

Proposing the capacity of bulk materials buffer in the simulation software

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Abstract: Storage is one of the primary activities of manufacturing enterprises. Mainly, enterprises deal with the storage of piece materials, but there are also production processes using bulk materials. For this material, enterprises need to create specific storage areas - buffers. The first activity before creating a buffer is determining the nature of its filling and emptying, which affect the main parameter of buffers, namely capacity. Specifically, it is necessary to know the hourly performance of the filling equipment, the method and speed of emptying, and the type and capacity of the means of transport into which the material is loaded. The simulation software brings a modern touch to the years-proven procedures for determining the capacity of bulk material buffers and speeds up the process. In the paper, simulation replaces the previous approaches to creating graphic outputs, which check the mathematical part of the algorithm and visualize the behaviour of the buffer in specific situations. The result of the use of simulation is the rapid creation of graphs of material supply and easy checking of several options through experimentation with the simulation model.

1 Introduction

In the primary industry, the dimensioning of bulk warehouses is an integral part of logistics activities in the production process. The task of storage is to create the necessary stock of material to eliminate the effects of uneven supply and removal of material, to further separate technological processes of other types from each other in time and to take into account the physicochemical properties of the processed materials [1].

Bulk materials are stored in landfills and storage buffers. Storage of bulk materials in buffers has its advantages and disadvantages. The main advantages include protecting the stored material from adverse weather effects and automation of filling and emptying the storage buffer. Buffers can be filled from the top by pouring. The discharge of the material is realized in the lower part of the buffer in the form of one or more discharge holes [2]. The main disadvantage appears

to be various flow defects. These include defects in flow continuity, vaults, stick rings, and dead zones in the bulk material [3]. Storage buffers are divided according to several aspects. From the critical point of view of floor plan and height dimensions, we distinguish between low bunkers and high silos. Bunkers are intended for short-term storage because they have a smaller capacity due to their geometric shape. Bulk materials of all characteristics can be stored in them. Bunkers can be placed above or below ground and have different shapes. Silos create a more extensive stock. Therefore, they are mainly used for long-term storage and are only suitable for powdery or fine-grained, small loose materials [4]. When designing a Buffer for bulk materials, it is essential to determine the process of filling and emptying the buffer, which is closely related to the design of its capacity. The course of filling and emptying it depends on several factors [5]:

Proposing the capacity of bulk materials buffer in the simulation software

Marek Ondov, Peter Gombos, Ivana Krajnakova, Karolina Bortakova, Zuzana Sedlakova, Ibrahim Mehana

- The method and speed of filling are represented by the hourly performance parameter of the filling device, e.g. continuously using a belt conveyor.
- The method and speed of emptying could be continuous or at specific intervals.
- Type and capacity of means of transport, e.g. truck, railway wagon, a system of conveyor belts.

The article aims to show how to speed up the process of designing the buffer capacity using a simulation software.

Many authors defined simulation as a research method [6,7]. A computer simulation is the most common approach to solving tasks in various areas, not only in transport [8]. Simulation is a research method, the essence of which is that we replace the investigated dynamic system with its model - simulator and perform experiments with it to obtain information about the original investigated state. The simulation is carried out outside real objects without influencing the actual operation or without the existence of a real, investigated system. The simulation results in information about the investigated system and its elements according to the defined parameters [9]. Simulation is an established analysis method for manufacturing and logistic purposes. It is frequently used when decisions with high risks must be taken, and the consequences of such decisions are not directly visible, or no suitable analytical solutions are available [10]. A simulation is a suitable tool for evaluating the efficiency of the production process even in the case of non-invasive changes, such as production adjustment, planning and rationalization of logistics operations [11].

Today there is a significant number of analytical software products focused on simulation in the information technology market. The range and variety of such software continue to grow. As the dominant basic concepts in modern simulation modelling are used [12]:

- discrete-event simulation systems (description-based systems for process description);
- systems based on network paradigms (are used in structuring causal relationships and modelling);
- systems with parallel processes, serving for stratification and algorithmization dynamics of discrete and discrete-continuous systems);
- systems based on process models and organizational structures;
- systems focused on continuous modelling;
- dynamic systems;
- other.

