be displayed and specified for each modelling block (Straka, 2007).

Researched transport system

Type of minerals in the railway wagon and its physical and chemical properties should be considered as input data for individual sub-processes.

The first activity in the process of unloading is the "in-feed motion" – supplying the wagons at the place of unloading (unloading ramp). Before this activity, there should be done operations such as an announcement about the arrival of wagons to be unloaded. When doing transhipment between railway wagons (form 3 - direct transhipment), it is also necessary to make an order for rail wagons that will be loaded.

After wagons are ported, wagon unloading takes place. During the unloading process, wagons are either still, or move in certain times or continuously depending on the type of unloading equipment - device. The unloading process consists of several activities. Figure 1 shows the simple formalized scheme of the process of unloading (Fig. 1).

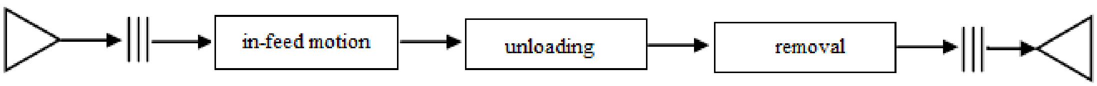

Fig. 1. A formalized scheme of the unloading process

When unloading with a gripper crane a wagon is still, and the unloaded raw material is unloaded directly to another means of transport (for example, right on the truck, through the hopper onto a conveyor belt, etc.). When unloading with a wagon tippler wagons are shifted to the rotary tilter where they are disconnected from the set, tilted, put out of the tilter, and subsequently joined to the wagon set again. Material falls from the rotary tilter into the containers that are then moved by conveyors. When using bucket unloaders, the wagons are still or continuously move depending on unloaders' construction.

Unloading of minerals is followed by its removal (displacement) to the destination such as operational stock, to the customer, stock for input materials, to the manufacturing process, etc. Figure 2 shows an example of a simplified flow chart of unloading of minerals from the railway wagons (Fig. 2).

The modeling of any process is based on pre-defined steps - an algorithm. The proposed algorithm is for unloading open wagons to trucks that are to be unloaded at a temporary landfill using portable gripper cranes. The results obtained from the model made according to the proposed algorithm can serve for assessing the current state of unloading and rationalization in order to increase the capacity of the existing system. During the rail wagon loading, the train set will remain at rest so that unloading equipment will move only.

Figure 3 shows the basic algorithm for unloading the mineral resources from railway wagons (Fig. 3). There must be known some input parameters to perform the unloading, such as (Fig. 3, a):

"*n*" - the number of railway wagons to be unloaded of the train set;
"*M*" - the volume of mineral resources in one railway wagon in tons;
"*N*" - the volume of mineral resources unloaded by one grab unloader in tons.

