Simulation of Conveyor System Loading

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***Abstract*—** Simulation of loading control of conveyor system in mine industry is under consideration. Real complex conveyor system is replaced with virtual system of conveyors and spatial domain is replaced with time domain. Developed algorithm computes the time to the start of unload for loaders which arrive at underground loading points randomly. Main control and computing criteria are achieving optimal efficiency of the whole system and to avoid overloading of the system. Proposed algorithm allows prompt operational modifications of the system configuration by the supervising human operator and includes solutions for possible technical bottlenecks and emergency situations which can appear in real system. Loading permissions for loader drivers are computed on the base of fist-in-first-out queuing. Communication between server and loading points uses RFID equipment.

***Keywords*—** Conveyor system, human-machine interaction, queue model simulation, spatial and time domain.

I. INTRODUCTION

In continuous mining industry, complex belt conveyor systems for transportation of bulk material are in use. Conveyor is a horizontal, inclined or vertical device for moving or transporting bulk materials, oil shale in present case study, or objects in a path predetermined by the design of the device and having points of loading and discharge fixed, or selective. Conveyor system is a common piece of mechanical handling equipment that moves materials from one location to another [1]. The continuous mining systems consist mainly of a string of equipment starting with filling equipment (bunker or bin filled by bucket wheel excavators or loaders), hauling equipment (scratch conveyor), transfer devices and main conveying equipment (belt conveyor in both cases), stock pile or bunker feeding equipment [2]. Due to the benefits they provide, conveyor systems are used widespread across a range of industries, including the automotive, agricultural, computer, electronic, food processing, aerospace, pharmaceutical, chemical, bottling and canning, packaging. Such system of serially and parallel connected elements is characterized by the throughput i.e. overall amount of material passing system during some time interval, which is dependent on the functioning state of each involved equipment, and is affected also by the process inherent variability.

Belt conveyor systems with long distance and huge traffic are the main delivery equipment in mines. Open conveyor systems have fixed material entry and exit points. Materials go across the system only once, and not to be carried back to the entry point and re-loaded if they need transportation across the system. A belt conveyor is a typical energy conversion system from electrical energy to mechanical energy. Its energy efficiency can be divided into four components: performance efficiency, operation efficiency, equipment efficiency, and technology efficiency [10]. Important controllable actions are unloading of loaders buckets at underground loading points which are situated apart from each other, as a rule. In this paper we present the simulation experiments of real case study appeared and realized in oil shale mining and processing enterprise VKG AS [11].

The monitoring and control of conveyor systems is studied in several papers [2, 3, 6 - 10] from different points of view. In this paper, we consider the problem of loading the material onto open uni-directional belt conveyor system for transportation bulk materials. The system has multiple input points, loading points and one output point. The latter does not reduce the generality of approach.


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Fig. 1. Underground loader. Picture by courtesy of VKG AS.

The main purpose of this paper is to introduce optimal control algorithm for loading of such conveyor systems to improve the performance efficiency, and present computer simulation experiments. The objective of control is to maximize the output of the whole conveyor system versus given initial constraints and to avoid the load amounts which exceed the allowed technical parameters [5]. Identify opportunities for improving existing systems is important challenge of the factory physics [4]. The improvement of loading operation control of the belt conveyor system gives better performance efficiency in the sense of maximum throughput flow of bulk material of the whole conveyor system. In the main importance is the methodology of issuing signals to drivers of loaders for starting unloading the buckets of wheel excavators (Figure 1).

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The volumes of loaders buckets are up to 9 tons and for technical reasons the unloading process has to be quite slow. E.g., for unloading the content of 9 ton bucket, 80 seconds are foreseen and theoretically this amount of ore has to be uniformly distributed on the conveyor space and form some kind of “sausage” on the belt. An example of the possible ore distribution is on the Figure 2. Coordinated placement in the whole conveyor system of these “sausages” with different length and with randomly distributed intervals between these, is the main task of computing and simulating software module. Network models are an important category of mathematical programs that have numerous practical applications. One example is the described problem of conveyor system loading control, which has no linear programming solution because of its discrete/continuous nature.

