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Labor intensity as a strategic KPI for evaluating the efficiency of coal mines

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Abstract
In the face of the growing demands of the modern economy, 21st-century technology, and the challenges of Industry 4.0, the classical management of mining enterprises is not sufficient, and it is transforming into a process approach to the organization. The usage of the process management concept creates a situation for improving the organization at many levels, both at the strategy and operational levels. This provides an opportunity for a comprehensive view of the organization, but it is necessary to define indicators that determine the flexibility of operations, the achievement of profitability, and effective operational management. These indicators, called key performance indicators, focus on crucial aspects of the organization's activity that are fundamental to its current and future success.
The contribution goal of the presented paper is to propose a new index for assessing the efficiency of coal mines, called the labor intensity index. The proposal is based on a previous three-area strategic analysis, including production indicators of coal mining companies, the state of coal mining in Poland, and economic factors affecting the current situation of the Polish coal mining industry. The analysis covered the period from 1988 to 2020. The use of new KPIs to assess performance in process terms is necessary to develop better new strategies for mining companies. It is particularly important in light of the industry's restructuring plans to restructure the mining industry and the far-reaching vision of decarbonizing the Polish energy sector.

Keywords
Process management, key performance indicators, labor intensity index, coal mining industry, Poland.

Introduction

Process management

Owing to dynamic changes in the economic environment (Cizmas et al., 2020), affecting the functioning of modern enterprises, A. Bitkowska (2019) and B. Kowal (2019) indicate the need to perceive and analyze processes both at the level of strategy as well as at the level of operational activities. However, functional orientation in management continues to play a dominant role (Kunasz, 2010; Schraeder et al., 2014). In addition, functional structures (Agwu & Onwuegbuzie, 2017) continue to be popular in many other organizational structures. This is the aftermath of the classical approach (Robbins & Coulter, 2020) based on the Taylor and Fayolian (Fayol, 1916) system of work organization. The division into individual functions performed within an enterprise is still common and easy to apply. However, in order to meet the challenges of Industry 4.0 (Culota et al., 2020; Maskuriy et al., 2019), such an approach may no longer be sufficient.

Due to the dynamically changing needs and technologies of the 21st century, functional orientation may be insufficient, and it is necessary to move away from classical management (Hatchueland & Segrestin, 2019) to process management (dumas et al., 2018) along with the process structure. This would allow for increases in an organization's resources by being able to meet customers' needs better and, as a result, gain competitive advantage. Therefore, a simple or even complex functional structure is insufficient in the face of the growing demands of the modern economy (Liao et al., 2017). It is important to note that using a process approach does not exclude classical management (Agostini & Filippini et al., 2019). Process organization allows for combining management functions in the classic layout with managing individual processes occurring within the organization (Wąchol, 2018).

The application of the process management concept creates a situation for the improvement of the organization on many levels (Miśkiewicz & Wolniak, 2020; Kowal et al., 2018). This is particularly true in the area of management efficiency: income, market share, resource efficiency, customer satisfaction level, cooperation within the company, and the implementation of strategic goals of the company (Rusinaite et al., 2016). Considering the wide range of impact of the process approach in the organization (Estrada-Torres et al., 2021), one may notice the main feature of the process approach - a comprehensive view (Ouyang, 2010). Therefore, implementing process management methods is, on the one hand, a great challenge but also an opportunity to achieve a competitive advantage in the market. In order to properly prepare for such a change, it is necessary to correctly identify the processes and properly define the key processes and indicators determining the flexibility of operations, achieving profitability, as well as efficient operational management (Kovanič et al., 2024).

This process may be defined as an activity that requires input and produces output (Barkowiak, Grabowska, 2020). The definition of this concept depends on the adopted view and modeling needs. There are several dozen definitions that have emerged over the centuries, ranging from A. Smith to the present day (Vergidis et al., 2008; Senkus, 2021). From the authors' point of view, three factors are vital - activities, costs, and duration of the process. These significantly impact the efficiency of an organization's operations (Grajewski, 2016; Slack & Brandon-Jones, 2018). According to Grajewski's interpretation, the most common processes in enterprises are fundamental, auxiliary, and management (Fig. 1).

Improvements in the production process (Madison, 2005) may involve both the entire production process as well as individual sub-processes, such as the material flow process, the manufacturing process, the research process, or the distribution and customer service process. Certain sequences of operations or activities may also be improved.

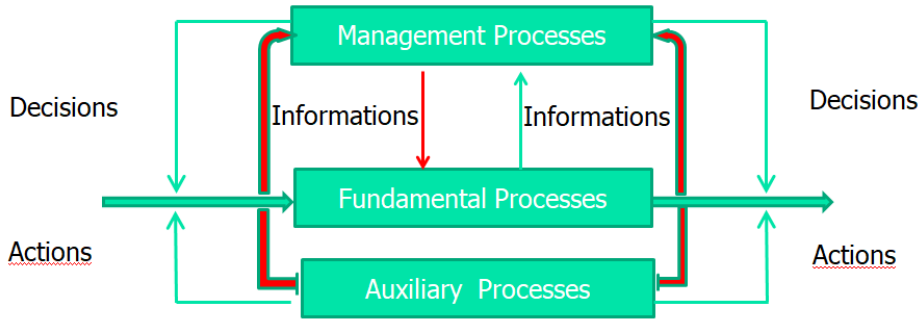

Fig. 1. Division of processes (own, based on Grajewski, 2016)

As part of the process structure, it is critical that managers at various levels are able to skillfully select and connect various processes, technologies, or other elements of the production system in relation to the timeline and cost of the operation. A synthetic management view should provide a greater organizational, synergistic, and successful management effect. It is important not to treat individual elements of the management and processes as separate entities. When analyzing and improving the process, they should be viewed as a whole. Greater efficiency is achieved only with the appropriate use of various concepts of the process structure in relation to the technologies

used, resource allocation, and the assumed output effects that satisfy the broadly understood stakeholders of the organization.

KPIs in business management

In process management, it is assumed that each sub-process in an organization creates value for an external or internal client. Indicators play a key role in process improvement (Kowal, 2019). Using these indicators, it is possible to describe and illustrate processes, as well as determine the results of activities, trends, and possibilities for change. These include indicators of supply, resources, and results (Rydzewska-Włodarczyk & Sobieraj, 2015).

Therefore, the efficiency of processes may be assessed according to various assumptions, depending on the needs and specificity of a company's operations. Unlike traditional performance measures based on financial results, in process evaluation, it is assumed that performance measurement may be achieved using both quantitative and qualitative financial and non-financial indicators. The basis for choosing a given measure is the set goals and tasks.

Modern methods of human resource management include management by objectives. The Management by Objectives (MBO) theory was created over 40 years ago by P. Drucker(2017). The key to this method's success is adapting the organization's real goals to its capabilities while ensuring its continuous development. This concept is based on continuous monitoring and assessment of situations, not employees. This method allows a company to adapt to a dynamically changing environment continuously. One of the management by objectives tools is the correct definition of indicators.

Therefore, in measuring the degree of achievement of objectives in process-managed entities, key performance indicators (KPIs (Parmenter, 2016) are of vital importance as they allow for the possibility of determining how and to what extent strategic goals and plans are being implemented. KPIs should be individually tailored to a given company and industry, covering a set of financial and/or non-financial measures. This allows for the detection of problems at an early stage, rapid reactions, and improvements in the management process of an organization. At the same time, the adopted KPIs should be easy to use and understandable for employees. Their precise definition allows for their proper determination and avoids the possibility of results being manipulated. The adopted set of KPIs in the unit should meet the following conditions (Grycuk, 2010):

- indicators should address issues that are important to the entity,
- indicators should be adapted to the situation and industry,
- the number of indicators should not be too large,
- indicators should be periodically inspected and improved,
- the costs of collecting the data cannot exceed the benefits of using indicators.

