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The value chain strategy for optimizing the process of drilling and using longwall gateroads in hard coal mines

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Andrzej WALENTEK [1*]

Author's affiliations and addresses:

[1] Central Mining Institute – National Research Institute, Plac Gwarków, 40-166 Katowice, Poland

*** Correspondence:**

e-mail: awalentek@gig.eu

tel.: +48 32 259 24 29

Abstract:

The process of gateroad development, also known as preparatory works, and then ensuring their stability throughout their lifetime, is a very important issue from the point of view of mining (extraction) operations. This article attempts to develop an optimal strategy for the gateroad development process in coal mines, based on the assumptions of the value chain model used by companies. The model developed is aimed not only at increasing competitive advantage due to a reduction in the cost of coal mining, but primarily at changing the mentality of employees and their approach to the work performed allowing for improved mining efficiency.

Keywords: longwall roadway, coal mining, life cycle, strategy, value chain

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1. Introduction

A characteristic feature of mining operations is the relatively long (several years) pre-production period, which includes the exploration of the deposit, its evaluation, the opening and gateroad development carried out before the deposit is mined, and the relatively long production (exploitation) period. The time alone to drilling longwall gateroads and cutting (gateroad development) for one longwall is a period of 10 to 12 months. In the cost structure of the direct processes of a longwall according to the phases of its operation, excavation represents 45.5%, longwall reinforcement 21.5%, exploitation 30% and longwall decommissioning 3% [1]. It is important to note that at each stage of the longwall's operation, expenditures are incurred [2], influencing the amount of costs incurred, shaping the final result of the longwall's operational efficiency. Hence, in assessment, it is necessary to analyse the costs incurred throughout the cycle, from the preparation phase to the longwall closure phase.

The above considerations led the author to attempt to develop a strategy for optimising the process of drilling and using longwall gateroads in hard coal mines, based on the value chain model (Porter 2006). The considerations and organisational assumptions for the model presented in the article may improve the quality of the excavations performed, which may also translate into improved efficiency of the longwall coal extraction process.

2. Materials and Methods

2.1. General characteristics of longwall roadways in the Polish mining industry

According to the definition, a corridor in underground mining is a gallery development carried out horizontally or almost horizontally (up to 5° inclination), with no direct exit to the ground surface. A corridor is excavated into a deposit and yields ore that is a useful mineral (e.g. coal corridors) [3].

Wall headings, in contrast to access headings, are short-lived headings whose existence is related to the time during which a given longwall field will be excavated. During this period, high dynamics of changes in the load and deformation can be observed in the working faces due to the direct influence of the moving mining front. This makes it essential, in order to obtain the highest possible productivity from the longwall, i.e. to maintain the repeatability of the mining cycle time of the coal casing, that the quality of the cuttings made is sufficient to ensure their proper usability during longwall corridor excavation on. Fig. 1 shows the full life cycle of a longwall gateroad.

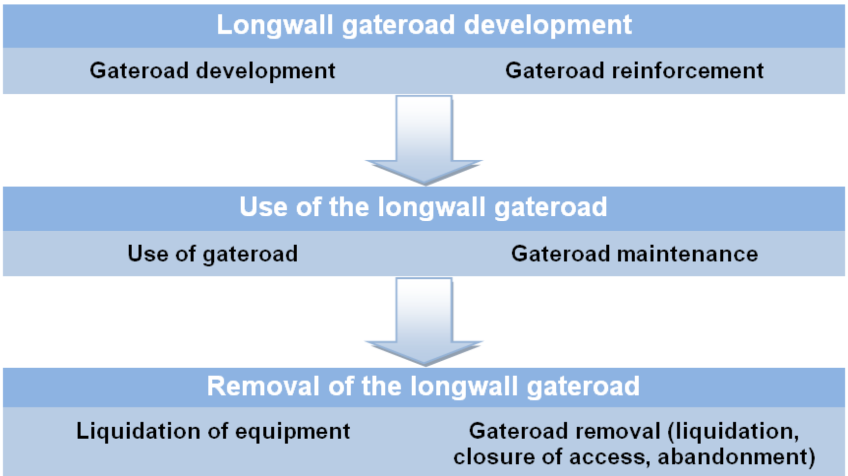

Fig. 1. Full life cycle of a longwall gateroad

Difficult geological and mining conditions and the additional influence of exploitation pressure caused by the moving longwall front cause the phenomena of vertical convergence, i.e. subsidence of the roof and uplift of the floor (Fig. 2a, 2b) and horizontal convergence (Fig. 2c) of significant values to occur in gateroads.

