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STABILITY OF PROCESSES IN THE MINING INDUSTRY

1. Introduction

The mining industry is specific due to variable conditions of the process environment. Operation of a mine significantly differs from operation of a typical manufacturing plant. Building the process stability in the mining industry is much more complicated also for this reason. The starting point for building the stability is to build models of processes and adequately parameterise them for the control needs.

A model of a process is a simplified description of the real process, built for the purposes of the research conducted (Fig. 1). It is constructed in a way that allows replacing the real object of research [1].

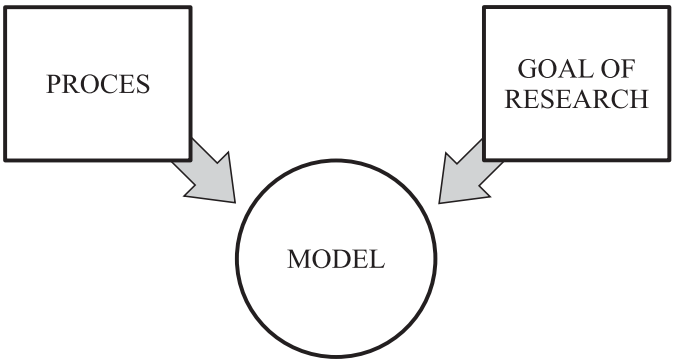

Fig. 1. Relation between a process, the purpose of research, and the model [1]

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On the other hand, a process is defined as a set of interrelated or interacting activities, which transform input elements into output elements [2]. From the perspective of a model, apart from the aforementioned dependencies between input and output data, it is also important to monitor process parameters, which may be controllable and uncontrollable. Control of a process takes place on this basis (Fig. 2) [3].

Building the stability of processes is significantly associated with constructing the models. It's because the fact that the tool in the form of a model allows answering the cognitive questions, e.g. determining the standard of process parameters [1, 4].

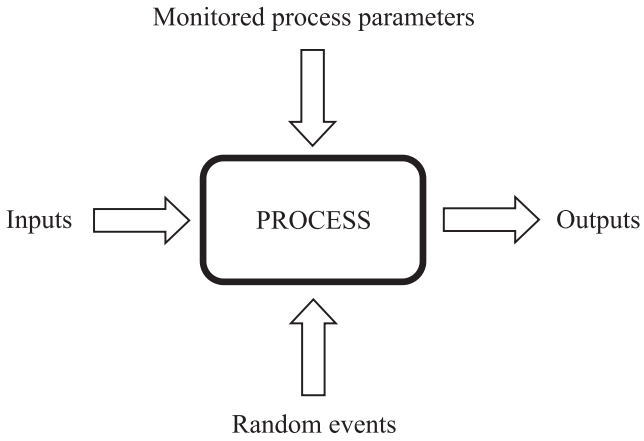

Fig. 2. Flowchart of a process

Stability considered in a very broad sense means invariability over time (constancy) of a feature or a certain sequence of states [5]. Stability is therefore understood as finding the state of balance after introduction of a disturbance. In most cases, stability is a necessary prerequisite for practical application of a system [6, 7]. In that case it is important to select such parameters of a process that allow maintaining its invariability over time. Building a model and then defining the parameters and the ranges of their values is therefore the starting point for stabilizing a process subjected to disturbances.

2. Multi-layer character of the structure of a system as a foundation for building the stability[1]

In order to achieve processes stability it is worth to use the multi-layer character of the structure of a system, as shown in Figure 3. The first step is to build the basic layer of a system

[1] Own study based on [5]

process, that is a model of activities in a given process (S_4). The model can be represented with the use of a variety of notations, e.g. BPMN, IDEF0 or UML. Selection of a suitable notation depends on what exactly the author wants to present with the use of a model. The parameterisation layer (S_3) should be then determined, which includes selection of appropriate parameters of the system elements that will be monitored continuously. The selected parameters should be taken into account in the process model built earlier. The next task involves comparing the values of the selected parameters with the standard (S_2). The standard is nothing else but a range of values that allow ensuring the stability of processes. On the basis of a comparative analysis, there are taken further actions in the control layer (S_1). Control, that is regulation, determines stability of specified values at the levels set, as defined in the standard. If values of the monitored parameters exceed the range of the standard, the purpose of this layer is to start the performance of activities that will allow the process to return to the state of stability.