A good selection of KPIs is an important task for the organization, but it must also be done skillfully in relation to the nature of the industry and the production processes used.

Industrial process in a mine

The processes performed in a mine (not only underground) are very often referred to as production processes (Durlik, 2019). However, attention should be paid to significant differences, one of which is of great importance: For the implementation of production processes, conditions are created for the implementation of such a process (buildings, technical production system, etc.). In the case of mining processes performed in mines, conditions are imposed by the place where the process is performed, including the geological structure of the deposit. This is one of the reasons why, unlike strictly production processes, there is a large variety of methods and systems for mineral extraction. The production processes of similar products are very similar to each other.

Unlike production processes that provide the client with the usability of a given form (e.g., shape), mining processes carried out in mines provide their recipients with the usability of space and time. These are the utilities typical of logistical processes. This is why mining processes should be treated as businesses or industrial processes but different from other production processes (Fig. 2).

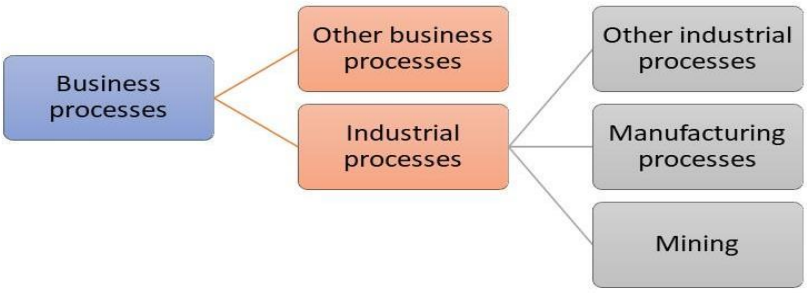

Fig.2. Mining processes in the area of business processes

The processes realized in the mines are, in fact, the processes of emptying what can essentially be called warehouses created by forces of nature from the goods (minerals) in order to deliver them to the customer (Fig. 3).

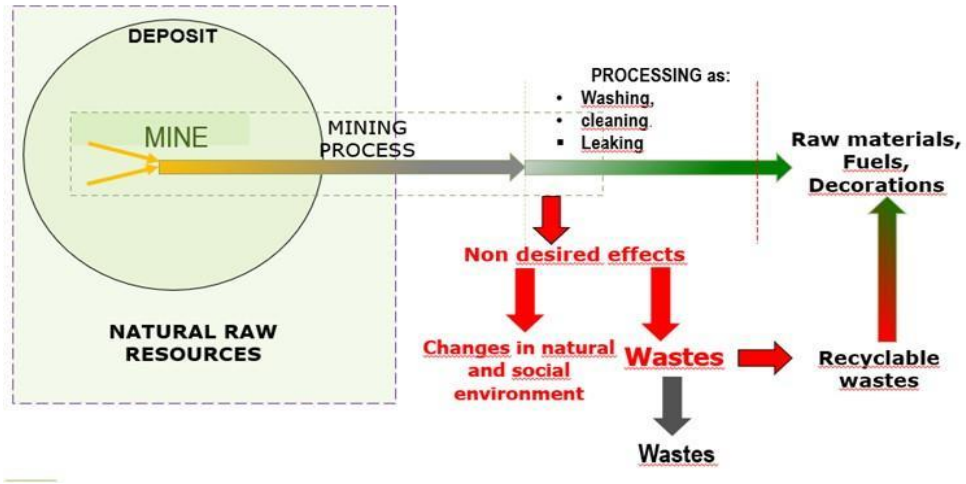

Fig. 3. General idea of mining as a core business process

Before starting the mining process as a mining target, it is necessary to design the mine, provide access to the deposit, and prepare it for mining using the adopted deposit selection method (development). This group of processes is fundamental, and without it, the mineral extraction process is not possible (Fig. 4). All material processes related to the construction of a mine and the excavation of a deposit require energy, materials, information, and staffing.

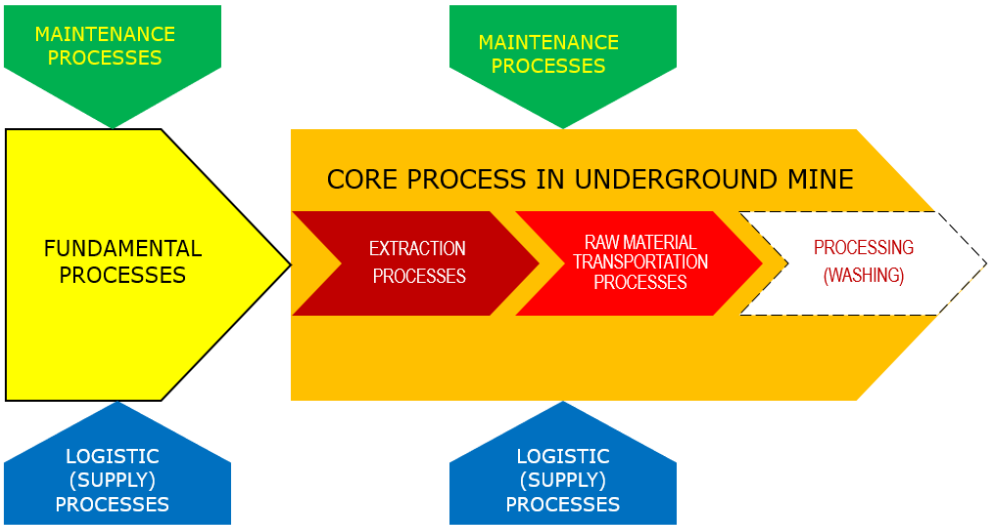

Fig.4. Core process and other necessary process in underground mines

The processes of supplying and maintaining the technical infrastructure of the mine system are existential processes. The presence of people in the processes carried out in underground mines results in additional necessary activities to ensure safe working conditions. Fig. 5 shows a complex network of activities (processes), the implementation of which is necessary to achieve the business goal of an underground mine.

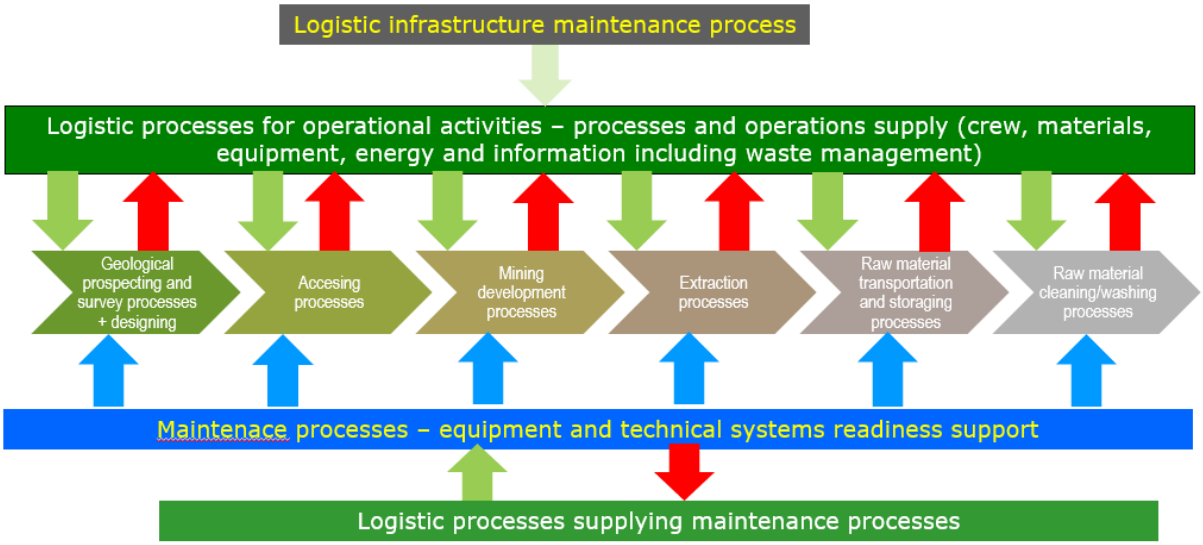

Fig 5. System (network) of processes in underground mine

Even in the case of highly efficient mining systems, low efficiency of the remaining systems for the implementation of fundamental processes (understood as a group of processes without which the mining process cannot be started) and existential processes (understood as a group of activities without which the mining process cannot be repeatedly performed).