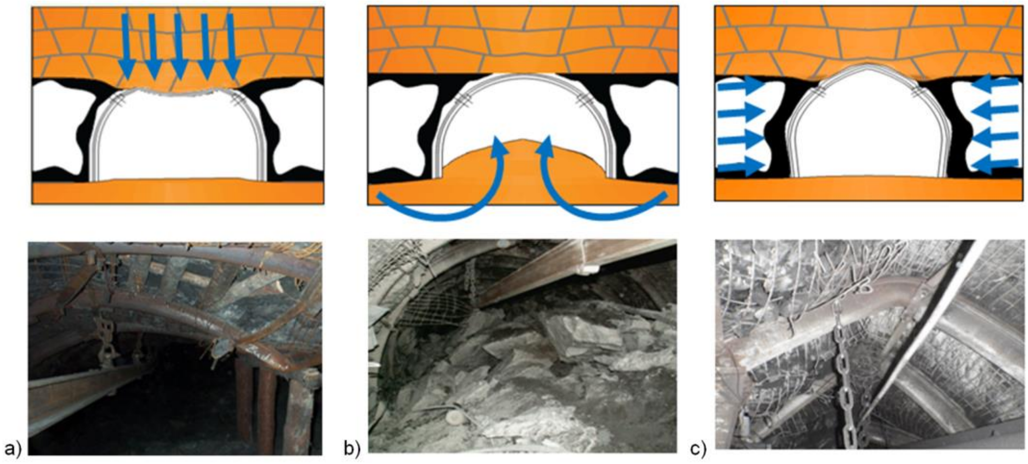

Fig. 2. Examples of deformation of longwall gateroads: a) subsidence of the roof; b) uplift of the floor; c) displacement of side walls

This phenomenon results in a strong deformation of the lining and loss of the cross-section of the gateroad. Such a situation adversely affects the rhythmicity of the longwall mining process and the ventilation of the mining field, worsening the comfort and safety of the crew's work, especially in the case of mining highly methane coal seams [4, 5]. The results of a recent study of cross-section loss in 28 longwall roadways are presented in Fig. 3 [6]. The largest averaged changes in the cross-sections of the workings occur in the area of the intersection of the longwall with the Tailgate 56%, in the Headgate 26% or when the gateroad is maintained behind the longwall face to a value of 58%.

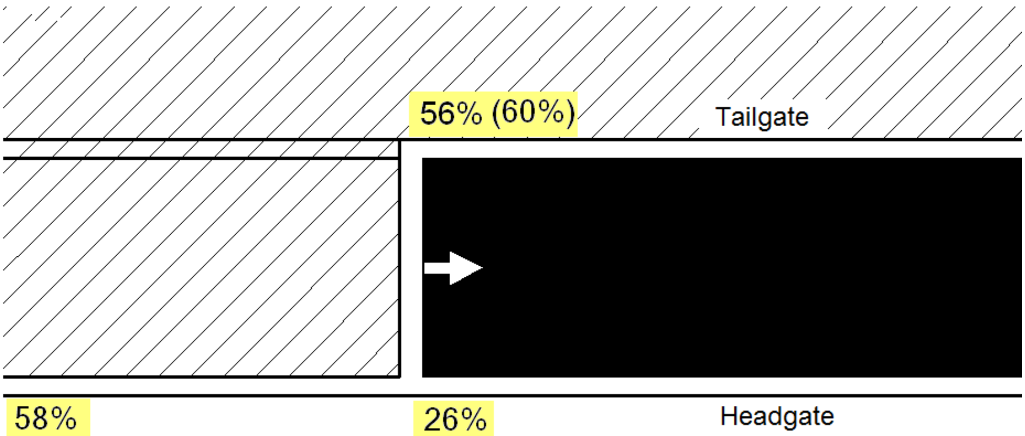

Fig. 3. Average percentage values of loss of cross-sectional area of gateroads in the area of inlets to the wall and 200 m behind the mining front [6]