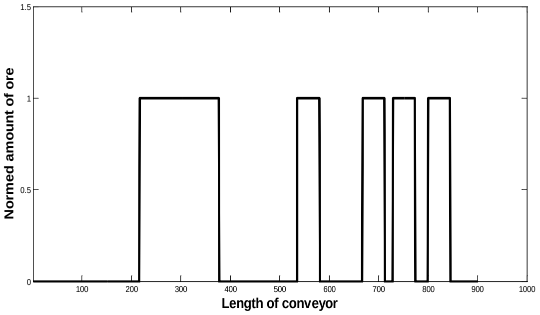

Fig. 2. Placement of ore material on conveyor belt. Capacity of the belt for a length unit is normed to one.

In the section two, we give an overview of real conveyor systems under consideration and explain the mathematical model of this. Important point is to introduce the virtual conveyor system, which replaces in loading control algorithm the real system. In the third section, the conditions of loading control are discussed and the method of computing and issuing of loading permissions is explained.

Introduced approach is implemented in VKG AS [11] for controlling of real system with more than 15 loading points and numerous sub-conveyors. Calibration of the whole control system parameters and technical equipment were successful and corresponding software is implemented.

II. REAL CONVEYOR SYSTEM

The main parameters for characterization of the systems of belt conveyors for bulk material transportation are lengths of conveyor’s sections or sub-conveyors, their velocities and load capacities. There may be one or more of loading and unloading points, or there may even be a common load/unload point on a single conveyor. Real conveyor system consists of sub-conveyors, which mean every carrier section between any loading points and/or points where the bulk falls from one conveyor to the next, or to the output point. Due to the long history of mines, the sub-conveyors have different technical properties – speeds, carrying capacities etc. Simulation software has to take all these details into account.

Figure 3 schematically shows an example of the dynamic model of a real belt conveyor system. Here the main conveyor (Conveyor1) is on scheme divided into two functioning sub-conveyors: from falling point A to falling point B and from B to the final output point OUT. The part which is on the left from point A is not under consideration in abstract scheme although there is a section of empty from bulk material real part of the Conveyor 1 and does not influence the output flow of bulk material. Real lateral conveyors (Conveyor2, Conveyor3,…, Conveyor8) have also several abstract sub-conveyors. For example, Conveyor 6, one real piece, is divided into sub-conveyors from point G to F and from G to D, correspondingly. In ellipses (points A,…,G), the bulk falls from one real conveyor to the next, triangles denote loading points (LP1, LP2, LP3) where the bulk mass enters the system. In mining industry loading points are usually apart from each other, underground and far from the endpoint of the conveyor system. At OUT, the material goes out of the system. Each of eight separate sub-conveyors has in general its own length, speed and load capacity. Consider general case. Let n be the total number of loading points in the conveyor system. Loaders arrive at the loading points randomly and form the service queue. Arrives of loaders at loading points are registered via radio frequency identification (RFID) receivers. RFID is the wireless use of electromagnetic fields to transfer data, for the purposes of automatically identifying and tracking tags attached to loaders. The tags contain electronically stored information about the loader and this is transmitted to the central server.

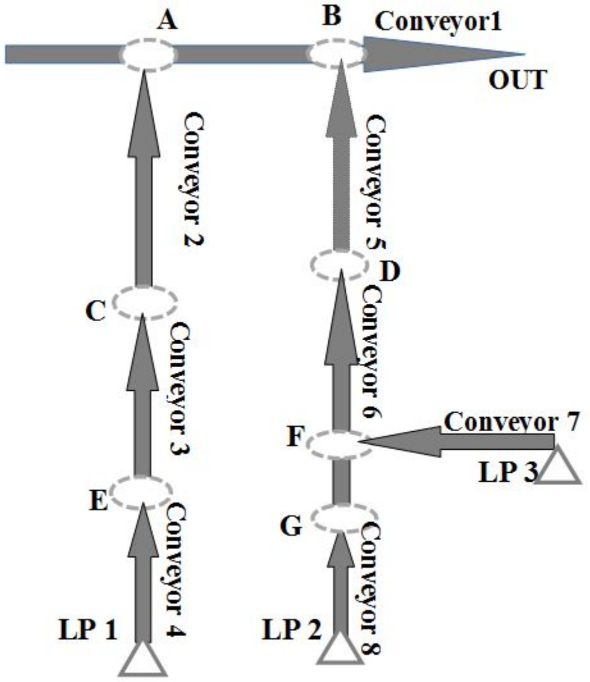

Fig. 3. Schematic view of real conveyor system with three loading points (LP1, LP2, LP3).