Methodology

A three-area strategic analysis was used in order to show and characterize the situation of the Polish hard coal mining industry (Gierszewska & Romanowska, 2021). The applied analysis (Tyrańska & Walas-Trębacz, 2010) was performed for three areas:

- production indicators for hard coal mining enterprises,
- the state of the hard coal mining industry in Poland,
- economic factors influencing the current situation of the Polish hard coal mining industry.

The ratio analysis for hard coal companies in Poland was performed utilizing a long-term analysis of changes in a selected group of technical parameters, considering the potential factors causing single, rapid changes within these indicators (parameters). This method was chosen owing to the high technological homogeneity in the Polish hard coal mining industry (deep mines, where almost exclusively longwall systems with dipheadings, the same legal regulations, similar traditions, and local factors). The dynamics of changes in individual parameters was determined to define the required management efficiency indicators in hard coal mines. The remaining part of the three-area analysis was analyzed in descriptive form, discussing the factors influencing the current situation of the Polish hard coal mining industry and the future conditions of its operation.

The analysis allowed for the selection of parameters that became the basis for the definition of management efficiency indicators, constituting the next stage of the research.

In the mining industry, various key productivity indicators of mining activity (KPI) are used, among them universal indicators and specific indicators created in mining companies adapted to specific conditions and the mining technologies used (Gackowiec et al., 2020). In underground coal mining in Poland, productivity indicators have been used for many years and have been adapted to the conditions and applied mining technologies (Jonek-Kowalska & Tchórzewski, 2016).

Since, as mentioned earlier, Polish hard coal mining utilizes practically one method of exploitation today, one of the most important KPIs is the productivity of one longwall face. As a measure of the economic efficiency of the basic process, the ratio of revenues obtained from economic activity to outlays (total costs) incurred for conducting this activity was adopted. The next index adopted for the analysis was labor productivity, calculated as the ratio of commercial coal produced per employee in the mines over a given period of time.

After comparing the strategic and index analysis, the authors proposed a new index for assessing management efficiency in mining enterprises - the labor intensity index of coal mining. To determine this, the methodology presented in Fig. 6 was adopted.

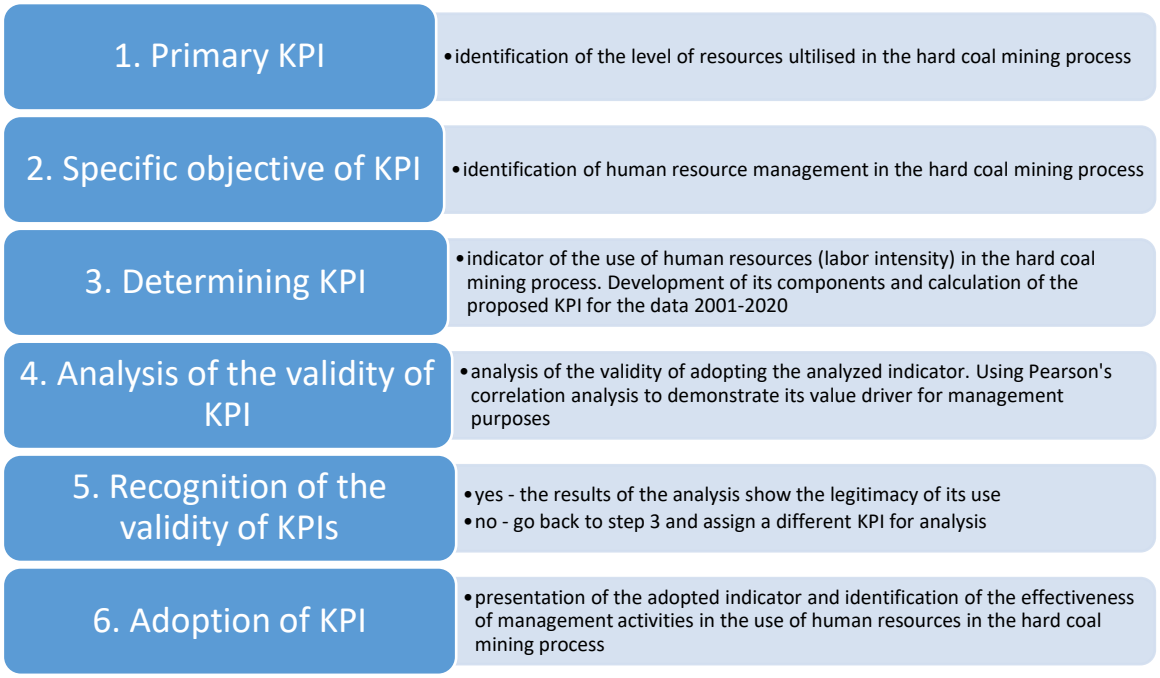

Fig. 6. Methodology for determining and analyzing the proposed KPI in the hard coal mining process

The use of the proposed index, better than the one used so far, shows the direction of necessary changes and strategic goals for the hard coal industry.

Analysis of production indicators for hard coal mining companies and the state of the industry

With the prices of primary energy carriers remaining at a high level, especially crude oil, and natural gas, the role of coal as an energy carrier is vital for the EU's energy security (Fuksa, 2021; Gawlik, 2019; Manowska & Bluszcz, 2022). As hard coal is the third largest energy source in the EU, its use should be considered despite environmental issues and aspects (Korski, 2016; Gajdzik et al., 2023). Studies suggest new effective combustion technologies, new technologies for coal processing into liquid fuels, and the production of high-quality ecological coal assortments (Frączek, 2013; Tobór-Osadnik et al., 2023). The current article presents changes in selected technical and organizational areas of Polish coal mining in the years 1988-2020 in graphic form. The data is derived from the website of the Ministry of Economy.