In view of the above, the use of additional reinforcement of the steel arch support is becoming more common in order to increase the stability of adjacent gateroads. In the face gateroads, usually in front of the face of the longwall, additional reinforcement of the steel arch support is used by means of steel or wooden props and by anchoring the steel beams with steel rockbolts [7]. In the case of gateroads maintained behind the face of the longwall (due to ventilation or its reuse), additional steel or wooden props and support strips, e.g. wood crib support, are used to increase the support of the lining [8]. An example of reinforcement of a gateroads held behind a longwall face is shown in Fig. 4.

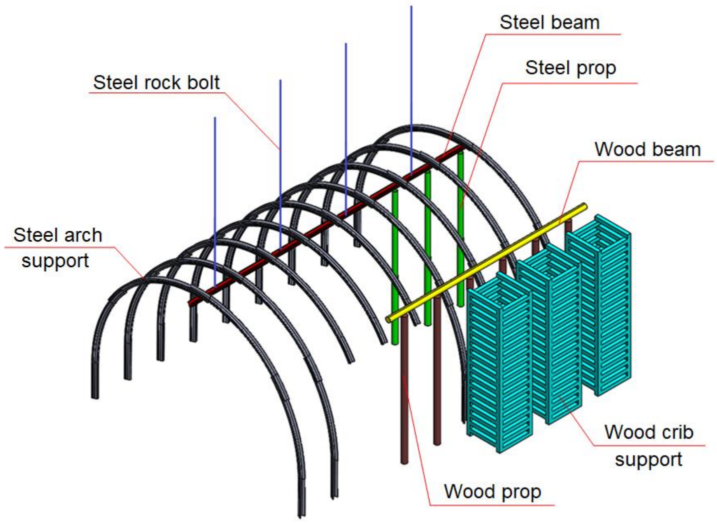

Fig. 4. An example diagram of the reinforcement of a longwall gateroads

The international research project, funded by the Research Fund for Coal and Steel (RFCS) - European Commission and carried out at the Central Mining Institute from 2013 to 2016, entitled "Advancing Mining Support Systems to Enhance the Control of Highly Stressed Ground" [9] has shown that mines, due to mining at great depths, will increasingly be 'forced' to use additional elements to reinforce the basic susceptible arch support, in order to maintain the stability and usability of workings located in difficult geological-mining conditions [10].

All additional reinforcements of the steel arch support casing, as well as the ongoing reconstruction and modernisation of the maintained roadways, affect the total cost of coal production [11, 12]. Nevertheless, the optimal design of the lining for specific geological-mining conditions [13] and the timely execution of all preparatory (reinforcement) works can ultimately have a positive impact on the entire mining process and reduce the cost of coal production.

One of the tools used to verify the efficiency of coal extraction with the longwall system are monitoring systems for machinery and equipment operating in deep mines. An example is the monitoring system offered by FAMUR called E-mine. An example of the application of the system in one of the longwalls, presented in the publication [14], allows us to indicate some areas of potential improvement in the efficiency of the mining process in longwalls (Fig. 5).