The most important part of RFID information, from the point of view of this paper, is the capacity of loader's bucket which in computing is treated as unloading time of the bucket content in seconds. This time is mandatory benchmark for drivers once the unloading is allowed; during this time, unloading must be finished. Drivers of loaders, when arrived, get visual signal about the registration of arrival and start waiting for the signal to start unloading. This signal contains time in seconds remained to the download start and this time is computed for him/her according to the queue processing by central server. It is done in principle first-in-first-out (FIFO). We can introduce one single output point on abstract scheme of conveyor system, point OUT in the example on Figure 3. This does not reduce the generality, because the problem is to compute and issue the time to the beginning on unloading action to loader driver who is the first in the service queue and the number of virtual output points in computing algorithm is set equal to the number of loading points, n (see next section).

Let us list the initial parameters which are needed for loading control problem. The human operator in charge fixes the values of those parameters at the beginning of working epoch, e.g. day. These values are once entered through the main server and then cannot be changed if only the whole system is restarted. Those parameters are called also conveyor system configuration parameters. Of course, also topology or reciprocal location map of sub-conveyors is needed. This topology is given via paths of sub-conveyors from loading points to the endpoint of the system.

(i) Number n of loading points and total number k of sub-conveyors.
(ii) The lengths l_1, l_2… l_k of sub-conveyors, measured in meters.
(iii) Distances between the points where the bulk falls from one conveyor to the next. These values are needed if there are such point
(iv) The speeds v_1, v_2,… , v_k of sub-conveyors, meters per second.
(v) The maximum allowed loads c_1, c_2,…, c_k for every sub-conveyor, kilograms per second. This consideration is explained with the fact that in technical specification, the load capacity of single sub-conveyors is given in units of tons per hour and this parameter is easily recalculated into kilograms per second.
(vi) The total amount m and list of loaders which corresponds to the information transmitted by RFID tags. The names of drivers which are important for workforce accounting are not needed for loading control. The time in seconds for unloading of bucket is necessary.
(vii) The maximum total amount $LOAD_{max}$ of bulk matter per one second which is allowed to come out from the final end of the conveyor system; point OUT on Figure 3. This amount means also the maximal possible throughput in second of the whole conveyor system.

On the base of these values, needed variables for numerical control of loading process are calculated. For virtual management of the queue of loaders, additional variables need to be fixed, as it is explained in the next section.

On Figure 3 we see an example schematic view of initial conveyor system with three loading points, LP1, LP2, LP3 and seven interim points, from A to G. There are 10 abstract sub-conveyors in this scheme:

1. From LP1 to E (the whole real Conveyor 4);
2. From E to C (the whole Conveyor 3);
3. From C to A (the whole Conveyor 2);
4. From A to B;
5. From B to OUT;
6. From LP2 to G (the whole real Conveyor 8);
7. From G to F;
8. From LP3 to F (the whole Conveyor 7);
9. From F to D;
10. From D to B (the whole Conveyor 5).

The total number of sub-conveyors here, k = 10. Mention that the numerating of sub-conveyors is not important for control algorithm; it is introduced in the interests of clarity. Corresponding values of lengths l_1, l_2,…, l_{10} in meters, speeds v_1, v_2… v_{10} in meters per second and carrying capacities c_1, c_2,…, c_{10} in kilograms per second determine the initial configuration of initial conveyor system. As sub-conveyors 4 and 5 are parts of real main conveyor, the corresponding speeds and carrying capacities are equal, $v_4 = v_5$, $c_4 = c_5$. Analogously, for pair of sub-conveyors 7 and 9, $v_7 = v_9$, $c_7 = c_9$. As mentioned, the lengths and speeds of sub-conveyors may vary a lot, depending of the historical development of mine enterprise. Preparation of input data for the simulation software module is so quite responsible task for operators.

