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Automated longwall in Polish hard coal mines – conditions and limitations

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Abstract:

The article presents the determinants and limitations of the possibility of implementing longwalls with a high degree of automation in the Polish underground coal mining against the background of similar solutions in the global mining industry. Significant differences in the conditions for mining with longwall systems in Polish conditions and the differences in the planned objectives of longwall automation in Poland were indicated.

Keywords: Longwall mining, automated longwall, automation in mining, mechanized longwall

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1. Introduction

Automation is a significant reduction or replacement (the process of replacing) human physical and mental work by the work of machines operating on the basis of self-regulation and performing specific activities without human participation (i.e. automatic) [1, 2, 3, 4]. Automation is also the use of machines for work that is impossible to do otherwise. Automation is the next stage after mechanization. For several years, the topic of automatic or even autonomous longwall has been returning in the Polish hard coal mining industry, but such a solution has not been used so far. The article attempts to analyse the possibility of implementing an automatic longwall in the conditions of Polish hard coal mines based on the analysis of known solutions of automated longwall systems and the conditions of their use.

2. Development of automation of powered walls in Poland and in the world

The development of coal mining automation in Poland has a long history [5]. In the 60s of the twentieth century, automation in the area of shaft hoists and belt conveyors was strongly developed. Work has also begun on full automation of longwall faces. Around 1964, the Polish hard coal mining industry (PGWK) started work on two types of automated longwalls (ASI-1 and BESTA), which were implemented in the Zabrze and Bielszowice mines (BESTA) (Fig.1), then in the mine. Lenin – Wesoła). The ASI system was based on the principle of controlling the machines via a central computer, and in the BESTA system, the shearer started the operation of the support section. In 1968, the Jan Automated Coal Mine was launched on a part of the Wieczorek mine, where an "automatic" ASI-2 longwall controlled by a computer was launched. In 1973, work on the automated longwall was abandoned, at the same time the development of automation of individual devices included in the mechanized longwall system was continued (and continues to this day).

The reasons for abandoning work on the development of automatic longwalls in Poland were:

- Significant capital expenditure and operating costs with no noticeable increase in wall performance/productivity.
- A prerequisite for the introduction of automation of a process or operation is the full (complete) mechanization of this process or operation – however, many activities and operations performed in the longwall at that time were performed manually (especially at the longwall-roadway intersection), and initially single-drum shearers worked in one direction and did not have mining height adjustment. The peeling process was therefore a manual and machine process.
- Availability of qualified specialist staff - a side effect of the launch of automatic longwalls in the Zabrze (ASI 1) and Bielszowice (BESTA) mines, and then the Automated Hard Coal Mine Jan, was the drainage of other mines of automation specialists. Another aspect of this problem was the resignations of project leader.
- State of the art and its imperfections - One of the biggest problems of ASI and BESTA automated walls was the high failure rate caused by sensor errors causing frequent stoppages.

In Table 1 are presented important events in area of LW automation in Poland and worldwide.

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Table 1. Selected events in the development of automation in the Polish and global hard coal mining industry – a chronological outline – own study based on [5, 6, 7, 8]

Year	Country	Development of longwall automation
1964	Poland	commencement of work on two types of automated longwalls (ASI-1 and BESTA)
1968	Poland	Commissioning of the Jan Automated Coal Mine with ASI-2 automatic longwall
1973	Poland	Interruption of work on an automatic longwall in the Polish mining industry
2000	Australia	Launch of the Longwall Automated Shearer Control (LASC) program
2007	Australia	Implementation of highly automated longwalls in Australian mining conditions
2009	Poland	Implementation of an automated ploughing system (LW Bogdanka)
2016	Germany	Automated/integrated longwall at Prosper-Haniel (RAG Mining Solutions)
2018	Poland	Announcement of the implementation of an autonomous longwall (JSW S.A.)
2020	Poland/China	MIKRUS complex with remote control and a master control system (FAMUR S.A.)
2022/2023	Poland	Procedure for an automatic longwall (KWK Piast - Ziemowit/PGG S.A.)