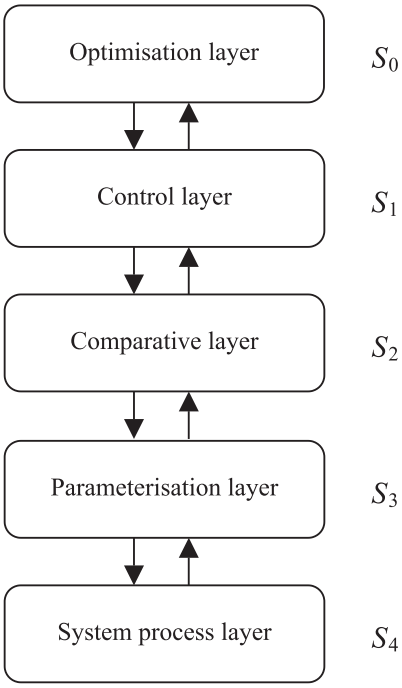

Fig. 3. Multi-layer structure of a system

The last and at the same time the highest layer is optimisation (S_0), which aims at solving tasks over a time horizon longer than control and is associated with finding such values of the process parameters that will allow, taking into account the restrictions set, obtaining the most desirable value of the specified indicator from the viewpoint of its management.

3. Analysis of the selected process from the mining industry

For further analysis of the problem of building the stability of a mining system, the process of loading and haulage was selected. This is one of the stages of the most important process, i.e. mining. Within the mining process, which generates an added value, there have also been identified other stages, such as drilling, winning, anchoring and removal of a selected space. Figure 4 shows a BPMN (Business Process Modeling Notation) model prepared for the analysed process. BPMN is a graphical notation used for modeling business processes — it does not model the data flow, but only the control flow [8].

In accordance with the multi-layer character of a structure, building a model of a process is a basic stage in forming its stability. By preparing a BPMN diagram, it is possible to represent the logic of the process and the flow of its elements.

The purpose of the loading and haulage process is to move the ore from the mine face to the dumping site. Participants in this process are: shift foreman, operator of a bucket loader, and operator of a haulage vehicle. The main activities include the permission for output winning, loading the ore, and unloading the output on the grate. Two key measures were established in the copper mine, the purpose of which is to parameterise the service performed, that is the mass of the ore hauled during one shift (in Mg/shift), and the engine hours of the operation of machines (a loader and a haulage vehicle). The measures of the process are used both for monitoring the process and for assessing its effectiveness. They also allow controlling the efficiency of the utilization of resources.

After a more thorough analysis of the process in question, it seems that determination of only two parameters in this process is insufficient from the viewpoint of the parameterisation, comparative and control layers. Therefore, one stage was selected during further studies in order to particularize the tasks of next layers of the structure. The selected stage is the process of loading a haulage vehicle (Fig. 5).

As it is known, every process is subject to disturbances, which disturb the balance of the system. In order to restore the state of balance in the system, the system must be stable [5]. In the case of the process of loading a haulage vehicle, disturbances may include: failures of machines, technical hazards, and insufficient amount of the output. Therefore it seems to be important both to inspect the state of the transport equipment (P_1) and to ensure an adequate number of machines in good working condition (haulage vehicles and bucket loaders) (P_2) — and such parameters should be monitored continuously. Another indicator, which would allow maintaining the state of balance, is provision of a sufficient quantity of the output in the mine face (P_3) and adequate transported mass (P_4). It is important to properly use the observations of the parameters for determining next control decisions. The aforementioned measures are only examples of indicators that should be controlled, and their purpose is only to indicate that a number of different aspects affect the process of ensuring the stability.

From the viewpoint of the whole loading and haulage process, the task of building the stability will consist in determination of values of the parameters for specific states at the moments t_0, t_1, …, t_n, ...