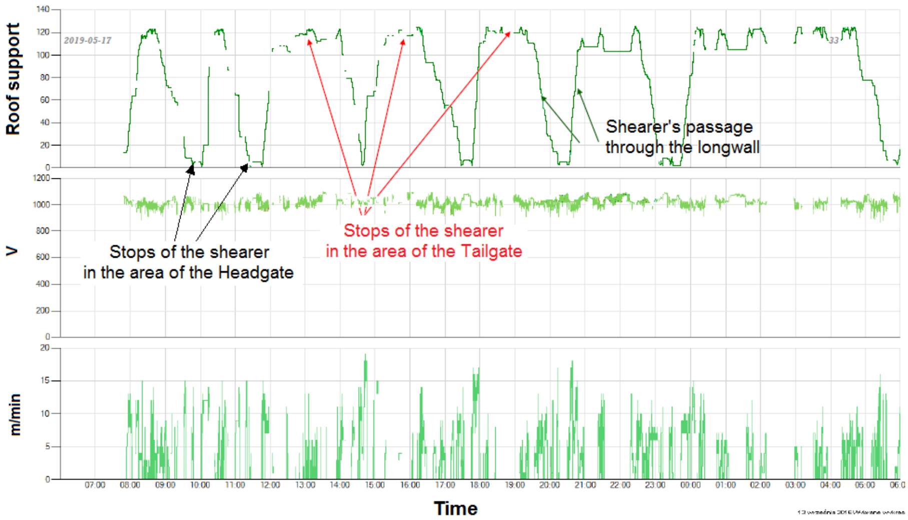

Fig. 5. Charts of the actual operation of the longwall shearer and speed changes in the report of the FAMUR e-mine system [14]

The upper part of Fig. 5 presents the recorded durations of full mining cycles, which consist of the time the shearer passes through the longwall (cut) and the time it takes to rebuild the intersections in the area of the Tailgate with the longwall, in order to perform the next cut. This figure clearly shows that much of the time (as much as 90 minutes) was lost to shearer downtime associated with rebuilding the intersection of the Tailgate with the longwall. The reasons for this situation are most often:

– improper design of the intersection of the longwall and the overhead walkway,
– inadequate execution of the longwall walkway,
– leaving behind unnecessary components and equipment, as well as excavated material after the completion of longwall excavation.

2.2. The value chain in theory

The concept of the value chain was formulated in the 1980s by Michael E. Porter [15] and, due to its high application value, quickly became one of the leading concepts in strategic management.

According to M.E. Porter, a value chain is a well-defined stream of different types of activities that are undertaken by companies, which in different ways form a common value system. This chain describes the various processes aimed at maximising the value of a given enterprise's own products. In other words, the value chain is a sequential representation of the elementary sets of functions performed in a company (from R&D, to production, to sales and warranty service). Each link in the chain generates additional value. The aim is to create value for the buyer with the assumption that the value is to exceed the costs incurred [15].

The underlying value chain distinguishes two types of activities, from the point of view of their contribution to value creation for customers: core activities and support activities. Core activities relate to the physical manufacture of products or the provision of services and to sales and after-sales service. They are usually realised in a sequential arrangement through the individual departments or divisions of the company [16]. In essence, the primary activities reflect the technological sequence carried out in the enterprise, beginning with the physical receipt of inputs into the enterprise and ending with the customer's handling of the usable product. The scope of the value chain is limited to what is realised between the supplier and the direct customer [16].

The second group of base activities of the value chain model are the supporting activities. They permeate the core activities and involve many departments of the company. In this sense, they come close to regulatory processes. Supporting activities do not directly participate in the creation of value, but fulfil a security function for the course of basic activities [17].

The components of the value chain base model and the characteristics of the links distinguished in it can be graphically illustrated in Fig. 6. It represents the most widespread and most important understanding of the value chain.

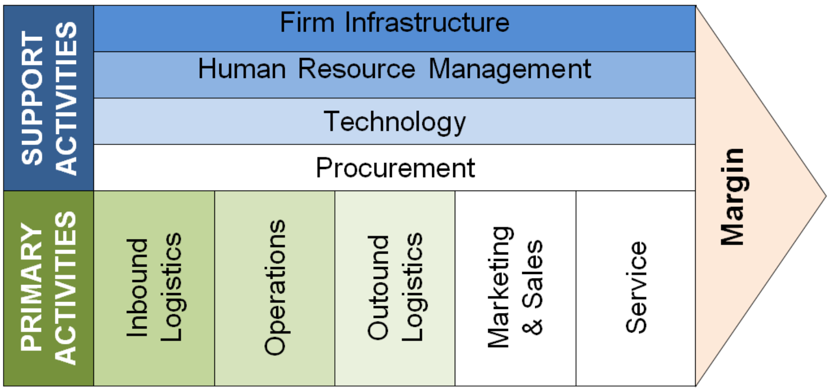

Fig. 6. Basic value chain model [18]