Work on the automated longwall was resumed in the 21st century. Around 2000, work began on a remote-controlled longwall at Śląsk Colliery. In 2009, a ploughing system with a high level of automation was implemented in the LW Bogdanka mine. It differed ideologically from the old solutions (ASI/BBESTA), but it allowed the movement of the powered support and conveyor sections following the progress of ploughing and the adjustment of the take-off.

In 2018, Jastrzębska Spółka Węglowa S.A. intended to implement an autonomous longwall in one of its mines without specifying the scope of automation and autonomy – the project was abandoned. In 2020, the Polish company FAMUR S.A. launched a thoroughly modernised MIKRUS complex for the exploitation of low seams in one of the Chinese mines, with a telecontrol system supported by a master control system. In 2022-2023, a tender for an automatic longwall system was announced and opened at the KWK Piast-Ziemowit coal mine, owned by Polska Grupa Górnicza S.A. The tender for the automated longwall announced at the Janina Mine (PKW S.A.) assumes the automation of mining and moving the support behind the shearer without the presence of the crew to complete the longwall mining cycle.

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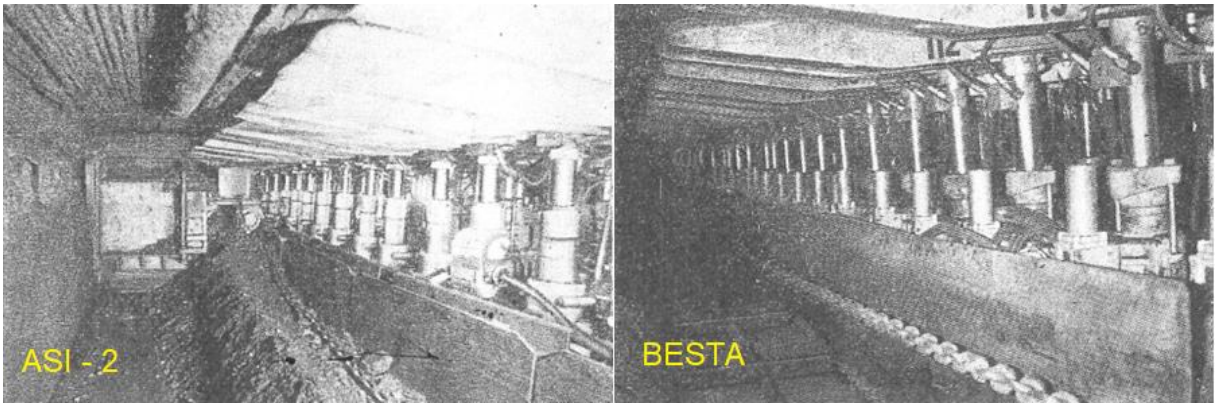

Fig. 1. Automated longwall system ASI-2 in JAN Automated Colliery and automated longwall BESTA in Bielszowice Colliery [5]

It should be noted that in the European hard coal mining industry, there has been practically no longwall with a high degree of automation or fully autonomous in operation to date. In the German coal mining industry, which has already ceased its mining operations, in 2016 RAG Mining Solutions and RAG Deutsche Steinkohle developed a computer system for the Prosper-Haniel mine in Bottrop, which integrates the automation systems of the individual devices included in the longwall excavation complex in the Zollwerein field. One of the key functions of this system is to ensure the interaction between the individual automation systems (modules): the Eickhoff SL750 shearer loader (Eickhoff EiControlSB module) and the longwall support and scraper section of the face conveyor. The most important tasks of the individual modules were to ensure a high degree of reliability and improve the efficiency of the use of longwall equipment. The ability to visualize the data necessary to supervise the operation of devices is also of great importance. The implementation of the new integrated automation system was to effectively improve the supervision of the entire longwall excavation process and the safety of the crew's working environment. The system was connected to the mine's control room and provided a 3D model of the infrastructure of the entire mining area [7]. In the coal mining industry of the Czech Republic, available automation elements of individual longwall system devices supplied by their manufacturers were implemented [7].