III. ABSTRACT CONVEYOR SYSTEM

Formalization of initial data in the spatial-velocity domain is complicated. For computer simulation and numerical processing, another approach to the abstraction of real conveyor system is needed. We do this in the time domain as following. For every loading point LP1, LP2,…, LPn, we introduce the virtual conveyor, the length of which is counted in seconds. These lengths mean the time it takes to arrive for a particle of material on working conveyor system from loading point under consideration to the endpoint of the conveyor system, OUT. Figure 4 shows the system of virtual conveyors that is obtained from the example on Figure 3.

The lengths s_1, s_2 and s_3 in seconds of virtual conveyors, correspondingly VC1, VC2, and VC3, depicted in Figure 4, are:

$$s_1 = l_1/v_1 + l_2/v_2 + l_3/3_2 + (l_4 + l_5)/v_4;$$
$$s_2 = l_6/v_6 + (l_7 + l_9)/v_7 + l_{10}/v_{10} + l_5/v_4;$$
$$s_3 = l_8/v_8 + l_9/v_7 + l_{10}/v_{10} + l_5/v_4.$$

The lengths of virtual conveyors are usually different from each other. This system of parallel virtual conveyors is the base of control algorithm of loading the real conveyors. In general, the parallel system of virtual conveyors consists of the same number of lines as loading points.

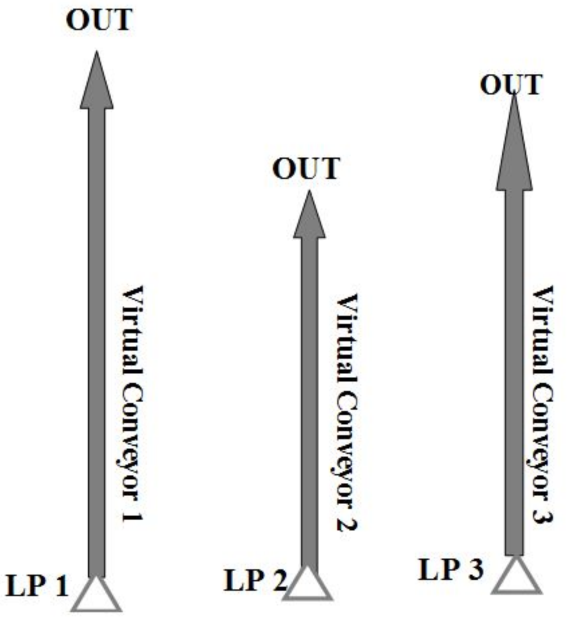

Fig. 4. Virtual conveyors which correspond to the real conveyor system on Figure 3.

The load capacities of virtual conveyors are determined by the smallest capacity of component abstract conveyors. E.g., the load capacity of virtual conveyor VC1 on the Figure 4 is min (c_1, c_2, c_3, c_4).
Now we have to speak about loaders (see Figure 1), which have to carry bulk material onto conveyors through loading points. In practice, these loaders come from distance and carry a certain amount of matter at once and these amounts are constants. The loaders are driven naturally by people and this makes the whole system considerable as human-machine interaction system. There can be several types of loaders in mines, everyone with its own volume of bucket but these volumes are the same every time the same loader arrives. Mention that the volumes of buckets are up to nine tons of ore. The arriving instants of loaders are essentially random and do not depend of each other. Here the discrete – continuous nature of the problem appears. The arriving are discrete events but unloading has to be continuous. Loader driver gets the fixed time to unload the bucket, which depends on the volume of loader, and load capacity of the total virtual conveyor. Once initiated, unloading action has to be finished and not interrupted.