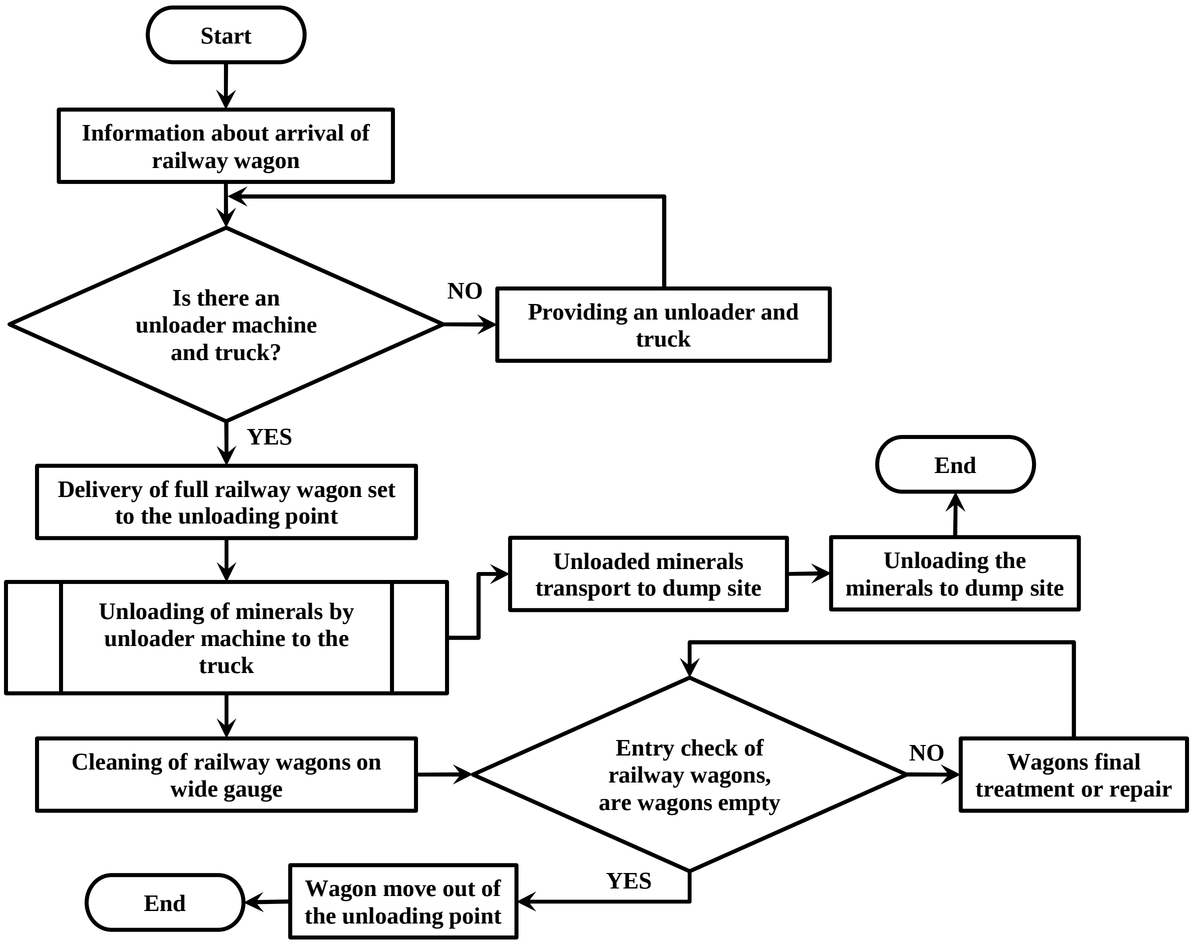

Fig. 2. A flow chart representing direct unloading of mineral resources from a railway wagon

The unloading process begins when rail wagons are furnished at the unloading point (Fig. 3, b). Subsequently, the unloading is carried out by cycle (Fig. 3, c) (step by step - wagon after wagon if we have a single unloader; in parallel – it is used in case of more unloaders) that begins by furnishing the unloader to the railway wagon (Fig. 3, d).