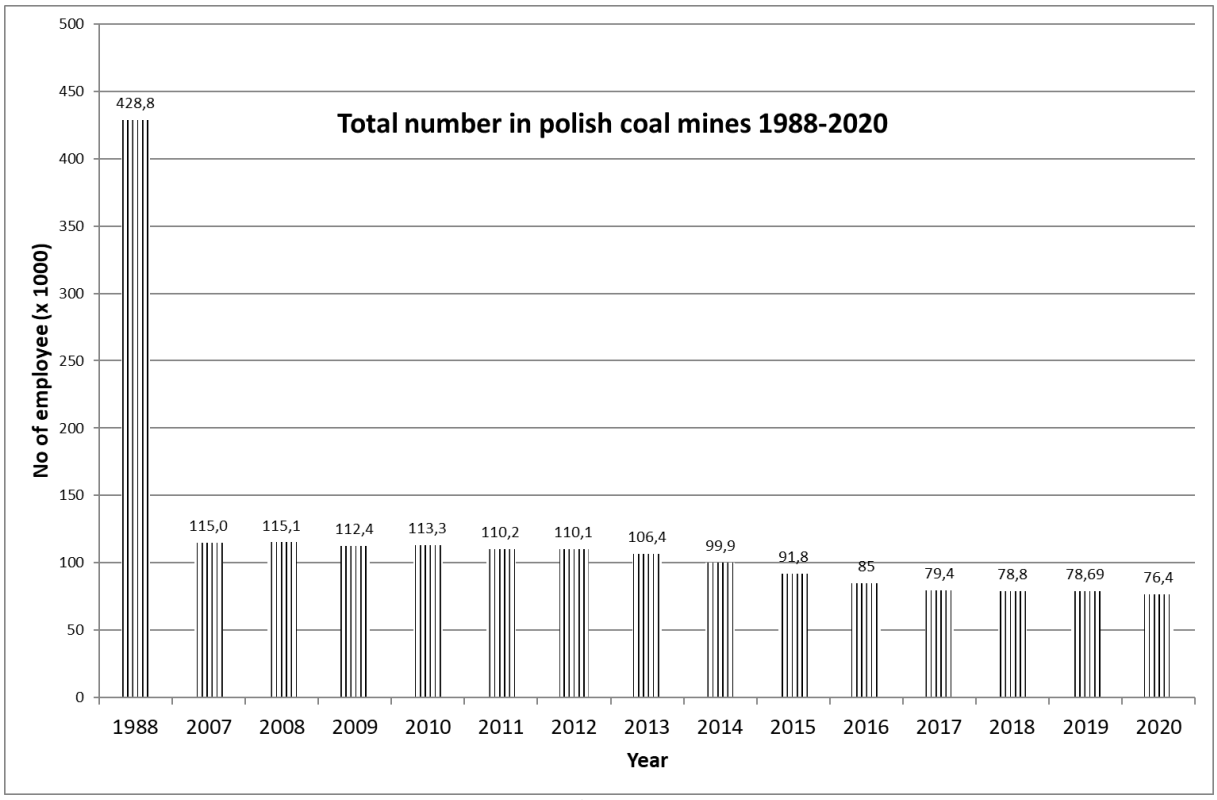

Fig. 7. Total number of Polish coal mines 1988-2020

Since 1988, there has been a decline in employment in mining companies (Fig. 8). In the analyzed period, this process was based on natural breakdowns, generally withholding admissions or limiting them to the necessary minimum and taking into account the need to further reduce employment in hard coal mines - this was and continues to be supported by social packages financed from the state budget, which constituted a financial incentive encouraging employees to leave the industry (Manowska et al., 2017).

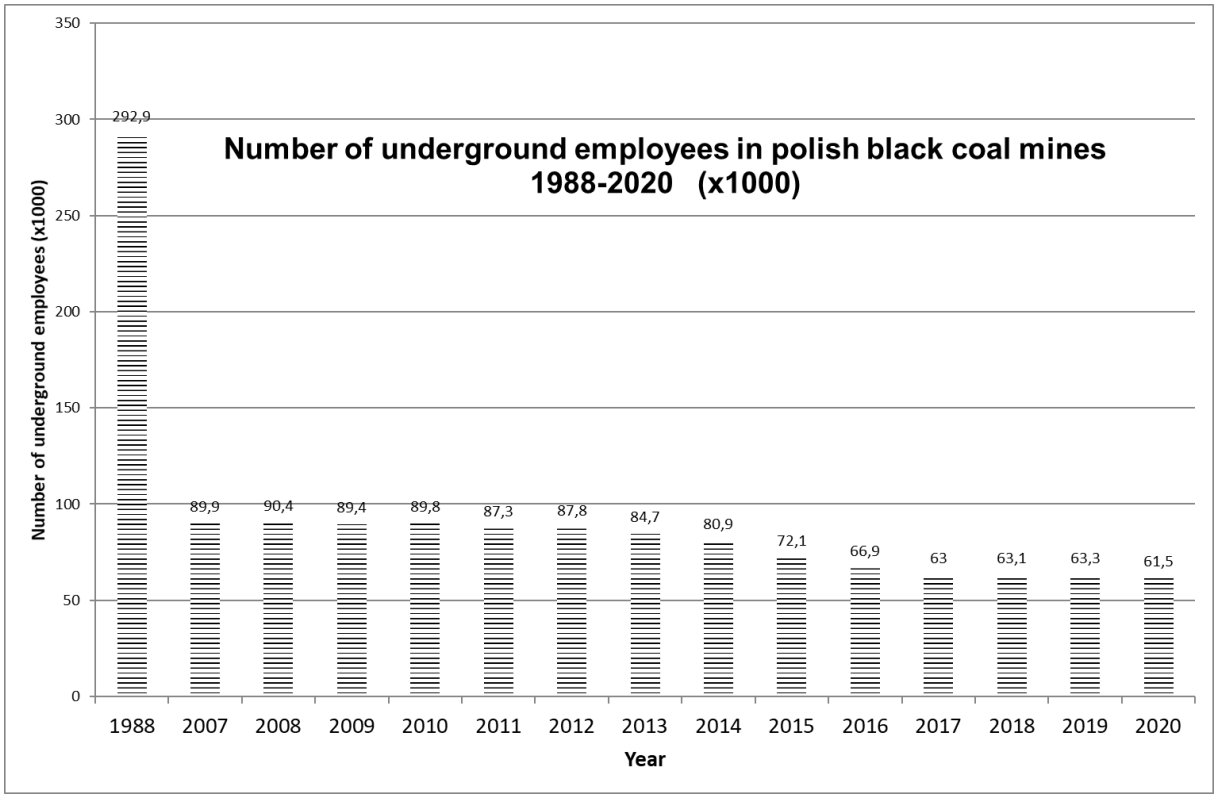

Fig. 8. Number of underground employees in Polish black coal mines 1988-2020

Rational management of jobs in mines by prohibiting the employment of new workers, introducing several further packages of voluntary redundancies, and outsourcing services provided in mines unrelated to the main area of activity have led to an improvement in the type structure of employment, thus ensuring stable and economically safe jobs in hard coal mines.

For many years, labor costs have accounted for over 50% of the total production costs in Polish hard coal mines. It is, therefore, expedient to constantly search for solutions to rationalize these costs and reduce the labor intensity of processes in underground hard coal mines.