In line with the requirement of the systems approach, the value chain base model distinguishes the relationships that occur between its elements - activities. The relationships between the core activities are called linkages in the base model. By linkage is meant here "[...] the relationship between the way one activity is performed and the cost or performance of another activity" [19]. These linkages contribute to competitive advantage in two ways, namely through optimisation and coordination. By optimisation is meant the search for the best possible ways of performing an activity under the conditions adopted, while coordination, on the other hand, should take into account the reduction of costs or contribute to the differentiation of an offer. Coordination can be considered in the internal area (the so-called inter-functional coordination, which is aimed at the relationships between the activities of the enterprise) and the external area (the so-called vertical coordination, aimed at the relationships between the activities of the economic unit and its suppliers and customers) [16].

The division of activities presented in Fig. 1 is not universal, as it depends on the specifics of the activities of a given organisation and the conditions of its operation. It follows that the decomposition and classification of activities should take into account the individual characteristics of the economic unit and each time the process follows different principles. Due to the fact that the implemented activities determine the success of the enterprise, their optimal location within the organisation should lead to the formation of a competitive advantage of the entity and, as a result, to the generation of profit [20].

2.3. Characteristics of processes in a mining enterprise

The technical and technological restructuring of hard coal mines in Poland, which has been carried out since the early 1990s, has resulted in a number of changes which, in many cases, have had a positive impact on the formation of the basic technical indicators of the mining industry at the threshold of the 21st century. This restructuring included, inter alia:

- liquidation of unprofitable regions, fields and mining levels,
- simplification of the spatial structure of mines, which contributed to reduced costs of pit maintenance,
- an increase in the concentration of extraction by reducing the number of active longwalls and increasing daily extraction from a single longwall due to the introduction of modern equipment and machinery into the mines.

In order to maintain the competitiveness of Polish hard coal in the conditions of a free market economy, it is important to improve the system of processes through the use of modern technologies, ensuring safety and economic efficiency, and in the sphere of management, the use of modern tools influencing rational decisions favouring its development [1, 21].

At this point, it is important to clarify what the concept of 'process' actually is. The simplest definition presents the term as a course of successive and causally related specific changes, constituting stages, stages of development, course, development, transformation of something [20]. The most common definition in the literature is that of M. Hammer and J. Champy, who characterise a process as a sequence of activities performed within a company, carried out in such a way as to result in a product or service [22].

In coal mines and coal mining companies, there is an economic process which, due to the size of the quantitative scale and the repeated cycles, is referred to as the 'industrial economic process'. The economic process consists of making decisions on economic activities so as to achieve a certain set result. It aims to achieve set objectives. However, it should be borne in mind that some of the processes that are directly related to the extraction of minerals must take into account the specific conditions of the implementation of mining processes in deep mines.

In the case of industrial processes that are realised in a company, there may be a serial process, during which each subsequent activity or action is conditioned by the completion of the previous activity (action).

In the case of simultaneous implementation of several processes (activities, actions), they may function as [21]:

- synchronous activities and processes implemented with periodic coordination in time (synchronisation),

– intersecting activities and processes, i.e. those in which the condition for starting a new activity is the completion of several preceding activities, or there is a coincidence of the place and time of realisation of activities and actions, or the completion of one activity is the condition for starting several others.

Synchronous or crossover processes place higher demands on the management of the industrial process, thus increasing the uncertainty of the result in the form of failure to achieve the objective, time or cost overruns. Polish coal mines are characterised by a very complex system of activities creating a high risk of economic failure. This can be evidenced by technical and organisational indicators that show an increase in the labour intensity of the preparatory and accessing process system [21, 23].