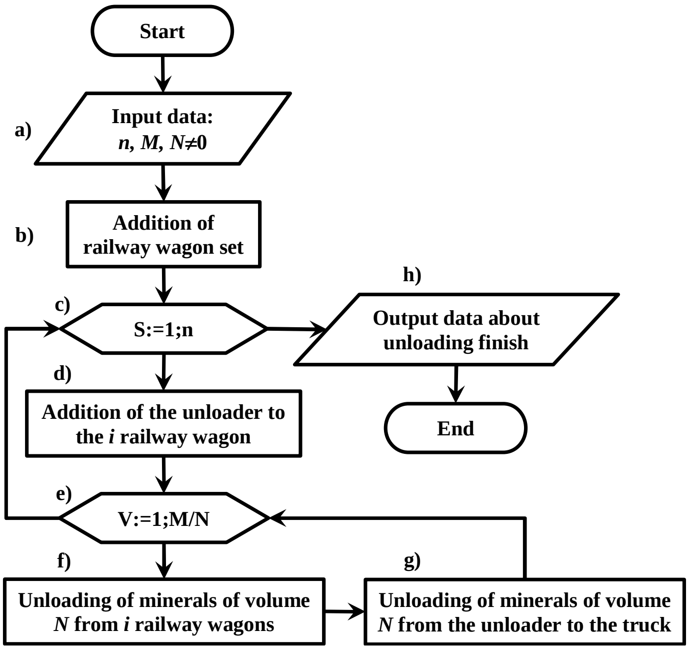

Fig. 3. A basic algorithm of unloading minerals from train set

Unloading of a single wagon is represented by cycle (Fig. 3, e-g) consisting from operations (Fig. 3, f) "Unloading of mineral resources of volume "*N*" from railway wagon by unloading means and its deposit into a transport vehicle" (Fig. 3, g) until the discharged amount of "*M*" isn't unloaded. After unloading a single wagon, the loader means is moved to the next wagon (Fig. 3, c, d) followed by unloading of the wagon by cycle (Fig. 3, e). After unloading the mineral resources of all railway wagons, the information about the completion of unloading of train set is interpreted by cycle (Fig. 3, h) and the unloading process is finished.

Figure 4 shows the secondary algorithm representing the realization of transport of unloaded mineral resources by trucks (Fig. 4). Input parameters (Fig. 4, a) in this case are: "*N*" - the volume of mineral resources unloaded by grab unloader [t]; "*K*" – truck capacity. The first step is an addition of a truck to the unloading equipment (Fig. 4, a). Consequently, the truck is loaded with suitable equipment (Fig. 4, d). After loading the volume of "*K*" to the truck, it is moved and unloaded (Fig. 4, e, f). After emptying (Fig. 4, g) the truck returns to the loading point, or its work is finished with that train set (Fig. 4, h).

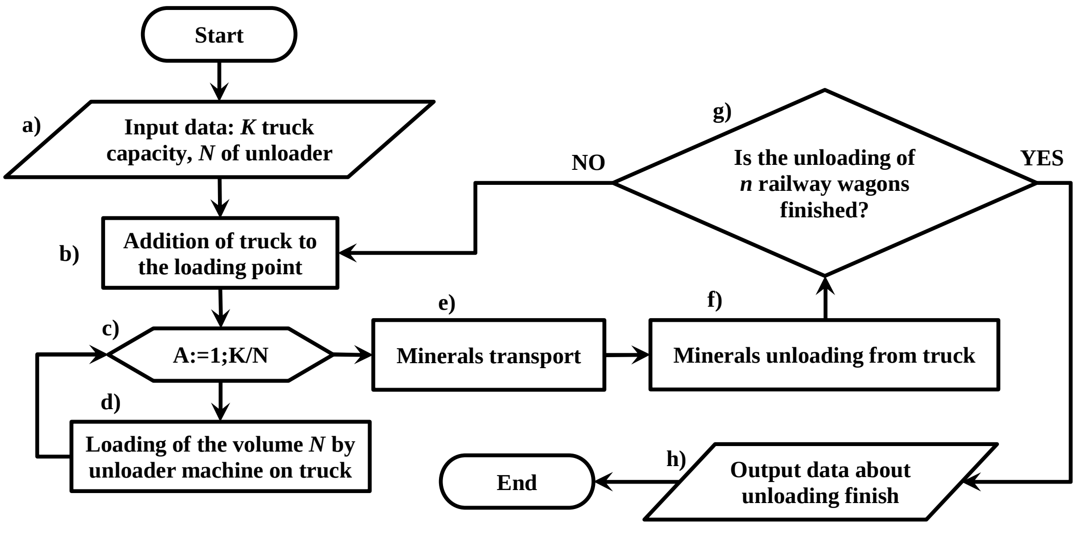

Fig. 4. Algorithm of transport of unloaded mineral resources

The creation of a simulation model by EXTENDSIM

Modelling requires some input data. Input data are dependent on questions like „What I want to achieve by the modelling? The modelling should result in:

- Project of the system of unloading.
- Rationalization of the existing system.
- Improving the capacity of the existing system and so on.

Input data can be categorized by these groups:

1. The type and properties of the mineral resources.
2. Operating conditions data in which the unloading will be carried out like intervals for wagons to be in feed, the number of wagons in the train set, the capacity of wagons, the distance between the place of unloading to the stock and so on.
3. Performance of the unloading equipment (per year, per hour) and related transport equipment.
4. The form and method of unloading.