In view of the growing expectations for longwall productivity in Australia, in 2000, the LASC Technology (Longwall Automated Shearer Control) program was launched on the initiative of the Australian Coal Association, the aim of which was to implement highly automated longwall systems in Australian conditions. In the conditions of Australian mines, longwalls are laid in regularly almost horizontally lying seam plots without geological disturbances (faults, undulations, significant changes in seam thickness) with longwall galleries in independent bolt support. There is no need to use a shearer loader to remove steel arching elements. It should be emphasized that a high degree of automation of many longwalls has been achieved in Australian mining [9, 10, 11, 12, 13, 14, 15, 16].

Ideologically, the concept of an automatic wall is evolving, which can be traced on the example of Joy Global, which has recently moved from defining detailed solutions in the automation process to defining automation levels from the warning level (manual control of the machine) to the level of full autonomy, where the system is aware of the position and implements the assumed plan, and the necessary changes to this plan are carried out remotely.

In the coal mining industry of China and the USA, advanced research and applications of longwall automation are carried out [16, 17], at the same time pointing to the problems and conditions for the use of such solutions [18].

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3. Longwall system in the process system in an underground coal mine

The longwall coal mining system offers the possibility of obtaining the highest efficiency among all those used in underground hard coal mining. A longwall is an underground excavation bounded by two, basically parallel to each other, horizontal workings (galleries) (longwall and longwall) or sloping (ramp). In the longwall, coal is mined (less often potassium salt, stripped soda - tron or phosphate rock) along its entire length. The longwall method of coal mining has been known since the 17th century, initially as traditional mining with all activities and operations performed manually. From the mid-nineteenth century, the first machines (notching machines) and then conveyors were used. Already at that time, the basic distinguishing features of the longwall system were defined:

- Wide (long) front of the selective face.
- Liquidation of the selected space immediately behind the face by a collapse of ceiling rocks (later also by filling the selected space partially or completely with the material provided, i.e. backfill).
- One-way movement of means of transporting excavated material in the longwall (first excavated boxes, then carts and finally conveyors).
- One-way airflow eliminating the need to use ventilation devices in the face (dams, partitions) causing difficulties and conflicts with the activities and operations carried out.

Regardless of the degree of mechanization, the longwall is used to perform the basic operations of the extraction process, i.e.:

- Mining of coal (less often other minerals),
- Loading excavated material onto the means of transport,
- Transport of excavated material along the wall to the outside of the face.

Other operations related to securing the excavation, liquidation of goafs or elimination of mining and technical hazards are also carried out in the longwall. Due to the movement of the equipment of the mechanized longwall system, it may be necessary to correct the mutual position of these devices and to correct the position in the excavation space.

The development of longwall system mechanization is shown in Fig. 2.