For loading control algorithm, it is enough to know these unloading times for each loader. We denote these times by t_1, t_2,…, t_m where m is the total number of loaders in the workforce list. Mention that the unloading time for loaders with bucket volumes of nine tons, are 80 seconds. As a rule, there are only small number of different loader types in use in concrete mine industry, so we have many similar values among those allowed unloading times but in general these can be also different from each other. Therefore, we have all together m loaders that can arrive at any loading point at any time, randomly. RFID equipment registers the arriving of loader to the loading point and transmits corresponding information to the central server. Then the first appropriate unloading start time instant is computed for the loader on the first position in the queue and the time left to the beginning of unloading is displayed for the loader driver on special display at loading point. The method for computing of time remained to the start of unloading, uses first-in-first-out approach. All approach bases on the assumption that loaders drivers keep the rules of unloading and follow the unloading times.

IV. LOADING CONTROL ALGORITHM

The problem of control of loading of the conveyor system in described as a decision making task for discrete – continuous process. The discrete component is the possibility that we have all together a set of loaders, every one of which can arrive at loading point randomly at any time. The continuous part is the unloading action. Loading permission is issued in seconds remained from current time instant to the beginning on unloading the bucket of loader on the first position in the waiting queue. Then the loader driver, human component of the system, has fixed time in seconds during which the unloading has to be finished. At the same time, driver has to keep rules not to unload the material from bucket too quickly to avoid the overloading of input device. Allowed unloading times t_1, t_2,…, t_m are determined by experts, separately for every type of loader, these unloading times are among the initial data and registered also by RFID.
The general block diagram of the loading control algorithm is on the Figure 5.

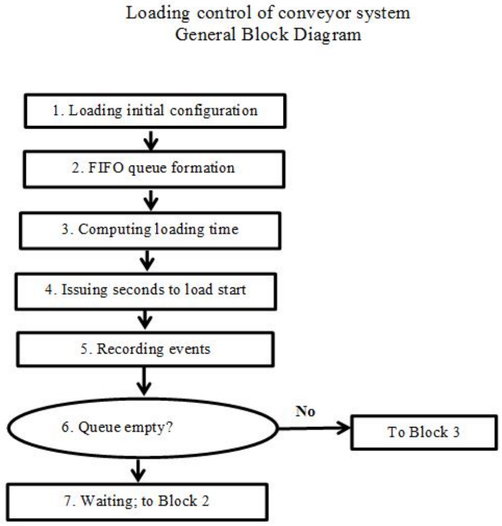

Fig. 5. Block scheme of the Loading Control Algorithm.

In Block 1, the software is started and the initial parameters and conveyor system configuration is loaded to workspace. Let us discuss further the initial parameters needed for algorithm.

a) Number n of loading points which coincide with the number of virtual conveyors. Every virtual conveyor corresponds to one loading point, so there are also n virtual conveyors under consideration. The value of n is given by operator.

b) The lengths $s_1, s_2, \ldots, s_n$ of virtual conveyors, measured in seconds. The length values are calculated in special initialization module of the software.

c) The maximum allowed loads for every virtual conveyor. These values are calculated in initialization module of the software and are determined by the smallest of allowed maximum loads $c_1, c_2, \ldots, c_k$ of sub-conveyors in the composition of present virtual conveyor. In practice, the smallest carrying capacities have the first sub-conveyor components of virtual conveyors, immediately after loading points. It is because these parts are less fixed and are changing with the loading point shifts.

d) The maximum total amount $LOAD_{max}$ of bulk matter in one second which is allowed to come out from the final end of the conveyor system. This parameter is in the main importance for loading control algorithm and is fixed also by the operator before the working époque. The times in seconds, loading_time, remained to the beginning of unloading action of matter from loader's buckets are computed just in way that the total sum of bulk does not exceed this value in all parallel points of virtual conveyors.

e) The length q in seconds of the empty area before the lengthiest virtual conveyor, this is needed to place the virtual load after issuing the next loading permission. This length is calculated in the central server on the base of previous numerical experiments. The necessity of this virtual space is explained below.

For completing of preparations for main software module, another reconfiguration of virtual conveyor system is needed. Parallel points of virtual conveyors mentioned in d), appear after this. Namely, the endpoints of virtual conveyors are placed at the same point, at distance p seconds from the common beginning of the whole system,

$$p = \max[s_1, s_2, \ldots, s_n] + r .$$

Here r denotes number of seconds, introduced above in e). Algorithm of loading permission computing uses this additional virtual space for reservation of unloading areas for loaders which get the permission. The new reconfiguration picture, in the case of our example is on the Figure 6. The distance between two dashed lines, lower and upper, is p seconds. Onto the empty space before the loading points LP1, LP2 and LP3 the computing module places virtually the load of bucket of the loader which was served last and got unloading permission.