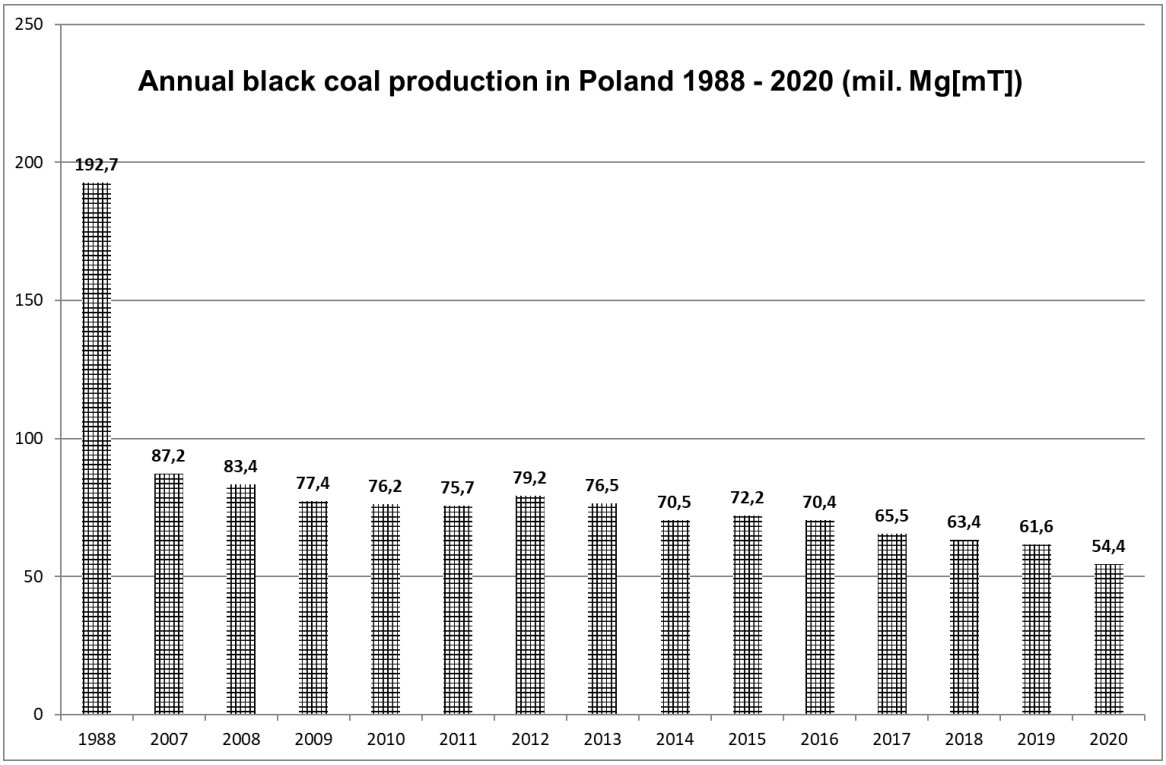

Fig. 9. Annual black coal production in Poland 1988-2020

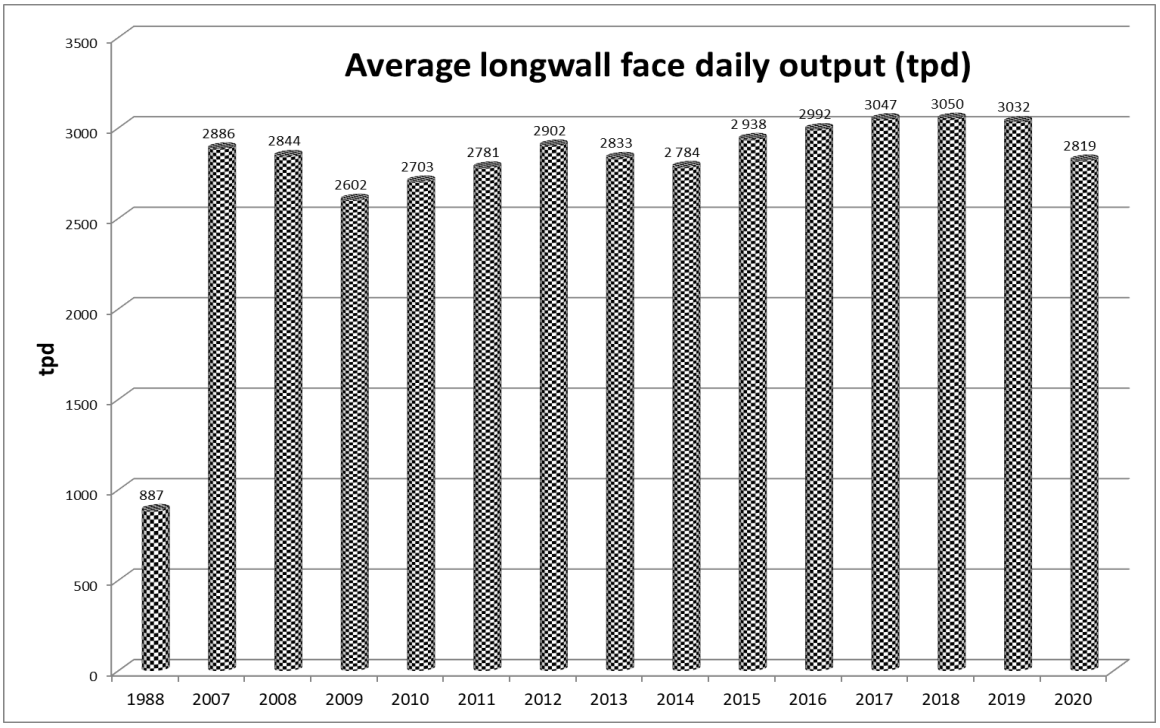

Fig. 10. Average longwall face daily output

Poland has over 80% of the hard coal resources in the entire European Union. Unfortunately, every year, coal mining decreases with increasing imports (Fig. 9). As part of the restructuring processes, the number of mines decreased due to the liquidation of mines and mergers of others (Fig. 7). The process of restructuring the Polish hard coal mining industry between 1990-2020 included significant organizational changes, but also technical and technological changes, however only in the form of goals. As a result of these changes, since 1988, the domestic extraction of raw materials has decreased from 192.7 million Mg to a level of approximately 54.4 million Mg in 2020.

What may be worrying is that with the continuous increase in mechanization and automation of processes - the statistical daily extraction from a longwall (Fig.10) decreases. At the same time, in the years 2009-2012 and 2014-2019, a slight increase in production was observed. Considering the continuous restructuring activities in the industry aimed at improving the efficiency of mining, the data presented in the chart above does not show any spectacular changes in this area. This has a direct impact on the efficiency of the entire production process.

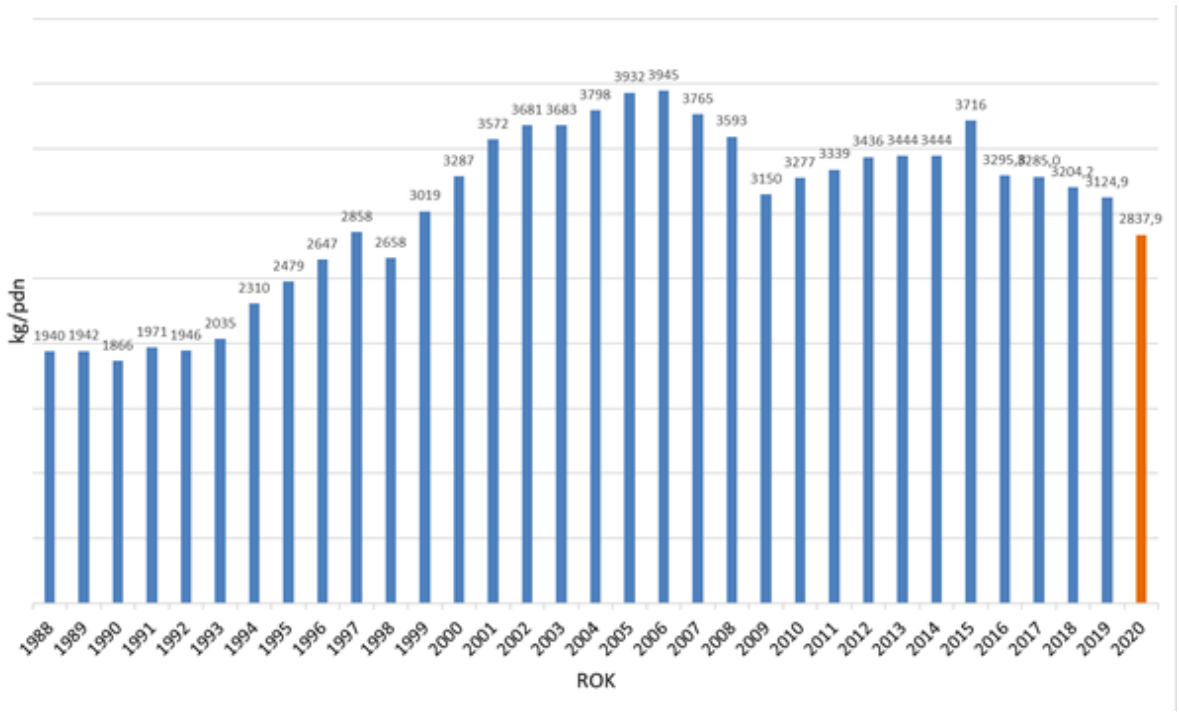

Fig. 11. Overall daily productivity per employee in the Polish hard coal mining industry in the years 1988-2020

As is clear from the overall daily productivity per employee in the Polish hard coal mining industry in 1988-2020 (Fig. 11), following growth in the first decade of the 2000s, in the next decade, there was a decrease from 3277 to about 2838 kg/ employee per working day.