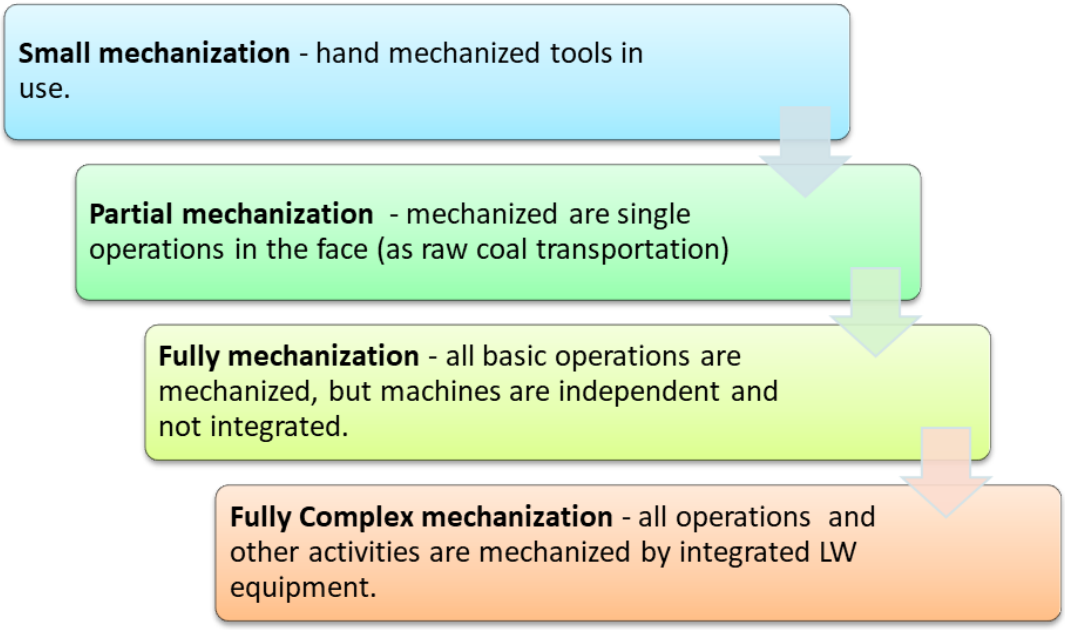

Fig. 2. Longwall mechanization development steps

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In the 1960s, the first solutions of comprehensively mechanized longwall systems appeared, the technical development of which continues to this day [19, 20], but traditional mining systems with a low degree of mechanization of works are still used.

A modern comprehensively mechanized longwall system consists of the following basic elements (Fig. 3):

1. Cutting machine (shearer or planer).
2. Scraper face conveyor, the so-called armored one.
3. Powered roof support.
4. Scraper beam stage loader with crusher.
5. Hydraulic pump unit feeding powered casing.
6. A hydraulic pump unit that supplies a combine with water or an air-water mixture.
7. A set of electrical devices supplying power to the wall equipment (apparatus train).

The basic elements of the mechanized longwall system perform various functions for the good operation of the above-mentioned elements and their-mutual correct cooperation.

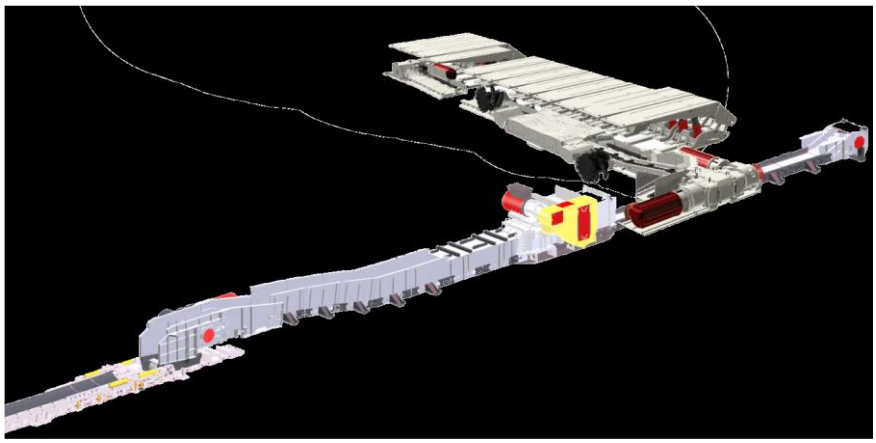

Fig. 3. Fully mechanized longwall complex with coal shearer – general view [own source]

The basic functions performed by the main devices of a comprehensively mechanized longwall are [20, 21]:

- **Coal mining:** A mining machine (shearer or plow) is basically used to mine coal (separate it from the coal pile) and load it onto a longwall scraper conveyor. An additional function of the cutting machine is to prepare (cut) space for other longwall equipment for their proper operation. Therefore, it is sometimes necessary to additionally trim the rocks in the vicinity of the coal seam (in the floor or in the ceiling) or to leave the coal in the floor or ceiling of the wall. In the case of high walls, crushers are sometimes used on the shearer loader (from the side of the reverse drive of the face conveyor) in order to crush large lumps of coal when mined with a shearer in the direction of the reverse drive (in the direction opposite to the direction of movement of the face conveyor chain).
- **Transport of excavated material:** An armoured longwall conveyor is mainly used to transport minerals mined by a mining machine (shearer or plow) in the longwall. A scraper face conveyor also has additional important functions: The longwall conveyor is also a kind of keystone (backbone) of the longwall – it is on it that the mining machine (plow or shearer) moves and the powered roof support is attached to it. In cable guides (penstocks) a movable – trailing part of the cables supplying the combine harvester moves. It is a mechanical connection of the longwall section of the powered roof support with each other (enabling their

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movement – movement). The longwall conveyor route also serves as a structure for routing electrical cables and hydraulic hoses through the longwall, and in the plow walls of the pull chain and the plow return chain (as in the Mikrus longwall complex). The design of the scraper conveyor causes the stream of the transported material to be partially leveled during transport.