All input data from all groups above are required when designing a new system from the beginning. While doing a rationalization of the existing system only or trying to improve the capacity of the existing system, the input data to be required are mainly from the groups 1-3. The performance of unloading equipment and related transport systems can be obtained from the prospectus, by calculation according to the known relationship or directly by observing under real conditions (just for existing mechanisms).

Input data (Table. 1) are required when creating a model of the process of unloading that is based on the algorithms above. Data (Table. 1) also lists other parameters closely connected with the formation of a model.

The model of the unloading process was created based on algorithms above (Fig. 3 and Fig. 4). Data connected with the formation of a model are listed in Table 1 (input data).

The model's result is to determine the time of unloading of the specified number of wagons under the given conditions, provided that the grab unloader has already been present at the first rail wagon of the set (excluding the initial presence of the grab unloader). That time of unloading serves as a basis for calculating the cost of demurrage of wagons.

Under real conditions, the number of railway wagons in one train set mainly depends on the length of the so-called handling (the loading) track. Quantity of mineral resources in the railway wagon depends mainly on the type of mineral resource and parameters of the wagon. The volume of mineral resources to be unloaded by unloading equipment during one unloading cycle depends on the type of the mineral resources, the volume capacity of an unloader and a coefficient of grab unloader's loading.

Tab. 1. Input data for modelling of the unloading process

Parameter	**Value**
Number of rail wagons in trains [-]	n = 10
Volume of mineral resource in the wagon [t]	M = 70 t
Volume of mineral resource unloaded during one cycle by a grab unloader [t]	N = 0.86 t
Operating cycle time of the loader [s]	T_{pcv} = 27 s
Number of operating cycles to unload 10 wagons by the claws of a grab unloader	810 cycles
The time needed for loader moving between the wagons [s]	90 s

The run time of the hydraulic operation of the grab unloader is specified by the manufacturer, or it can be set on the basis of practical measurements – the operation then may vary depending on the type of raw material and the size of the work equipment - the grab. The run time consists of the following partial steps: dropping down the grab into the wagon $\rightarrow$ loading the material (opening the grab + loading + closing) $\rightarrow$ lifting up the grab and moving over the truck $\rightarrow$ opening the grab (unloading the material) $\rightarrow$ lifting up the grab and moving over to the wagon.

Another model parameter is the time it takes the grab to move to the next wagon and the number of loaders used for loading. Based on the parameters (Table 1) and simple calculations, we can determine the so-called "starting" - the technical time of unloading of 10 wagons "T_T" by one unloading grab. Unloading time consists of the sum of individual times for unloading of wagons and relocation times needed for the grab to move from one unloaded wagon to a full wagon. 81 unloading cycles are needed to unload one wagon at given capacity, unloading time of one cycle is 27 seconds, for all cycles it is 2187 seconds or 36.45 minutes. Net time of unloading 10 wagons is 364.5 minutes and can be reduced using multiple unloaders. Time of movement of loader between two successive wagons, also considering a safe operation, is 90 seconds as can be seen in Table 1. Movement of a loader in order to unload 10 wagons will be performed 9 times; it is 13.5 minutes. Based on these values, the time of unloading 10 wagons is T_T = 378 minutes or 6.3 hours.

Thus the specified time of unloading does not take into account the process of raw material transportation which depends on the distance to which the raw material is being transported, the number of used trucks and their capacity.

The capacity of a truck is again given by the type of raw material and truck's parameters. In practice, the capacity of a truck can be determined by the number of unloader's operations as determined by the ratio of the truck's volume to the volume of the unloader and the truck's capacity to the amount of raw materials. The transport distance affects the turnaround time of the truck, the time it takes for the truck to return, the number of truck needed for the continuous work. An insufficient number of trucks may result in long unloader downtime and increased unloading time, which could have a negative economic effect. Other additional input data listed in Table 2 were required during the creation of the model.

The model of unloading of the mineral resource has been developed according to the algorithms previously described and for input data as in Table 1 and Table 2.