Applied KPIs - key performance indicators and Polish coal mining industry

In practice, Polish coal mining utilizes one coal extraction method today, i.e., a longwall system with dip-holdings. Technological diversity was previously greater. However, since the 1980s, the industry has been consistently switching to a mechanized longwall method with armored face conveyors (AFC), mechanized longwall supports, and cutting machines in the form of longwall shearers or, less frequently, coal plows. Therefore, one of the significant KPIs is the productivity of one longwall face - Fig. 6 shows the development of this indicator in Polish underground coal mining in 2010-2020 (Fig. 12).

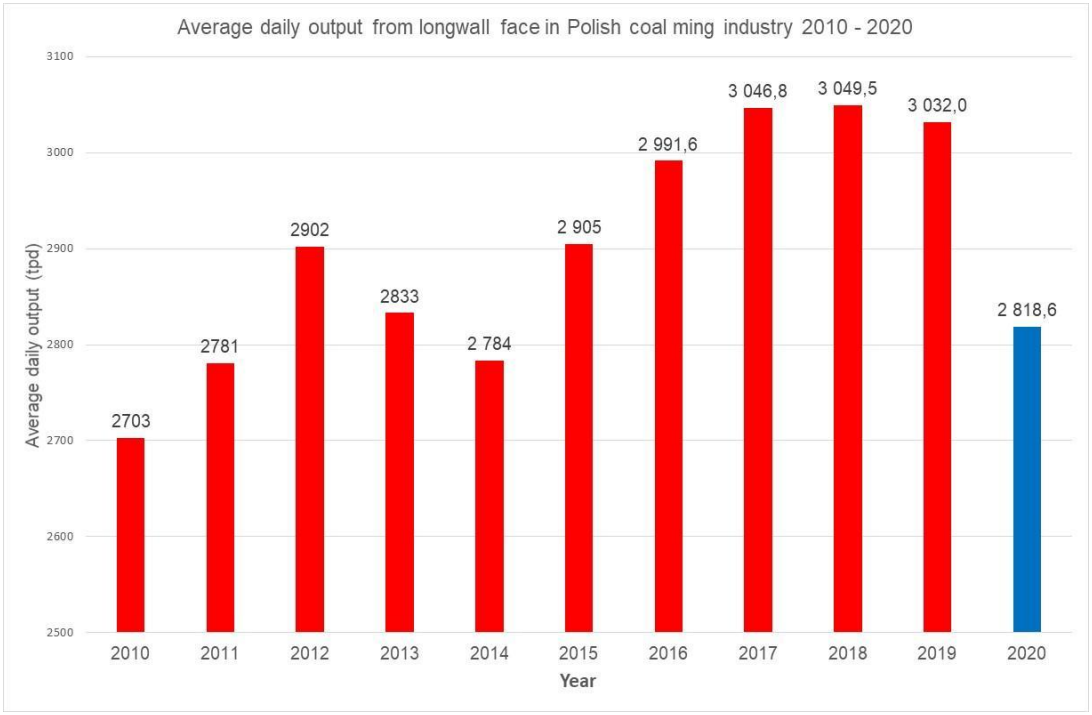

Fig. 12. Average daily output from longwall face in the Polish Coal Mining Industry 2010-2020

In the global mining industry, particularly in the most advanced mining countries in the world, results are obtained at least several times higher. It is also worth noting that this indicator is also significantly higher in some mines (e.g., LW Bogdanka) (Myszkowski, 2016; Henderson, 2021; Peng, 2019). Fig. 13 presents the productivity in mines as the amount of commercial coal mined per day (or annually) per employee in the mines.

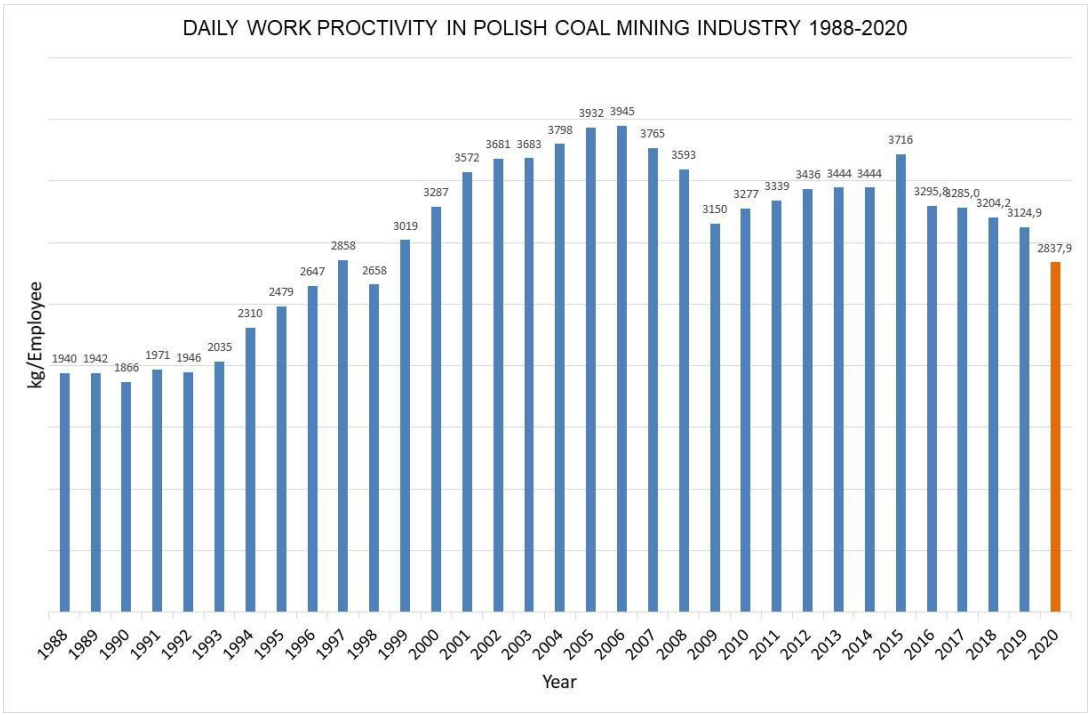

Fig. 13. Daily labor productivity in the Polish Coal Mining Industry

Since 2006, there has been a clear downward trend, which in recent years can be explained, among others, by transferring mines and staff to an economic entity dealing with the closure of the mines. However, as the chart shows, the overall performance is still unfavorably different from global trends. The economic consequence is the negative economic efficiency of the Polish hard coal mining industry as a whole.

Considering this system or network of processes performed in an underground mine, a new indicator (KPI) was developed to assess the reasons for the low efficiency of the Polish hard coal mining industry.

Proposed KPI - an index of the use of human resources (labor intensity of mining) in hard coal mining processes - coal mining labor intensity index

Determining the KPI to assess the use of human resources (labor intensity) in the hard coal mining process

This indicator is presented in the form of a coal mining labor intensity index in terms of underground and total labor consumption. The idea of the KPI for the use of human resources (labor intensity of mining) in the mining process is to calculate the number of employees, statistically, per longwall or a system serviced by one set of face machines (e.g., in the Room&Pillar system). Such an indicator allows for a quick assessment of the labor consumption with regard to the processes performed in a given mine or group of mines. It can be used in mining planning using various methods to select the most effective solution.

Figures 14 and 15 show the overall and underground labor consumption index in the Polish hard coal mining industry in the years 1988-2020. It is important to note that the beginning of the analyzed period predates, by one year, significant political and economic changes in Poland.

Fig. 14. Coal mining labor intensity index (total)

Despite the intensive restructuring of the Polish hard coal mining industry in the areas of technology and organization, including employment, especially in the years 1990-2000, the total number of employees per one longwall grew rapidly.

Analysis of the validity of using the proposed KPI - Pearson's correlation analysis

The study of the relationship between the number of underground workers per 1 longwall and changes in the level of extraction in hard coal mines was carried out using the Pearson linear correlation coefficient. This coefficient is used to study rectilinear relationships of the studied variables, in which an increase in the value of one of the features causes proportional changes in the mean values of the other feature (increase or decrease). Weak or no dependence occurs at values below 0.2.