- **Protection:** Powered roof support – its primary function is to protect the working space of the longwall. This is done by supporting the ceiling and/or protecting against rolling into the working space of the caving debris wall. In addition, powered support: It is the basic strut for moving the face conveyor forward. The sliding system actuator is used to move the powered roof support section forward, its structural elements are the basis for attaching additional actuators – actuators (for correcting or stabilizing wall equipment elements). Stabilizes the conveyor with the cutting shearer. It is the basis for the installation of other wall equipment, including hydraulic hoses, electrical cables, control system elements (including housing), communication and signalling, lighting, etc.
- **Pre-processing of excavated material:** A scraper beam stage loader with a crusher is used to unload the excavated material from the scraper face conveyor, the stream of which is uneven and contains quite large lumps of excavated material. The design of the beam stage loader equalizes the stream of excavated material, and the crusher built on it breaks up large lumps of excavated material before loading it onto the next conveyor – a belt conveyor, which is highly sensitive to overloading and/or the presence of oversized lumps of material. In addition, beam stage loaders are equipped with sandwich devices that enable the movement of this conveyor in the roadway, sometimes together with the belt conveyor turning station.

The other previously mentioned elements are used to supply the above-mentioned utilities and support their operation.

However, the potential high productivity of a mechanized longwall system is currently associated with high capital expenditures (CAPEX) and operating costs (OPEX) of acquiring and using comprehensively mechanized longwall systems and other technical systems adapted to their capabilities in order to implement a complex system of processes related to coal mining in an underground mine [22, 23]. Due to the expectations regarding the high efficiency of mechanized longwall systems, the aim is to fully use their technical potential and eliminate time losses [24, 25, 26]. One of the directions for improving the efficiency of longwall systems has become automation, the prerequisite for which is full mechanization of work.

4. Objectives of longwall system automation

Since the 1960s, the main goal of wall automation has been to eliminate the presence of people in the faces, where there are a number of natural and technical threats to humans. The experience of the Australian mining industry gained with the rapid development of technical longwall equipment indicated the need to automate activities and operations in the longwall due to the psycho-physical limitations of people limiting the possibility of using the technical potential of longwall equipment and favourable mining and geological conditions. Main goals of longwall automation are presented on the Fig.4

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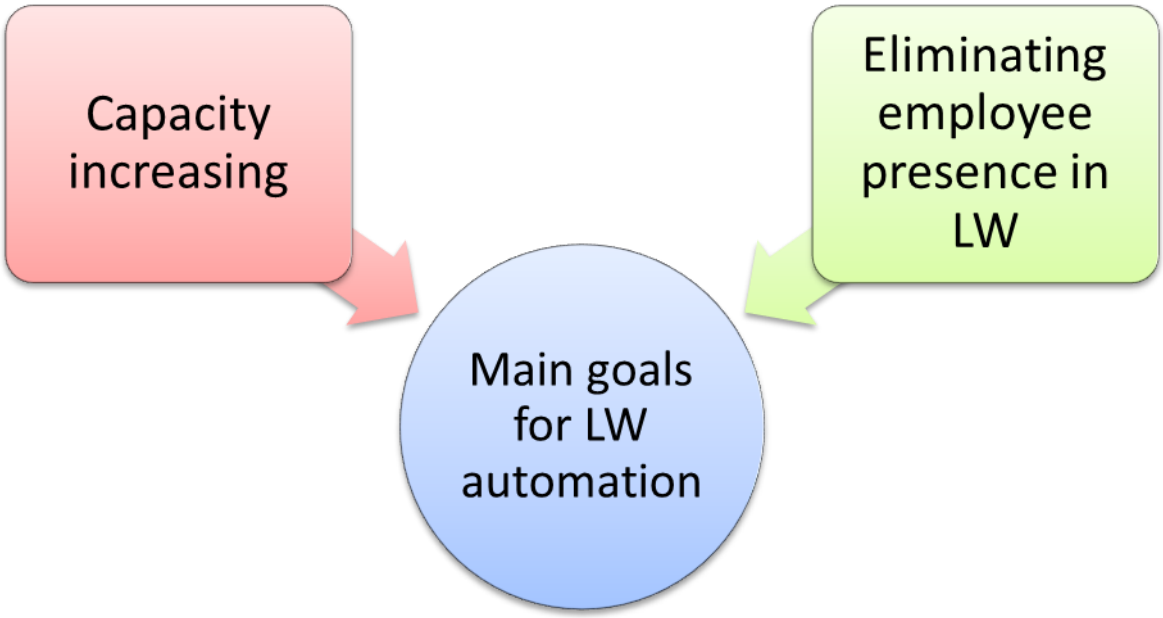