For example, assume that the loader number j with bucket volume of t_j seconds appears at loading point LPi and appears on the first place in FIFO queue, so gets serviced first, and its load does not cause overloading of the system of conveyors. Then inner variable loading_time will be set equal to zero is issued and algorithm fills t_j positions before the initial point of virtual conveyor VCi.

The initial points of different virtual conveyors are shifted now towards the endpoint of the system; these shifts are computed by the software. According to arrive to real load point, the live queue appears where service keeps the FIFO principle. For the first loader which arrived earlier than others in the queue, the beginning of loading time is computed. Then in simulation environment, the expected unloading result is saved. This means the technically allowed length (in seconds) for loader driver to accomplish the unloading process. As mentioned, this time might to be quite long so the unloading action is not a trivial task for drivers.

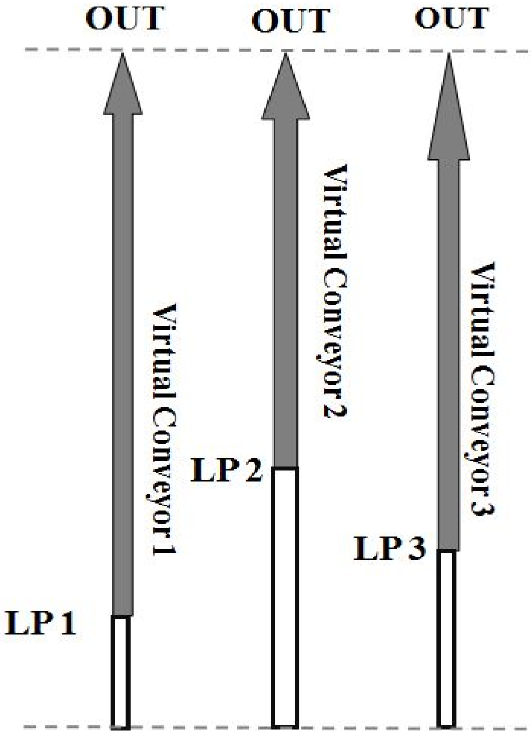

Fig. 6. Virtual conveyors with additional free space for current loads.

V. IMPLEMENTATION AND SIMULATION

Described approach for control of conveyor system loading process was implemented in Estonian mining company VKG [8]. Figure 7 shows an underground real loading point.

In real system, there are 15 underground loading points, each of which has RFID system for identification of loaders. RFID receivers are connected with main server which connects and coordinates the actions of components of the control system: supervising operator, computing software modules and procedures, module of initial data, registration part of all events in the system and visual communicators at loading points. The number of sub-conveyors in VKG industry is up to

50, configuration of the whole conveyor system is modified regularly.

Fig. 7. View of a Loading Point. Picture by courtesy of VKG AS.

Next figures demonstrate a simulation example for three virtual conveyors (see also Figures 3 and 4). In this example the carrying capacities of virtual conveyors are normed by one, the maximum load, $LOAD_{max}$ is equal to 3, initial points of virtual conveyors in the scale p = 1000 seconds are, correspondingly at time instants 150, 350 and 275 seconds.

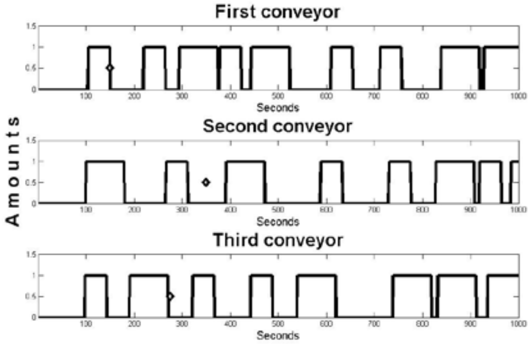

Fig. 8. Simulation example of loaded conveyors.