The correlation (interdependence of features) defines the interrelationships between the selected variables. Values ranging from -1 to 1 positive correlation (value of the correlation coefficient from 0 to 1) - informs that an increase in the value of one feature is accompanied by an increase in the mean values of the other feature, negative correlation (value of the correlation coefficient from -1 to 0) - informs, that the increase in the value of one feature is accompanied by a decrease in the mean values of the other feature.

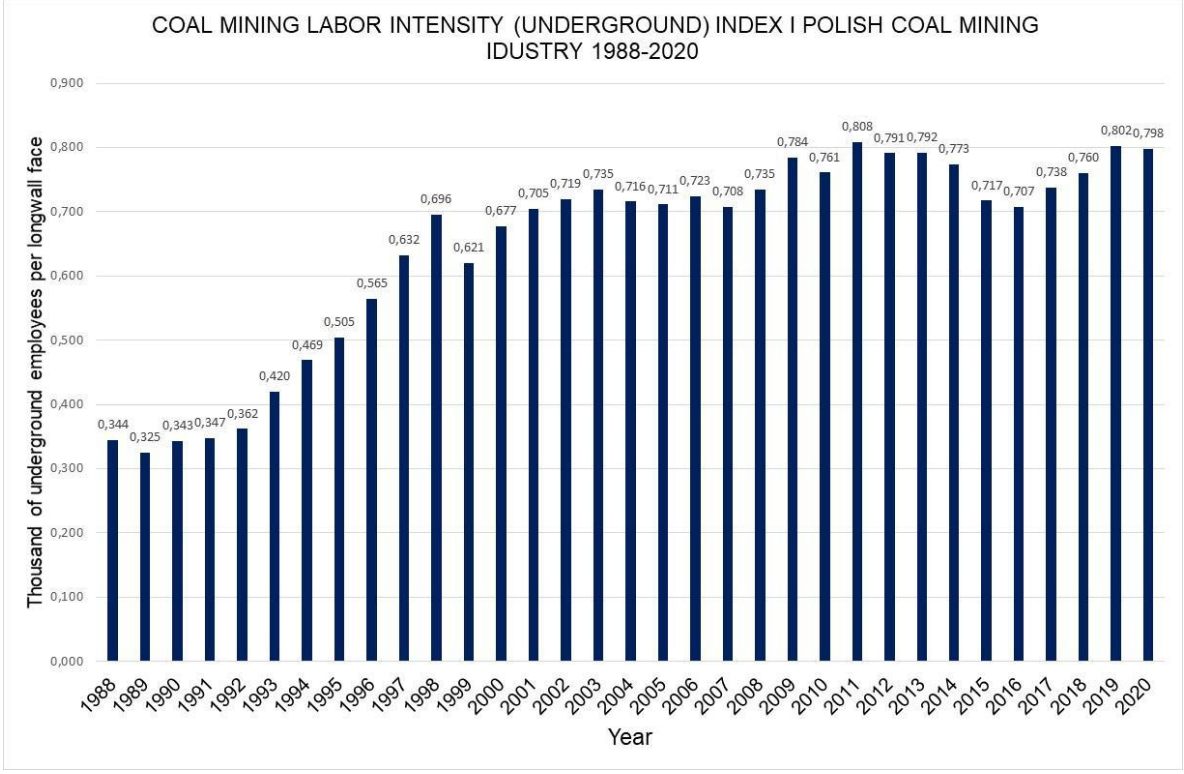

Fig. 15. Coal mining labor intensity index (underground)

Table. 1. Number of underground workers per longwall (A) and changes in the level of extraction (B) in hard coal mines

Number of employees of underground mines per one longwall (A)	thousand person/wall	0.344	0.325	0.343	0.347	0.362	0.42	0.469	0.505	0.565	0.632	0.696	0.621	0.677	0.705	0.719
Extraction (B)	million Mg	192.7	177.4	147.4	140.1	131.3	130.2	132.7	135.3	136.2	137.1	116	109.2	102.2	102.8	100.4

The coefficient was calculated at the level of -0.896 (Table 1), which indicates a high negative correlation between the number of underground workers per longwall (A) and changes in the level of extraction (B) in hard coal mines. A negative relationship means that when the values of one variable (A) increase, the values of the other variable (B) decrease; that is when the production decreases with the increase in the number of underground workers per 1 longwall.

Assessment of the effectiveness of management activities in the light of the proposed KPI

In light of the changes in the technology of coal extraction in Polish coal mines in the form of abandonment of semi-mechanized longwall systems and abandonment of mining from longwalls with backfilling (particularly hydraulic), the increase in the value of the proposed KPI seems incomprehensible. This may be partly due to the increase in the depth and extent of the mines but also from the backlog of unnecessary technical infrastructure. The main reason, however, lies in the very high labor consumption and low work efficiency in auxiliary processes other than the basic process (fundamental, such as preparatory works, liquidation and reinforcement of walls, and existential ones).

Conclusions

The use of new KPIs to assess the effectiveness and efficiency of management activities in terms of processes is necessary to develop better new strategies for mining enterprises. This is particularly important in light of the plans for in-depth restructuring of this industry and, consequently, the far-reaching vision of decarbonizing the

Polish energy sector. The change in the presented indicator highlights the need for an in-depth diagnosis of the processes and further management actions. At the same time, the analysis shows that the increase in the value of this indicator is an unfavorable phenomenon, reflecting the deterioration of the efficiency of the operation process due to its greater labor consumption. At the same time, if it remains constant, it should affect the analysis of the interdependence of factors in a given network of processes.

References

Agostini, L., & Filippini, R. (2019). Organizational and managerial challenges in the path toward Industry 4.0. *European Journal of Innovation Management*, 22 (3), 406-421. https://doi.org/10.1108/EJIM-02-2018-0030

Agwu M.E., & Onwuegbuzie, H. (2017). Strategic Importance of Functional Level Strategies as Effective Tools for the Achievement of Organizational Goals. *Archives of Business Research*, 5, 12, 338-348. https://doi.org/10.14738 /abr.512.4012

Bartkowiak, P., & Grabowska, I. (2020). Implementation of process management - a case study of a production company. *Przegląd Organizacji*, No. 2, 10–19.

Bitkowska, A. (2019). Model of process architecture. *Przegląd Organizacji*, No. 2, 14–21.

Cameron, E., & Green M., (2019). *Making Sense of Change Management: A Complete Guide to the Models*, *Tools and Techniques of Organizational Change* (5th ed.). Kogan Page.

Cizmas, E., Emoke-Szidónia, F., Mădălina-Dumitrita, M., & Vlad-Anghe. S. (2020). Team Management, Diversity, and Performance as Key Influencing Factors of Organizational Sustainable Performance. *Sustainability*, 12 (18), 7414. https://doi.org/10.3390/su12187414

Culota, G., Nassimbenia, G., Orzesb, G., & Sartora M. (2020). Behind the definition of Industry 4.0: Analysis and open questions. *International Journal of Production Economics*, Vol. 226, August, 1-15. https://doi.org/10.1016/j.ijpe.2020.107617

Drucker, P. (2017). *Management practice*. MT Biznes, Warsaw.

Dumas, M., La Rosa, M., Mendling, J., & Reijers H.A. (2018). *Fundamentals of Business Process Management* (2nd ed.). Springer, https://doi.org/10.1007/978-3-662-56509-4

Durlik, I., (2019) *Management engineering*. Placet Publishing House, Warsaw.

Estrada-Torres, B., Camargo, M., Dumas, M., García-Bañuelos, L., Mahdy, I., & Yerokhin, M. (2021). Discovering business process simulation models in the presence of multitasking and availability constraints. *Data & Knowledge Engineering*, Vol. 134, July. https://doi.org/10.1016/j.datak.2021.101897

Fayol, H. (1916). *General and Industrial Management*. Institute of Electrical and Electronics Engineering, Paris.