Fig. 4. Basic objectives of longwall automation

In one of conferences in 2021 CAT indicates the basic goals of automation as a:

- Improving health and safety.
- Protecting employees from dust and hazardous and harmful areas.
- Increase in efficiency.
- Transition from control by the employee to control over the process management.
- Reduce downtime and costs – improve equipment reliability.
- Repeatability and accuracy of operation.
- Consistent and predictable performance.

The discussion on the automation of longwalls in the conditions of Polish underground hard coal mines, which has been undertaken in recent years, has also pointed to goals that are not aimed at increasing the efficiency of the extraction process. Justifying the purposefulness of purchasing an automatic longwall, two objectives were indicated:

- Maintaining the daily production volume from one longwall and
- Creating conditions that suit the young generation of employees, accustomed to using smartphones, tablets, etc.

It should be noted that in the conditions of Upper Silesian hard coal mines, the average daily production from one longwall remains at a constant, very low level and in 2022 amounted to 2679 tons per day for the Upper Silesian Basin mines.

5. Conditions and limitations of longwall automation in the conditions of Polish hard coal mines

Due to the lack of experience of the Polish mining industry in the automation of modern longwalls, the conditions in Polish and Australian mines, where longwalls with the highest level of automation are currently mined, were compared (Table 2).

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Table 2. Conditions for laying comprehensively mechanized longwalls in Polish and Australian coal mining – comparison [own study]

Poland	Australia
Walls with a slope of up to 35°	Horizontal or nearly horizontal walls
Walls with variable slope in length and wall run-out	Flat walls or walls with little variation in slope
Longwall galleries in support – arch support	Wallwalks anchored with a rectangular cross-section with a height equal to the thickness/height of the exploitation gate
A large share of manual work at the longwall-pavement intersection.	Fully mechanized intersection zones
Low efficiency of methane drainage of the seam before operation	Effective pre-emptive methane drainage of the seam prior to operation
Mining in zones of significant geological disturbances.	Avoiding exploitation in zones of significant geological disturbance
Exploited seams from thin to thick.	Medium and coarse seams mined
Acceptable operation with high levels of natural hazards	Avoid high-risk mining that limits mining efficiency
Single longwall galleries	Longwall galleries in multiple systems (at least double)

In Polish, supposedly mechanized, shearer walls, work at the ends of the longwall – in the area of longwall galleries – is still associated with a large share of manual work, so these are manual and machine operations or processes. Among the manually performed activities in the area of the intersection of the wall and the pavement, the following should be mentioned:

- Unfastening the arches of the roadway support.
- Relocation (or disassembly) of pavement reinforcements in the vicinity of the wall window.
- Cleaning of the forfeit material to spacers.
- Removal (robbing) of the pavement behind the front of the wall.

Significant differences result from the longwall mining conditions between Australian (including American or Chinese) and Polish mines. In the conditions of Australian and American mines, where the slopes of the seams are small, there is no need to correct the position of the section – therefore the support section has much fewer executive devices – actuators (two stands, roof support and shifter), which also significantly simplifies the control system and possible automation. The relatively large take-off and stroke of the shifter cause the section to automatically correct its position in relation to the conveyor. In walls with a slight longitudinal slope, thanks to the section pitch of at least 1.75 m or more, there are fewer problems with maintaining the lateral stability of the support. In the case of full automation, too many sensors will not be required and the system software will be simpler. The risk of section automation malfunctions will also be lower.