Currently, many simulation programs are used, such as TECNOMATIX, SIMUL8, WITNESS, ExtendSim or ARENA [13]. In this article, a simulation model created in ExtendSim is presented. ExtendSim is a block-oriented simulation program that offers both discrete and continuous simulation. Program blocks are divided into Value, Item, Chart, Rate, Utilities and Animation

libraries. The number of blocks in the model is not limited. Pre-prepared blocks with a built-in programming language make it easier for creators to work logically with the model [14]. Several researchers have used this simulation software. For example, Ondov et al. [15] present a simulation model as a tool used in the redesign of the medium enterprise production process, Šaderová et al. [16] present a simulation model of selected activity in a warehouse operation, Kopytov et al. [17] present a simulation model for the supply chain "producer – wholesaler – 3 customers, and other authors [18].

Among the partial objectives, the use of simulation as an analytical tool to monitor the behaviour of the designed buffer and the proposal of various measures to rationalize the amount of raw material in the buffer can be pointed out.

2 Methodology

The volume and capacity of an already existing buffer are simply determined by calculation based on its dimensions. Another case occurs when it is necessary to design the capacity and volume of a new buffer for specific operating conditions. The volume and capacity must be designed effectively so that it is not over-dimensioned or under-dimensioned and could represent a bottleneck in the production or transport process. The design of buffer capacity and volume can be divided into two parts. The first part – computational, is the basis for the development of the second part, the basis of which is the graphic representation of the filling and emptying of the buffer and the subsequent determination of its volume and dimensions [19]. According to the buffer design algorithm, the following steps must be followed [19]:

1. Design of the shape and dimensions of the buffer outlet.
2. Calculation of the permeability of the hole.
3. Calculation of the buffer emptying time.
4. Calculate the time of filling the buffer with the amount of material for one means of transport.
5. Calculation of the minimum amount of material in the storage buffer before loading.
6. Construction of a graph of supply and removal of material from and to the storage buffer. At this point in the algorithm, the simulation software is used.
7. The maximum amount of material in the buffer is determined.
8. The amount of material is recalculated using the volumetric bulk weight of the raw material.
9. They determine the dimensions of the buffer.

The chosen simulation software is ExtendSim 10, which contains many blocks in its libraries. The following

Proposing the capacity of bulk materials buffer in the simulation software

Marek Ondov, Peter Gombos, Ivana Krajnakova, Karolina Bortakova, Zuzana Sedlakova, Ibrahim Mehana

blocks [20] are key to creating a simulation model according to point 6 of the algorithm mentioned above:

- Create - This block provides items or values for models. Introducing items or values is controlled by five options offered in the block's dialogue.
- Activity - Holds one or more items and passes them out based on the processing time and arrival time for each item.
- Holding tank - Accumulates the total of the input values, allows to request an amount to be removed, and outputs that requested amount, if it is available.
- Constant - Generates a constant value at each step.
- Batch - Allows items from several sources to be joined as a single item. This is useful for synchronizing resources and combining various parts.
- Line chart - traces the history of values received overtime during the simulation. The Chart can trace up to 20 lines.



Figure 1 Important blocks for creating a simulation model [20]

Other blocks used to supplement the correct operation of the simulation model should be the Executive blocks to manage the simulation time. Queue as a place to store entities after their creation. Gate limits the flow of entities, and Exit allows entities to leave the model.

3 Results and discussion

Before the simulation model was created, it was necessary to perform calculations according to the algorithm. The authors of these publications give the relationships for the calculated values [21].

The simulation model for filling and emptying the buffer was created in the program ExtendSim 10 and is shown in Figure 2.