3. Results - the value chain as a strategy for optimising gateroad development

In a mining company, as in an industrial company, the construction of company value and the generation of profits are achieved in various areas of its operation. In multi-company mining companies, the basic system of operational processes in the form of mining and (not always) mine enrichment is realised at mine level.

The excavation of corridors, especially longwall gateroads are one of the most costly processes in the complex industrial process system of deep mines. The search for cost-saving and efficiency-enhancing solutions in tunnelling is a logical direction for improving the efficiency of gateroad development.

The focus of this paper is on optimising the process of excavation of longwall gateroads in terms of the entire life cycle of the roadway, i.e. from drilling to decommissioning. It was assumed that the strategy to get there would be based on a value chain model. When introducing the concept of the value chain into this gateroad development, it is important to indicate who in this chain will be the final customer. In this case, it will be important to introduce and define the needs of the internal customer. From the perspective of a single workstation, all processes that precede a given action step become suppliers against whom expectations should be formulated and to whom feedback should be provided on the level of service they provide. The recipients of subsequent actions should be treated as customers who should also be satisfied [14]. In the case of gateroad development, we can identify four internal customers, which are:

- geological department - geological reconnaissance of the deposit,
- machinery department - reinforcement of the longwall with machinery and equipment (shearer, conveyor, mechanised lining sections),
- transport department - transport of materials to the longwall,
- extraction department - driving out the longwall.

Taking into account the work carried out by the Author to date in the field of designing the support for the longwall gateroads and verification of production plans of hard coal mines, it should be pointed out that the application of more expensive solutions related to securing the excavations at the stage of their excavation may bring measurable effects in the final settlement. An important factor affecting the achievement of rhythmicity in production is the time taken to rebuild longwall-pit crossings. Reducing this time makes it possible to increase the number of mining cycles carried out, thereby increasing the daily output from the longwall.

In addition, further benefits are gained in terms of improved comfort and safety for workers when using appropriate reinforcement of the roadheading at the stage of excavation. There is also an improvement in the efficiency of the use of machinery and equipment, both in the preparatory and mining phases. All the above-mentioned factors indicate that the proper design and ordering of the activities of the preparatory process (gateroad development) brings great benefits to the direct user in the mining process. Thus, we can attempt to develop an appropriate value chain for preparatory works, based on a baseline value chain model that takes into account the primary and supporting activities. The developed value chain model for gateroad development is shown in Fig. 7.

SUPPORT ACTIVITIES	**Firm Infrastructure**	• control of longwall roadways development costs, • control of the cost of using gateroads, • control of technical condition of gateroads, • control of technical condition and monitoring of machines and equipment: excavating, hauling and anchoring, • control of effective working time of employees, • control of stock levels,
	Human Resource Management	• selection of cadres for the gateroad development branch, • selection of personnel for the anchoring division, • training of employees in optimization of mining works and geomechanics - cooperation of the pit casing with the rock mass, • introduction of a bonus system for achieving increased longwall mining capacity,
	Technology	• execution of a project for the selection of optimal casing for longwall gateroads, • execution of a project for forecasting the convergence of longwall gateroads exposed to operating pressure, • introduction of small-scale mechanization to improve the efficiency of shoring and anchoring installation work,
	Procurement	• ordering of materials (steel arch support, meshes, struts, steel stringers, rock bolts, adhesives), • ordering high quality consumables, i.e. shearer knives, drill crowns, • planning material purchases, • maintenance planning, • overhaul planning,
PRIMARY ACTIVITIES	**Inbound Logistics**	• transportation of shoring elements, nets, struts, steel stringers, anchors and adhesive loads, • close and systematic storage of material in the excavation, • issuing used elements to surfaces,
	Operations	• mining cutting of coal and rock, • installation of steel arch support, nets and struts, • execution of careful lining in order to obtain precise contact of the casing with the rock mass, • making holes for rock bolts, • installation of the steel support and rock bolts,
	Outbound Logistics	• making the excavation available to geological survey services for geomechanical testing of the rock mass (strength and extent of the crack zone), • handing over the excavation to the machinery, transport and mining departments for use,
	Marketing & Sales	• product development - improvement of shoring reinforcement systems for longwall gateroads, • implementation of lining reinforcement system for all longwall gateroads, • increasing work safety in transportation, • increasing work safety during the reconstruction of longwall-roadway intersections, • increasing the mining capacity of the longwall,
	Service	• maintenance of machinery (mining, hauling and rock bolting), • maintenance of machines in operation, • checking the efficiency of machines,