Even if software for automatic control of powered roof supports was available in the conditions of Polish mines (large and variable inclinations, faults, etc.), each section would have to be equipped with a system of numerous sensors (inclinometers, pressure gauges, length measurements) with a much greater degree of complexity than in Australia, the maintenance of which would be a great challenge (see the paradox of additional protections). Failure of a single sensor can halt the movement of the wall.

Another limitation is the type of longwall support used, which affects the operational length of the longwall system and the labour intensity of the intersection of the longwall excavation with the

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longwall excavation during the progress of mining, as well as the possibility of mechanisation of work in this place.

A distinguishing feature of Polish conditions is also the fact that mining is allowed in difficult geological conditions and with a high level of natural hazards. Limiting this level, e.g. by using methane drainage of the seam before mining, is not very effective – the efficiency increases after the commencement of mining (after the seam is relaxed), while at the same time the effect is increased methane release during mining [27].

6. Classification and requirements for the automation of mining processes

Table 3 presents a proposal for the classification of mining systems and possible scopes of automation depending on the degree of mechanization. Most of the mechanized longwall systems used in Poland carry out mining processes corresponding to manual and machine processes (group 2) with limited automation capabilities.

The use of a fully automated longwall system in much more complex mining and geological conditions than in Australia will require the creation of a very complex technical longwall system.

It should be remembered that the requirement for automation of a given process is its repeatability at every step. In the case of hard coal mining, especially in changing mining and geological conditions, this poses a challenge for human operators. The more complicated the process, the more difficult it is to automate – and the longwall operation in this context is definitely complicated.

Among the requirements related to even partial longwall automation, it is indicated that it is not possible to introduce longwall automation until many other necessary elements, apart from full mechanization, are ready, such as:

- Qualifications and skills of the team supported by appropriate training.
- Reliable equipment with automation capabilities.
- OEM hardware and software to support automation.
- Maintenance systems.
- Operating system – organizing the mine.
- Collection and processing of information (databases).
- Utility supply, including water management.

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Table 3. Types of Extraction Processes in Relation to the Degree of Their Mechanization and Possibility of Automation – A Proposal for Classification [own study]

Level of automation	Process Type	Process description	Degree of process automation
1.	Manual operations	Operations occurring in mining processes in which no machinery is used to obtain a mineral	Manual processes
2.	Manual and machine (mixed) operations	Operations in which some of the extraction cycle operations are performed by the machine, and the operator decides to start and stop the machine and controls the operation of the equipment.	Manual and machine processes (mixed)
3.	Manual and machine (mixed) operations with automatic cycle	Operations in which the machine automatically starts and ends the production cycle, and the operator is responsible for supervising and making interventional corrections (locally or remotely).	
4.	Automated mining processes	The operator's job comes down to supervising automated machines.	Automated processes
5.	Autonomous mining processes	The operator's work comes down only to remote supervision of the process.	

7. Summary and Conclusion

On the basis of a comparison of Polish conditions with Australian conditions (where the automation of the longwall mining process is the most developed), an analysis of longwall mining processes in Polish mines and general requirements for the automation of any process, it is possible to draw the following conclusions.

1. The principles of longwall construction and mining and geological conditions in practice exclude the possibility of implementing fully automated longwalls in the Polish mining industry. The repeatability of the entire longwall coal mining process in such conditions is severely limited, unlike in Australian mining.
2. Without improving longwall productivity, over-development of longwall automation systems will result in a drastic increase in capital expenditure.

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3. It is justified to implement elements of targeted automation to be implemented in the conditions of Polish hard coal mines, such as those that serve to improve the safety and increase the reliability of the extraction process.
4. It is advisable to implement a system limiting the shearer feed speed with an increase in the amount of methane emitted, as a system increasing the predictability/continuity of the longwall mining process.
5. Without improving the productivity of walls, excessive development of wall automation systems will result in a drastic increase in expenditures - automation of inefficient processes is ineffective in itself (an effective process should be automated).

Before commencing activities related to a fully automated (or even autonomous) longwall, the following question should also be asked:

Have all the opportunities to increase longwall productivity in the Polish coal mining industry been used? And will the automation of longwalls bring the expected results?

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