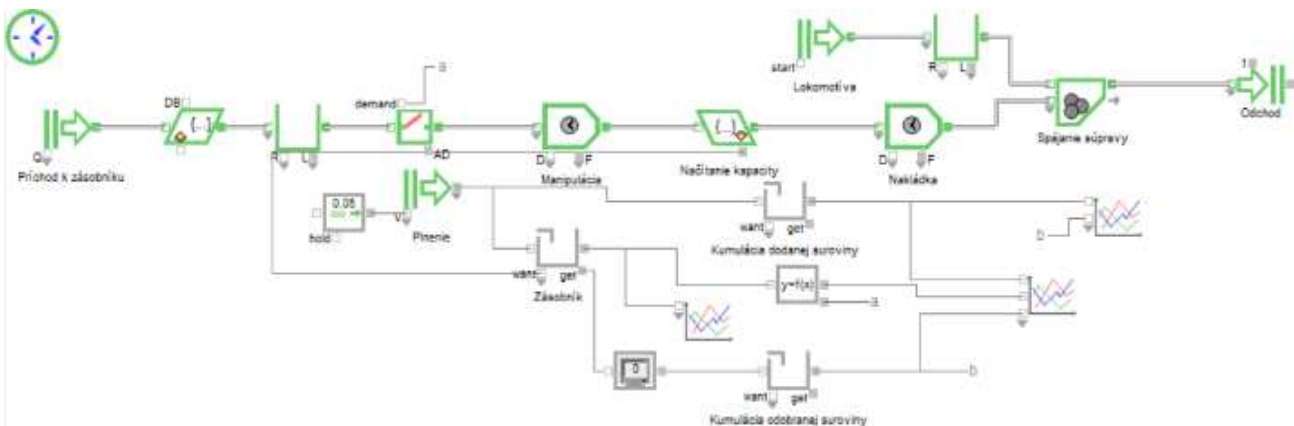


Figure 2 Simulation model of buffer filling and emptying

The simulation model in Figure 2 is a combined simulation model in which the green blocks represent the discrete part of the simulation, and the grey blocks the continuous part of the simulation. Time is recorded at certain moments. The "Príchod k zásobníku" block generates the wagons of the train set regularly so that after the wagon is loaded, the manipulation of the next wagon immediately begins. In the next block, the value of their capacity is assigned to the wagons. The following pair of blocks is fictitious and inserted only for the correct functioning of the simulation. The block gate from the mentioned pair will not let the next wagon for loading if the buffer does not have the required capacity from the wagon. This adjustment is necessary from the point of view of the chosen solution of the simulation model because the model could otherwise fill the wagons with a value different from the capacity. After the wagon is admitted for loading, manipulation is performed in the activity block, and the get block reads its capacity and sends the request to the buffer. Then another activity block simulates the delay during loading. The discrete part ends with the connection of ten

wagons and the locomotive, generated in the highest positioned create block and the departure of the train set. In the continuous part of the model, the "Plnenie" block regularly fills the reservoir with the value generated in the block before it - a constant block. The buffer is represented by the holding tank block named "Zasobnik". Holding tank accumulation blocks also accumulate values for plotting curves in graphs created in line chart blocks. The block connected to the buffer is an equation. In this block, the condition of the amount of material in the buffer is checked, and the closing and opening of the gate before loading is controlled.

In the first experiment, the filling time of one train set, i.e. ten wagons, is monitored. The authors set the simulation duration to 300 minutes based on a subjective estimate. To set up the blocks, it is necessary to establish the parameters. These parameters are selected input values and calculated values according to formulas. These values are shown in Table 1.

Proposing the capacity of bulk materials buffer in the simulation software

Marek Ondov, Peter Gombos, Ivana Krajnakova, Karolina Bortakova, Zuzana Sedlakova, Ibrahim Mehana

Table 1 Input and calculated values needed to create a simulation model, source: author

	Parameter	Value
Input data	power, in hours, of continual filling equipment Q_h^{FD} , t.h ⁻¹	180
	volumetric bulk density of stored material ρ , t.m ⁻³	1,6
	maximum size of the discharged pieces in the buffer z , m	0,05
	the capacity of a vehicle K_v , t	45
	Coefficient of filling the cross-section discharge outlet φ .	0,5
Calculated data	throughput - the performance of an outlet hole of the buffer, Q_h^T t.h ⁻¹	560
	the buffer emptying time T_{ET} , min	7
	time of a wagon manipulation T_{VM} , min	3
	Time of the buffer filling by material for one wagon T_{FT} , min	23
	the minimum amount of material in the buffer before loading K_T^{\min} , t	48

The results of the first experiment are shown in Figure 3.