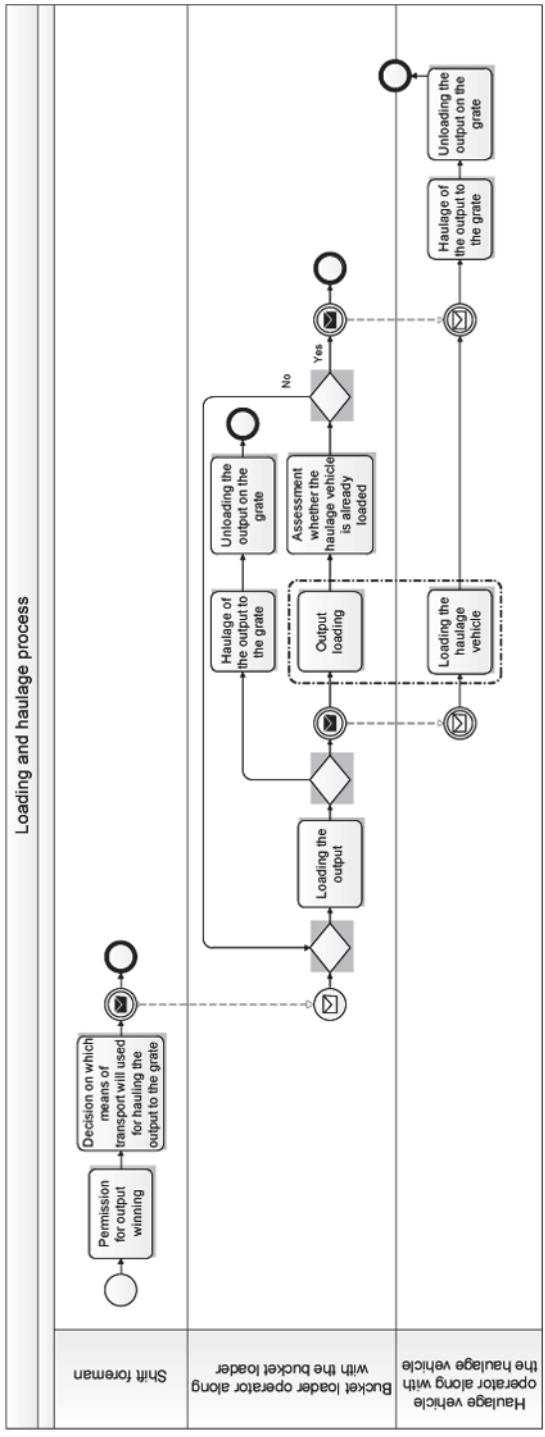

Fig. 4. BPMN diagram of the loading and haulage process in a copper mine

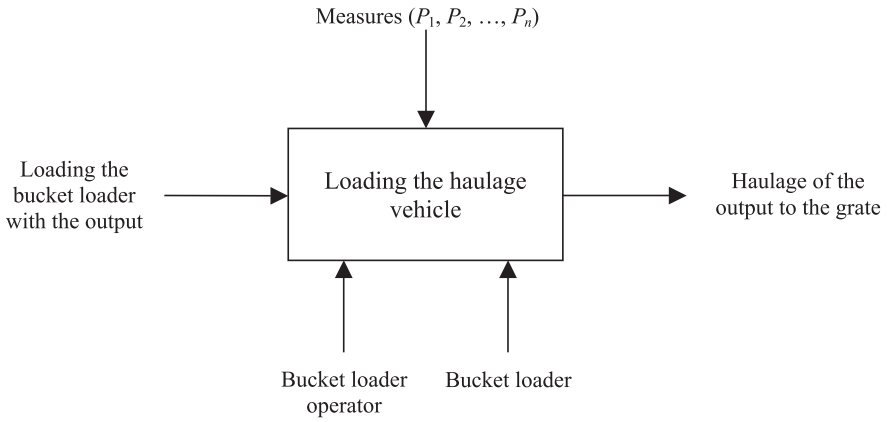

Fig. 5. Sub-process of loading a haulage vehicle

For example, the operation of loading the output on a haulage vehicle is described by the values at the moment t_n, while the features of the process at the moment $t_n + 1$ will concern the operation of unloading the output on the grate. If a process is to be stable, there must be ensured the stability of individual stages, and therefore the measures in specific moments of the process should approach to the x values from the standard.

$$P_n\left(t_n\right) \rightarrow x \tag{1}$$

So the goal is to maintain specific outputs of the system at the level set. The states at the moment t_n or $t_n + 1$ can be described as the vectors, whose coordinates determine the values of all features concerning the stages of loading the output on a haulage vehicle and unloading the output on the grid. By comparing the values of the parameters with the established standard it can be concluded whether the transport of the output to the grate is stable.

Figure 6 shows a sample diagram of the multi-layer character of the loading and haulage process, which includes a fragment of the system process layer together with possible disturbances, as well as the control layer and the optimisation layer.

Optimal functioning of processes, i.e. such functioning that enables individual indicators of the parameters to reach the most desired value while fulfilling all the restricting conditions, is associated with defining the standard of values. The standard covers the range of values that will allow maintaining the stability of processes. Continuous monitoring of the parameters will allow determining an optimum standard. For example, the parameter of the transported mass should be constant — both too small and too large mass of the transported ore output can disrupt the operation of the entire system. Therefore, it is important to select such parameters and such ranges of their values that will ensure the invariability of the process and, over a longer period of time, also its optimisation.

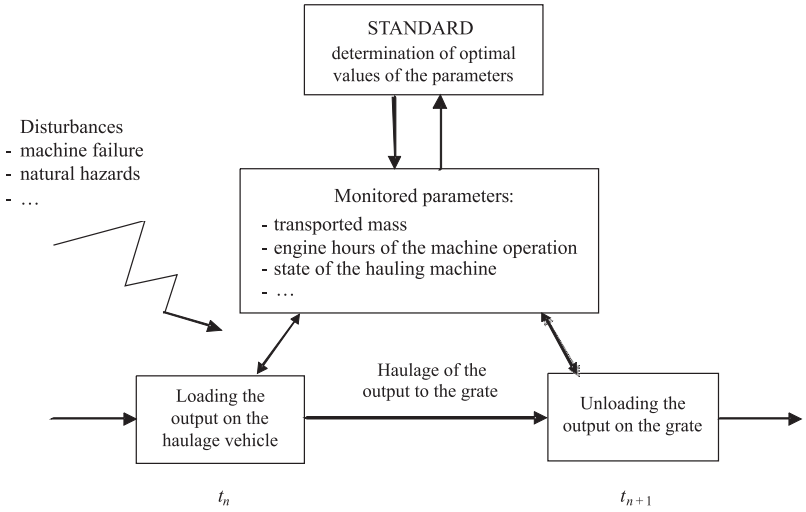

Fig. 6. An example of the multi-layer character of the structure of the loading and haulage process