Frączek, B., (2013). Development of the REIT Market in the World. International Economic Relations: Selected Institutional Factors and Real Processes in the Conditions of World Instability, 170, 69-80.

Fuksa, D. (2021). Opportunities and Threats for Polish Power Industry and for Polish Coal: A Case Study in Poland. *Energies*, 14, 6638. https://doi.org/10.3390/en14206638

Gackowiec, P., Podobińska-Staniec, M., Brzychczy, E., Kuhlbach, Ch., & Ozyer, T. (2020). Review of key performance indicators for process monitoring in the mining industry. *Energies*, 13(19), 5169. https://doi.org/10.3390/en13195169

Gajdzik, B., Jaciow, M., Wolniak, R., Wolny, R., & Grebski, W. W. (2023). Assessment of Energy and Heat Consumption Trends and Forecasting in the Small Consumer Sector in Poland Based on Historical Data. *Resources*, 12(9), 111. MDPI AG. Retrieved September 26, 2023 from http://dx.doi.org/10.3390/resources12090111

Gawlik, L ., & Mokrzycki E. (2019). Changes in the Structure of Electricity Generation in Poland in View of the EU Climate Package. *Energies*, 12(17), 3323. https://doi.org/10.3390/en12173323

Gierszewska, G., & Romanowska, M. (2021). *Strategic analysis of the enterprise*. Polish Scientific Publishers, Warsaw.

Grajewski, P. (2016). *Process organization*. PWE, Warsaw.

Grycuk, A. (2010). Key Performance Indicators (KPIs) as a tool for improving the operational efficiency of lean-oriented manufacturing companies, Organizational Review, 2.

Harmon, P. (2019). *Business Process Change: A Business Process Management Guide for Managers and Process Professionals* (4th ed.). Elsevier Science & Technology.

Hatchueland, A., & Segrestin, B. (2019). A century old and still visionary: Fayol's innovative theory of management. *European Management Review*, 16(2), 399-412. https://doi.org/10.1111/emre.12292

Henderson, P.G. Experience in longwall mining at Coalbrook Collieries. Retrieved October 10, 2021 from https://www.saimm.co.za/Journal/v080n01p022.pdf

Jonek-Kowalska, I., & Tchórzewski, I. (2016). Efficiency indicators for the use of machines and devices in hard coal mining - a critical approach to unification and standardization. *Mining Engineering*, 4.

Korski, J., Tobór-Osadnik, K., & Wyganowska, M. (2016). Reasons of problems of the Polish hard coal mining in connection with restructuring changes in the period 1988–2014. *Resources Policy*, 48, 25–31. https://doi.org/10.1016/j.resourpol.2016.02.005

Kovanič, Ľ.; Peťovský, P.; Topitzer, B.; Blišťan, P. Complex Methodology for Spatial Documentation of Geomorphological Changes and Geohazards in the Alpine Environment. *Land* 2024, *13*, 112.

Kowal, B., Ranosz, R., Karkula, M., & Kowal, D. (2018). Process Management in Hard Coal Mining

Companies. *Journal of the Polish Mineral Engineering Society*, 20(2), 111–116. https://doi.org/10.29227/IM-2018-02-14

Kowal, B. (2019). Key performance indicators in a multi-dimensional performance card in the energy sector. IOP Conf. Series: Earth and Environmental Science, 214, 012093. doi:10.1088/1755-1315/214/1/012093

Kunasz, M. (2010). *Practical aspects of process management*. Szczecin: Economicus.

Liao, Y., Deschamps, F., Loures, E.D.F.R., Ramos, L.F.P. (2017). Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal. *International Journal of Production Research*, 55(12), 3609-3629. http://dx.doi.org/10.1080/00207543.2017.1308576

Madison, D. (2005). *Process Mapping, Process Improvement, and Process Management: A Practical Guide for Enhancing Work and Information Flow*, Paton Professional, Chico, California.

Manowska, A., Tobór-Osadnik, K., & Wyganowska, M. (2017). Economic and social aspects of restructuring Polish coal mining: Focusing on Poland and the EU. *Resources Policy*, 52, 192-200. https://doi.org/10.1016/j.resourpol.2017.02.006

Manowska, A., & Bluszcz, A. (2022). Forecasting crude oil consumption in Poland based on LSTM recurrent neural network. *Energies*, 15(13), 4885. https://doi.org/10.3390/en15134885

Maskuriy, R., Selamat, A., Maresova, P., Krejcar, O., & Olalekan D.O. (2019). Industry 4.0 for the Construction Industry: Review of Management Perspective. *Economies*, 7(3), 68. https://doi.org/10.3390/economies7030068

Miśkiewicz, R., & Wolniak R. (2020). Practical Application of the Industry 4.0 Concept in a Steel Company. *Sustainability*, 12(14), 5776. https://doi.org/10.3390 / su12145776

Myszkowski, M. (2016). *High performance remote controlled longwall extraction of low seams exploiting plow systems*. Materials of the School of Underground Exploitation, Kraków

Ouyang, C., Wynn, MT, Fidge, C., ter Hofstede, A.H.M., & Kuhr, J-Ch. (2010). *Modeling Complex Resource Requirements in Business Process Management Systems*, ACIS 2010 Proceedings. 60. https://aisel.aisnet.org/acis2010/60

Parmenter, D. (2016). *Key Performance Indicators (KPIs). Creation, implementation and application*. Onepress, Gliwice.

Robbins, S.P., & Coulter, M.A. (2020). Management (15th ed.). Pearson Education Limited.

Rusinaite, T., Vasilecas, O., Savickas, T., Vysockis, T., & Normantas, K. (2016). *An approach for allocation of shared resources in the rule-based business process simulation*, Proceedings of CompSysTech 2016, 25–32. https://doi.org/10.1145/2983468.2983481

Rydzewska-Włodarczyk, M., & Sobieraj, M. (2015). Measurement of process efficiency using key performance indicators. *Scientific Journals of the University of Szczecin*, no. 864 Finance, Financial Markets, Insurance, 76, 2, 333–347. https://doi.org/10.18276/frfu.2015.76/2-25

Schraeder, M., Self, D.R., Jordan, M.H., & Portis, R. (2014). The Functions of Management as Mechanisms for Fostering Interpersonal Trust. *Advances in Business Research*, 5, 50-62.

Senkus, P., Glabiszewski, W., Wysokinska-Senkus, A., & Panka, A. (2021). Process Definitions - Critical Literature Review. *European Research Studies Journal*, XXIV(3), 241-255.

Slack, N., & Brandon-Jones, A. (2018). Operations and Process Management: Principles and Practice for Strategic Impact (5th ed.). Pearson.

Tobór-Osadnik, K., Gajdzik, B., & Strzelec, G. (2023). Configurational Path of Decarbonisation Based on Coal Mine Methane (CMM): An Econometric Model for the Polish Mining Industry. *Sustainability*, 15(13), 9980. MDPI AG. http://dx.doi.org/10.3390/su15139980

Tyrańska, M., & Walas-Trębacz, J. (2010). *The use of strategic analysis methods in a company*. Publishing House of the University of Economics in Kraków, Kraków.

Vergidis, K., Turner, C., & Tiwari, A. (2008). Business process perspectives: Theoretical developments vs. real-world practice. *International Journal of Production Economics*, 114(1), 91-104. https://doi.org/10.1016/j.ijpe.2007.12.009

Wąchol, J. (2018). Process management versus other management methods 6 in the conditions of globalization. *Scientific journals of the Silesian University of Technology*, Organization and Management, iss. 120, 219-230.

Peng, S.S. (2019). *Longwall Mining* (3rd ed.). CRC Press.

www1: https://www.consolenergy.com/operations/ Retrieved September 10, 2023