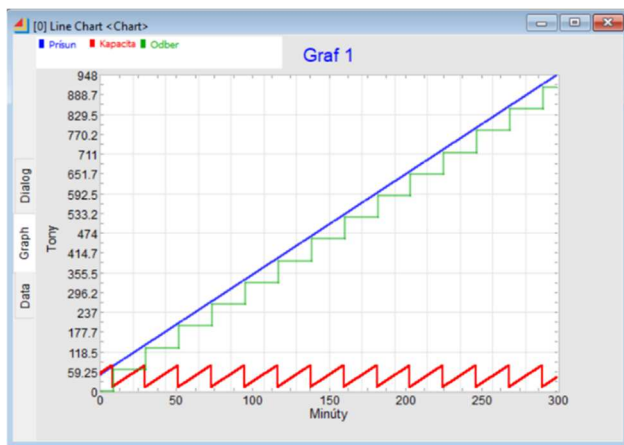


Figure 3 Graphic display of experiment outputs

The material in the buffer decreased slightly during the simulation but did not fall to zero. The blue feed curve does not go below the level of the displacement curve. During the simulation, 14 wagons were filled, which means that one train set was able to leave for 300 minutes. 948t was added to the value in the buffer. Figure 4 shows the detailed evolution of the storage capacity.

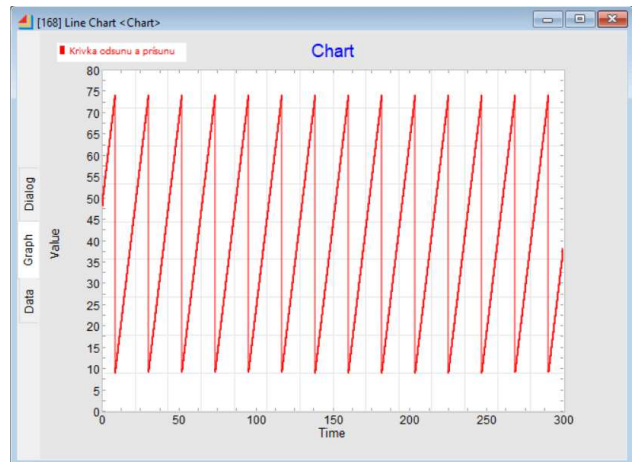


Figure 4 Graph of supply and removal of material from and to the buffer

The process set up in this way points to the correctness of the relationships stated in the available literature. The ideal situation would be if, at the end of the shift, there was again a minimum amount of material in the buffer. In our process, instead of the minimum 48t, only a little less remained - 38t.

The following experiments were also performed on the simulation model:

1. How many wagons can be filled in one shift (450 minutes), Experiment 2.
2. How long will it take to load ten train sets (100 wagons), Experiment 3.
3. How will the loading time change when the performance of the continual filling equipment is changed to $Q_h^{FD} = 250$ t/h, Experiment 4.

Experiment 2 shows the graph in Figure 5. During one shift, 450 minutes, two train sets left the simulation model, and one more wagon was filled. One thousand three hundred ninety-five tons flowed into the buffer, and 1,365 tons of material was removed.

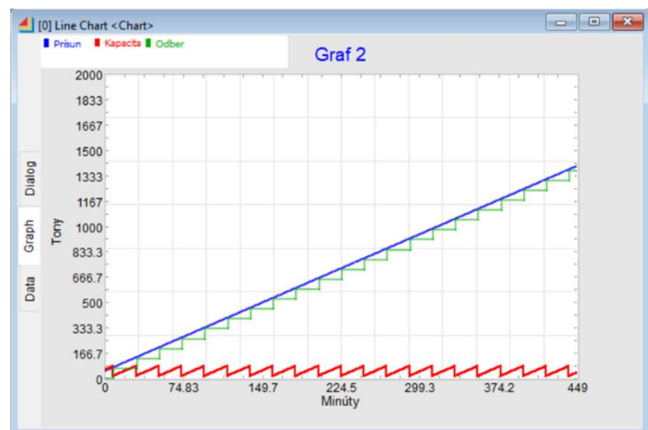


Figure 5 Results of Experiment 2

Proposing the capacity of bulk materials buffer in the simulation software

Marek Ondov, Peter Gombos, Ivana Krajnakova, Karolina Bortakova, Zuzana Sedlakova, Ibrahim Mehana

Experiment 3 is shown in Figure 6. In this experiment, the goal was to find the time needed to load ten train sets, i.e. 100 wagons. The resulting time is 2,164 minutes, which is less than five shifts. Out of the fifth shift, we need 365 minutes to complete the loading. As part of loading, 6,500t will be removed from the buffer, and 6,543t will be added.