Tab. 2. Input data for modelling of the unloading process

Parameter	Value
Truck capacity	K = 7.77 t (capacity of 9 claws)
Time for loading a one truck	t_n = 243 s
Route length for the transport of mineral resource	L = 450 m
Truck cycle time (transport, unloading, return journey to loading point)	t_o = 270 s

Before the model itself was created, it had to be determined based on Table 2. A number of trucks (N_T) is able to manage the performance of unloader. Based on the capacitive conversion of truck transportation, the required number of trucks on a distance of 450 m is N_T = 2,1. Figure 5 shows the model of unloading where transport of unloaded mineral resources will be done by two trucks (Fig. 5). The model was made on the basis of the assumption that the loading process starts at the moment the unloader has arrived to the first wagon, as indicated above. It can be seen on the graphic model a process of wagon unloading RW_1 to RW_{10}. The unloading of each railway wagon consists of two lines that are represented by trucks T_1 and T_2 providing removal of the mineral resource to the destination. Black stripes represent unloading activities that alternate depending on the truck to be loaded. Red stripes represent down-time "t_i" of an unloader that is caused by waiting for the trucks in operation (T_1 or T_2). Green stripes represent moving of an unloader to the next wagon. Grey stripes represent truck circulation (driving time out and back, time of unloading and its bringing again to rail wagon). Blue colour stripes are a truck waiting for loading.

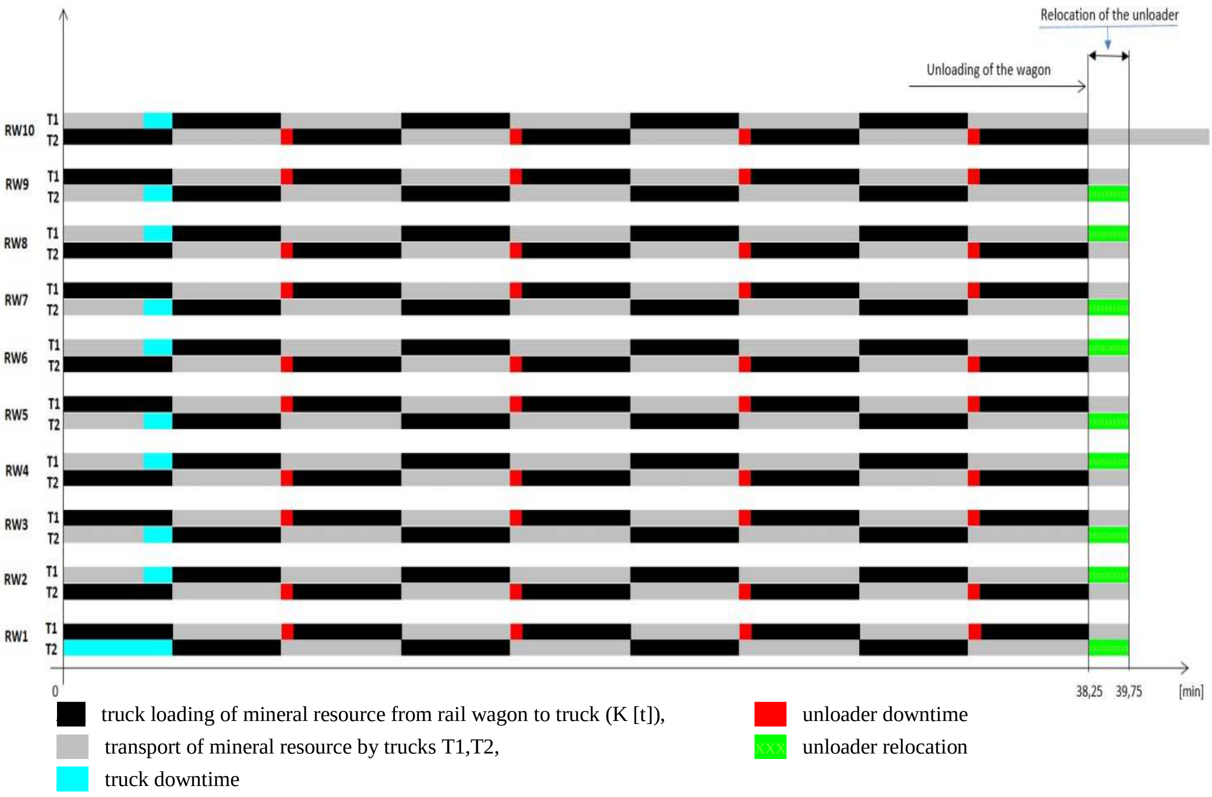

Fig. 5. The graphic model of unloading with the transport of unloaded mineral resources