On Figure 8, we see a simulated example of loads on virtual conveyors. There are three virtual conveyors under consideration and the load capacities are normed to one.

On Figure 8, p = 1000 seconds, maximum load q of one conveyor is normed to one, diamonds indicate the initial points in time domain of virtual conveyors. These initial points are at 100, 150 and 176 seconds, respectively. The length in seconds of the empty area before the lengthiest virtual conveyor, r = max(100, 150, 176) = 100 seconds. There are simulated random arrive of loaders to the loading points (diamonds on Figure 8). Two capacities of buckets are possible: with unloading time 45 seconds and 80 seconds. Widths of impulses on the figure show corresponding values.
The example of dynamics of total load in conveyor system is on the Figure 9. The sum corresponds to the situation generated on Figure 8.

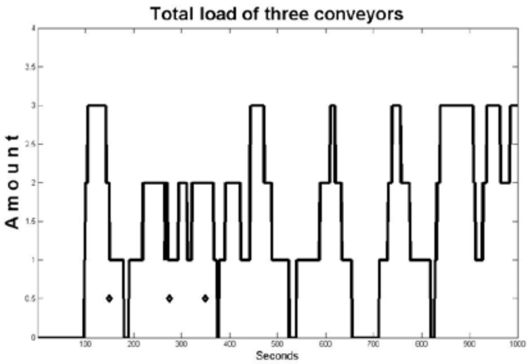

Fig. 9. Total load or amount of material on conveyors.

Here the total amount of bulk material does not exceed three because the number of virtual conveyors is three. The constraints for overloading are not used in this simulation experiment.

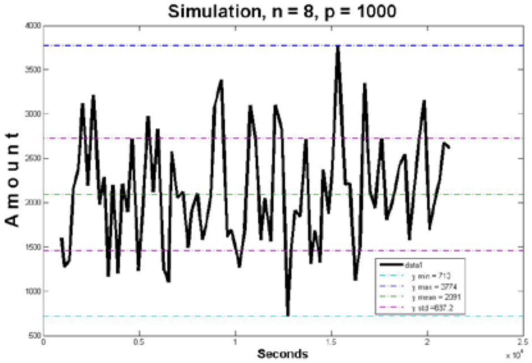

Fig. 10. Simulation results for 8 virtual conveyors: total load.

Figure 10 shows the simulation results of loading control algorithm, total loading amount on conveyor system. We see the stage of working process, where the amount on the conveyor system is stabilised. Namely, after starting, it takes a while to fill normally all sub-conveyors and just this is seen on the figure. Simulation time was 6 hours and on this plot we see the amount which falls out during every 250 seconds sub-periods. Inputs through loading points are again normed to one, the maximum allowed load amount $LOAD_{max} = 3$. One sees the fluctuation of output amount. This shows the discrete-continuous nature of events in the system. Moving real conveyor system does not allow any changes on sub-conveyors upper of loading points and the loader drivers in queue have to wait there turns.

The simulation software foresees appearance of emergency situations in real system. In the presence of multiple conveyors and sub-conveyors which have different use of time, the breakdowns are possible with great probability. Sometimes it is not practical to obtain completely new equipment but repair and change some details in old system. And then some parts of conveyor system has to be stopped. After reparations are done, of the main importance is to restart the stopped system without the risk of overloading. This risk is minimized by reducing the maximum allowed load, $LOAD_{max}$, in the whole system for a while. When the real system is working normally, the value of $LOAD_{max}$ can be restored.

VI. CONCLUSION

The loading control of conveyor system in industries plays an important role and needs improvement. In this paper one possible approach is explained. As mine industry is not fully automatized and there is human impact in performance results, the electronic devices between the processing stages have to be properly steered. In the contribution, a model of loading control of multiple input conveyor system and simulation program is described. The model is based on a system of connected conveyors. Simulation approach has proven to be successful. Experiments with the model show that used method enables to model also complex conveyor systems in mining industries. The model can be also used for evaluation of capacity requirements and for testing of planned changes in the system control. Obtained during the implementation experiences show that the most serious bottleneck can appear in human-machine interaction processes. Here the explanation of principles of mathematical modelling and of control software implementation are very important.

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