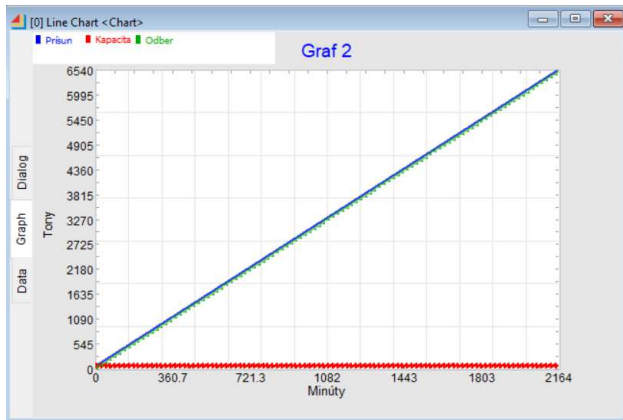


Figure 6 Results of Experiment 3

The last experiment is Experiment 3. The performance of the continuous filling equipment is changed to 250 t/h. The time of the buffer filling by material for one wagon and the minimum amount of material in the buffer before loading depend on this value. Based on the calculation according to the formulas, the time of the buffer filling by material for one wagon was determined to be 15.6 minutes, and the minimum amount of material in the buffer before loading is 36t. The results of the experiment are shown in Figure 6.

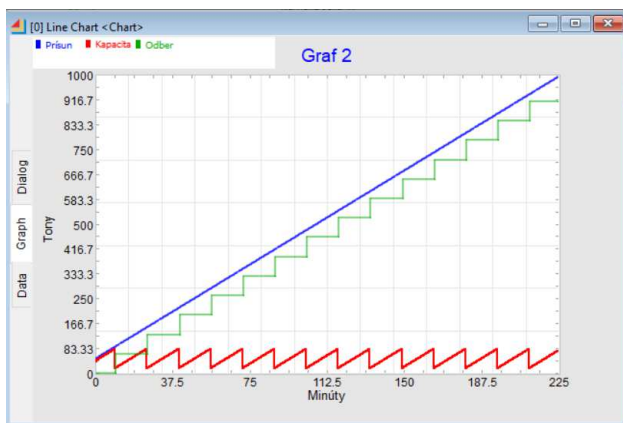


Figure 7 Results of Experiment 4

With such a change, 14 wagons from Experiment 1 can be filled in just 225 minutes.

4 Conclusions

By inserting the simulation into the algorithm for determining the capacity of bulk materials buffers, we can determine the capacity of the buffer by reading

the values from the graph of supply and removal of material from and to the buffer relatively clearly. This graphic solution should be supplemented with a recalculation. When we subtract the maximum amount of material in the reservoir and convert it using the volumetric bulk density of the material into volume, the resulting value is the basis for determining the dimensions of the buffer.

The graphical results of the simulation show the correctness of the formulas used. Returning to the buffer's original value of the amount of material is considered an ideal state. In our experiments, we had deviations from the original value in the range of 10 to 20% after completion.

The application of simulation software in the process of determining the capacity of a bulk buffer eliminated the laborious drawing of graphs. Furthermore, it was possible to perform several experiments in a relatively quick time sequence, and the rapid change of parameters was immediately reflected in the graphs.

In addition to the mentioned experiments, buffers can be emptied into vehicles of different types and capacities. For example, different trucks with different capacities can be loaded. In this case, the arrival cycle of vehicles at the buffer must also be considered. In practice, there are also different approaches to filling or emptying the buffer. The simulation model can be easily adapted by correctly calculating the selected devices' data and inserting new parameters into the blocks.

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