The simulation model of the transport processes (Fig. 6) of the mineral resource has been created in the simulation system called EXTENDSIM. It is the product of the Imagine That, Inc. USA company. A simulation language that is used belongs to advanced simulation capabilities where the simulation model consists of blocks that are grouped in the libraries. Its use is simple and intuitive. The simulation model is a model of discrete simulation and is built from the blocks of the library "Discreet Event" and "Plotter" (Straka, 2007). The upper part of the model represents the unloading of wagons; the lower part shows the transportation of mineral resource.

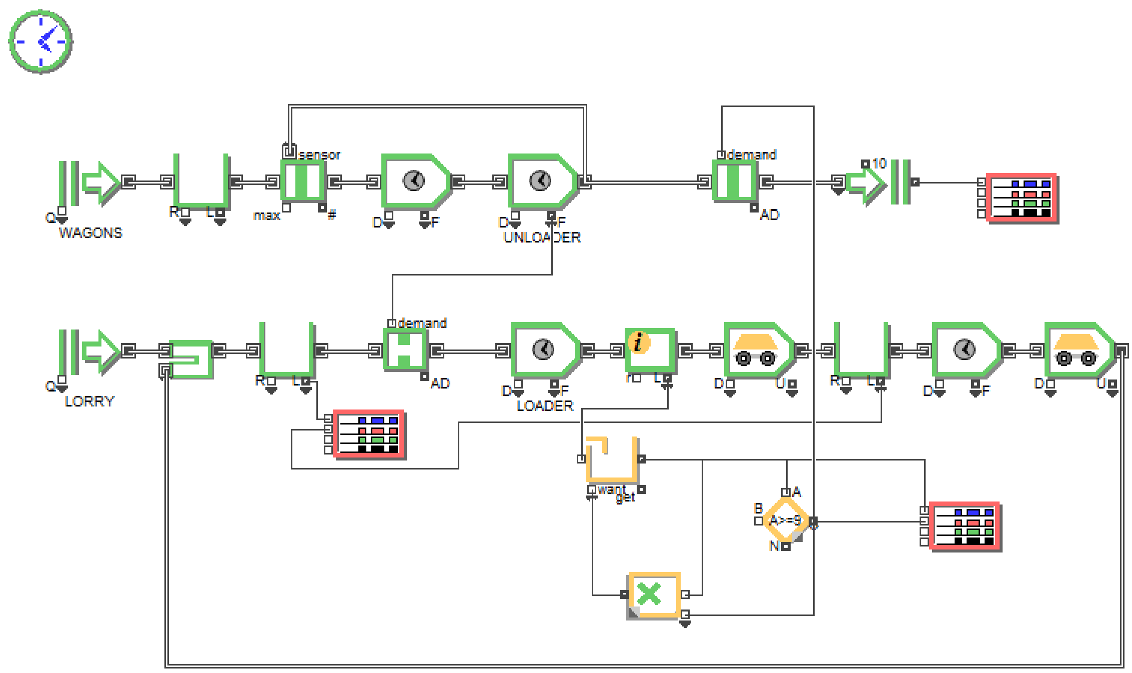

Fig. 6. The simulation model of the transport processes by EXTENDSIM computer simulation system

Results and discussion

The graphic model on Figure 5 results in the following: 9 trucks are needed to unload 1 rail wagon, every wagon can be unloaded within 2295 s = 38.25 minutes, this time includes 4 unloader downtimes (totally 108 s) caused by waiting of trucks T_1 (resp. T2), 90 trucks are needed to unload mineral resource from 10 rail wagons, 6.075 hours netto is needed to unload 10 rail wagons, totally 40 downtimes is formed while unloading 10 wagons; it is 0.3 hours (18 minutes), the unloader is moved – times during the unloading; it is 0.25 hours (15 minutes), time of unloading T_T is 6.60 hours.