4. An example of controlling a parameter in order to maintain the stability of a process

As mentioned earlier, the stability of a process is affected by many various parameters. After the stage of building a model of the process and its parameterisation, next steps should be taken in order to ensure its stability, i.e. values of the parameters should be compared with the standard, and then process control should be commenced. Loading and haulage will still constitute the analysed process, but only one parameter of the process will be considered in terms of maintaining the stability, that is the mass of the output hauled during one shift. Figure 7 shows a sample algorithm for building the process stability, which uses an analysis of the above-mentioned parameter.

As shown in the diagram, such manner of controlling the process so that it returns to the state of balance requires continuous monitoring and measurements.

5. Summary

Ensuring the stability of processes in the mining industry is a very real possibility. By building a model of a process, parameterising it, and determining an appropriate standard, it is possible to monitor the process and to maintain its invariability over time. The paper presents the course of proceeding for only one process, i.e. loading and haulage, which however is sufficient for understanding the idea of the research and for ensuring the stability. Proper organization of work, the standards of execution and the course of production processes, as well as solving the actual problems are very important factors also in the mining industry.

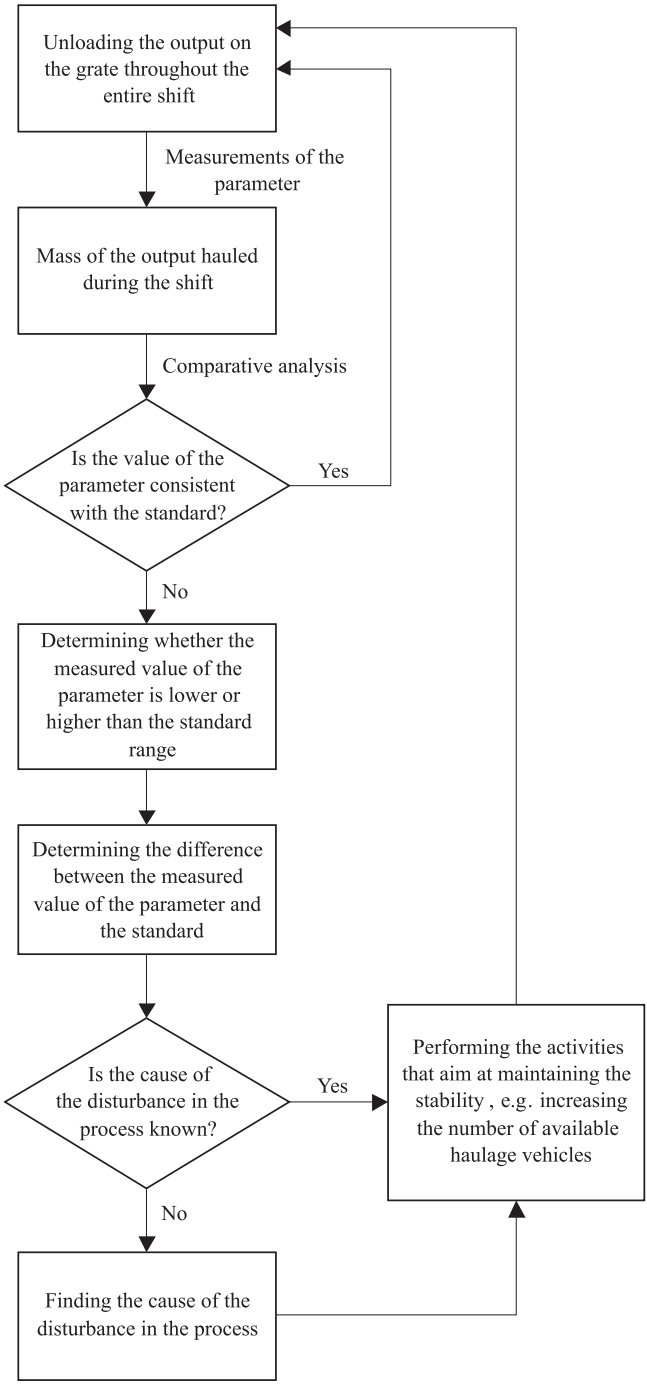

Fig. 7. Process control algorithm

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