Total cost of coal production

Fig. 7. The value chain model for gateroad development in hard coal mines

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The supporting and basic activities of the value chain for the process of excavation of longwalls with the use of an arch support additionally reinforced against the effects of the future excavation pressure of the longwall being excavated, summarised in Fig.7, show that it is possible to apply this type of strategy in part of the underground processes of a mine. By observing today's activities in the mining sector, it can be seen that there are mines that are characterised by a strong organisational and underground working culture that fits into this value chain strategy. An example here is the LW Bogdanka mine, which achieves the highest gateroad development progress of 500 m/month on average, with a record of 820 m/month set in 2018. On average, the other mines have gateroad development rates of around 200 m/month. In addition, at the stage of excavation, the Bogdanka mine applies appropriate reinforcement of the steel arch support, mechanical lining, conducts thorough research into the strength parameters of the rock mass, measurements of primary stresses in the rock mass, and adjusts the arrangement of the individual elements of the arch supports to the thickness of the seam. All of this ultimately allows the internal customer (the mining division) to obtain high extraction capacities from the longwall.

According to the literature, the following are important in value chain analysis:

- linkages - denote the outflow of other activities on the cost of performing the activity under study. The obvious impact within both the primary and supporting activities must be examined;
- couplings with other organisational units of the company - involves, for example, joint use of supporting activities;
- integration - reflects the possibility of reducing the costs of individual activities through vertical or horizontal integration of the company's activities.

The above also fits with the possibility of applying value chain strategies to the gateroad development process in coal mines.

4. Conclusions

Operating a longwall system requires a number of mining works to be carried out in advance, including the drilling of longwall gateroads, which must ensure safety and usability throughout the life of the longwall. The execution of this type of work must be linked and aligned with the mines' appropriately chosen strategy.

The application of a value-chain-based strategy for the design and execution of longwall gateroads can improve the production capacity of coal mines. Increasing the initial expenditure on gateroad development during the drilling of longwall gateroads, in the perspective of their later use, can reduce coal mining costs, as a result of the increased longwall mining capacity.

The greatest advantage of this strategy, however, is the value it creates for the internal customer, who receives good-quality workings that enable him or her to maintain an appropriate cross-section during longwall excavation, increase material transport and haulage flows, and obtain a good geological diagnosis of the rock mass. A key role is also played by the exchange of information between the various processes, which will ultimately lead to the common goal of increasing the effective working time of both employees and machines.

The basis for deciding whether it is possible to implement a value chain strategy in the process of drilling longwall gateroads is the fact that mines are making low progress in gateroad development and also in extracting the longwall. In recent years, it has been observed in mines that a lot of costly work is being carried out, which often does not have the intended effect and sometimes even has the opposite effect leading to huge financial losses. This is due to the great lack of basic mining knowledge that has arisen due to the emerging generation gap, the lack of making long-term plans and the consequences of their implementation, the lack of willingness and courage to implement innovative solutions in mining, as well as making ill-considered and hasty decisions.

The aim of introducing the strategy described in this article into the process under analysis is not only to increase the competitive advantage due to a reduction in the cost of coal mining, but above all to increase the awareness of employees and their attitude to the work performed allowing for improved

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mining efficiency. The analysis of the value creation chain can be supported by activity-based costing [24]. This is because traditional cost accounting deals with the measurement of costs that are incurred on an ongoing basis and their recognition according to where they arise.

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