Time for unloading a train set can be reduced by deploying multiple loaders and the corresponding number of means of transport. Losses caused by waiting for a truck can be eliminated in several ways:

1. By deploying multiple trucks (Option 2).
2. By increasing a truck capacity (Option 3 and 4).
3. By increasing a loader capacity (Option 5 – 8).

Similar models have also been developed for these options, and the results are found in Table 3. In option 2 (deploying a 3 trucks) each wagon is unloaded in t_u = 2187 seconds = 36.15 minutes. It is similar to Option 1, but there are no downtimes caused by waiting for a truck. Unloading time T_T is reduced to 6.3 hours. The deployment of three cars will reduce unloading time by unloader downtime, but on the other hand, there is downtime on average 3.60 minutes per vehicle turnover, which is on one side. For the same time, it landed raft even with Option 3 and 4, since the time of loading one car is equal to or greater than the circulation time of the car, resulting in downtime remained in a car with a capacity of 9.5 tons.

In Option 5 and 6 by increasing the volume of claws to 1.2 m^3 the time of unloading compared to other options will rise up to 6.43 hours or up to 6.64 hours by increasing the volume of claws to 1.30 m^3 in options 7 and 8. The increase, in this case, is due to the time increase in the unloading cycle and not by unloader's downtime. Deploying grabs with a larger volume negatively impacts the time utilization of trucks. However, such downtime provides enough time in case the route needed for unloading the material takes longer than expected. Table 3 shows recommended color-coded options which should be applied when unloading at given input data.

Tab. 3. Results of modelling

Parameter	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8
V_D	1.1				1.2		1.3	
N [t]	0.86				0.94		1	
K [t]	7.77	7.77	8.64	9.50	8.46	9.40	9	10
t_n [s]	243	243	270	297	270	300	297	330
t_o [t]	270	270	270	270	270	270	270	270
N_T [-]	2	3	2	2	2	2	2	2
t_u [s]	2187	2187	2187	2187	2234	2234	2310	2310
t_i [min]	18	0	0	0	0	0	0	0
T_T [h]	6.60	6.30	6.30	6.30	6.43	6.43	6.64	6.64

We can assume based on the values for option 2 that during the 12-hour shift, one unloader unloads about 12 wagons, i.e. 840 t. 70% of the time shift of 12-hour shift represents the time of unloading; for example, 504 minutes (8.4 hours). The time needed for moving will account for 8.3 hours.
Unloading time is greatly influenced by the time wagons remain at the loading track and time needed for moving the wagons, thus affecting the cost of wagons demurrage.
If the cost of staying for a single wagon is 3 EUR / hour, the total cost of the stay for 12 wagons will be 12x8,3x3 = € 298.8 or 0.356 euros/tone of unloaded mineral resource. Using multiple unloaders will lead to reducing not only unloading time but the costs also (Table 4).

Tab. 4. Modifications to the parameters when deploying multiple loaders

Number of wagons	12	12	12
Number of deployed loaders	2	3	4
Unloading time [h]	4.15	2.77	2.05
Costs per stay for 12 wagons [€]	149.40	99.72	74.70
Costs per 1t of handled mineral resource [€]	0.18	0.12	0.09

Unloading time of a wagon with a capacity of 60-70 t based on observations and measurements in practice varies on average from 30 to 45 minutes. The same is confirmed by our graphical model.
The simulation was performed for different variants of the unloading process. The simulations in this article simulate the process of unloading of ten railway wagons and one unloader (SIM1 to SIM3) by a different number of trucks providing a transfer of mineral resources. The output data and the results obtained by simulation are shown in Table 5. The truck circulation time for all the simulations is taken from Table 3.

Tab. 5. Output data and simulation results

Parameter	SIM1	SIM2	SIM3
Number of wagons	10	10	10
Number of unloaders	1	1	1
Number of trucks	2	3	4
t_u [s]	47.58	36.45	36.45
T_T [min]	417.58	379.50	379.50

A graphical representation of simulation SIM2 is shown in Figure 7. It is unloading of 10 wagons by one unloader using 3 trucks (Lorries). The blue line represents the unloading of a wagon to 9 trucks while the red line represents the completion of unloading the wagon from the train set.

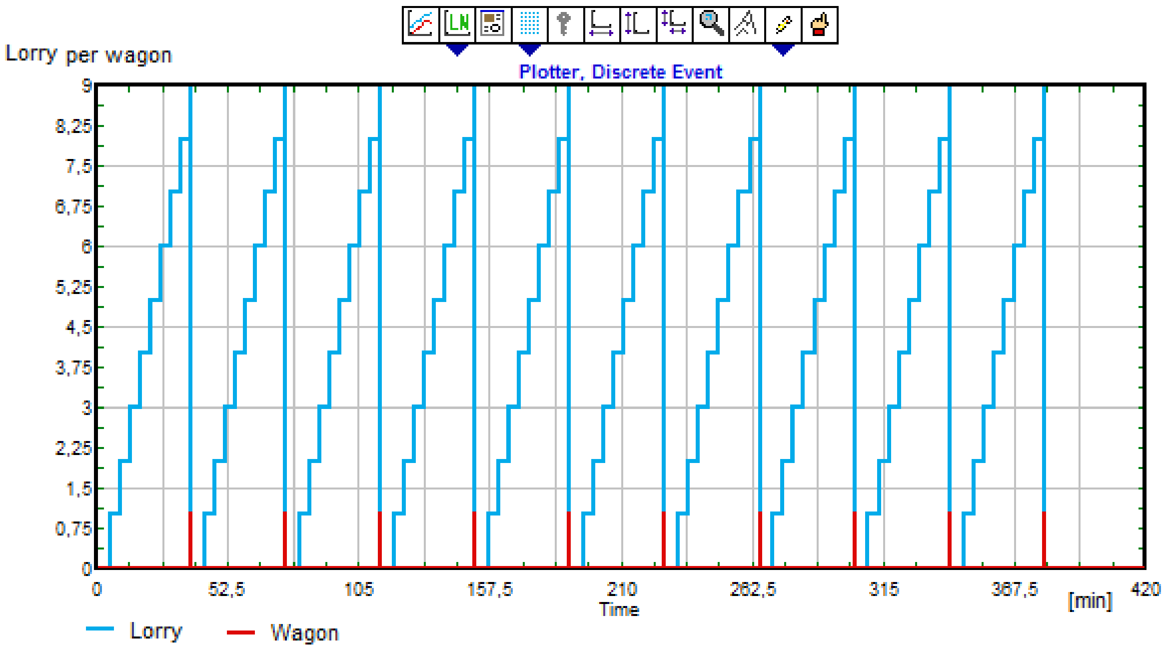

Fig. 7. Graph of the simulation of the transport processes

The simulation results show that the lowest unloading time is reached when unloading by one unloader working with three or four lorries. Extra downtimes are present when using four lorries.

Summary

This paper was aimed to use a model approach create an algorithm and creation of graphic and simulation model by EXTENDSIM for the needs of modelling the unload process from railway wagons using the grab unloader followed by transfer of minerals by trucks. In order to create an algorithm, there was a short overview of the process of unloading described in the article's introduction: forms, methods, types of unloading facilities and types of wagons used to transport raw materials. We can allege that the aim of the study solution was reached.

This algorithm forms a basis for the creation of the specific model in graphic form as well as a simulation model. The algorithm can be modified easily for any way and form of unloading. This is only one of many procedures which can be used to address the problem. The other methods such as simulation, software applications can be used to solve the problem and the decision-making process with the use of multi-criteria analysis. That job does not end with the creation of the algorithm and forming specific actions that are necessary. Next, it is necessary to monitor and evaluate the process using the tools of controlling as well as to ensure the efficiency of the operation. The future research should focus on the extension of the existing model and the application thereof to other unloader types and unloading methods, either underground or on the surface.

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