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INTEGRATED SUBSYSTEMS OF MATERIALS AND INFORMATION FLOW FOR CONTINUOUS MANUFACTURING OF COAL AND STEEL

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Abstract:
With the concept of Industry 4.0 production processes are moving towards autonomy and intelligence. Technologies equipped with artificial intelligence (AI) are involved into processes that are more and more digitized. Collaborative technologies are a feature of discrete processes. The automotive industry has achieved many successes in the process innovation towards smart factories. Other plants, such as smelters or coal mining are also striving to develop smart manufacturing with integrated computer systems to support processes. A continuous production is different from a discrete or batch production. Industry 4.0 concept is focused on discrete production (with high level of automation and robotization of manufacturing) meanwhile there is a gap in implementation of these approach in the continuous production. The objective of the publication is to prepare and design the integrated computer management system based on processes realized in coal and steel manufacturing. Coal and steel production are key elements in a chain of any industrial manufacturing e.g. automotive or machinery engineering. These processes are crucial in building of smart value chain. In our paper we present the structure of processes for the continuous production. Based the processes model we proposed the next steps to build the smart manufacturing for continuous production.

Key words: *Industry 4.0, coal mining, steelworks, continuous production, smart manufacturing, control levels*

INTRODUCTION

Automation is the basis for the development of Industry 4.0. Kagermann indicated that the factory of the future must be automated and digitalized [1]. Digitalisation, which was initiated in the third revolution, is booming in the fourth revolution. Automation and digitalization solutions allow precise management of industrial processes and simulation of changes. Systems automatically regulate machines (technologies) and production parameters (temperature, current voltage and others). Advanced production control systems watch over the continuity of the main production processes in factories. When a change in one of the key system operating parameters alters a number of other values, automatic control solutions are needed. Advanced control systems allow a designated process and change to be managed precisely and optimal, without allowing it to stop.

In the coal mining processes IT support is used for coal extraction, transport, coal preparation, coal magazine, loading and other processes. Examples of systems in coal production: automation systems with safeguards during coal extraction (methane level control), coal quality control during preparation process or monitoring of coal flow using SCADA (Supervisory, control, and data acquisition), monitoring quantity parameters – railway scales etc. In the steel industry – in steelworks – station control systems are used at each stage of the production, processing, transport and storage of steel and steel product. Examples of systems in steel production: control systems for blast furnaces and arc furnaces, control systems for cutting lines, control systems for rolling mills, control systems for continuous casting lines, control systems for metal processing lines (inspection, cleaning, annealing, coating, cutting). Moreover, dedicated process management software is used in both sectors.

This paper proposes a Manufacturing Processes Model (MPM) that integrates processes on all control level of manufacturing. The MPM can be used as a support for building integrated information system allowing control of technological processes according to specific of manufacturing. The model consists of all processes of continuous manufacturing on the strategic, tactical and operational levels.

The paper is based on an analysis of the processes of coal mining (hard coal mining) and steel production. The authors first analysed separate processes in these sectors and then created a common MPM model for continuous production.

LITERATURE REVIEW

This section presents an approach to process management, which is supported by IT systems in the concept of Industry 4.0. No production process is perfect. The reason for this is disturbances that determine the variability of process parameters and indicators. Process control should therefore focus on identifying process parameters and the causes causing disruptions and try to eliminate them or at least limit their impact. The latest generation of IT technologies control the process parameters and, through intelligent and predictive functions, are able to indicate optimal operating parameters of machines (technologies) and establish optimal process conditions. "Industry 4.0" assumes broadly understood integration, coordination and cooperation of autonomous machines, robots and various classes and generations of transaction and analytical systems [2]. The foundation of "Industry 4.0" is smart manufacturing, that includes the integration process of technical means in production (i.e. machinery, production lines, industrial infrastructure, means of transport) and cyber-physical systems supporting operational and management processes. The aim of these activities is to achieve full autonomy of control, monitoring and production control operations through direct exchange of data and messages between various industrial machines and robots and the use of a new generation of IT systems with artificial intelligence algorithms. Smart technologies can consolidate preventive activities and implement their results in process control systems. In the concept of "Industry 4.0", each production process must be supported by intelligent IT systems in the area of planning, monitoring and control of technological and manufacturing processes as well as decision-making at the strategic, tactical and operational levels. The basis for their operation will be the use of a new generation of cyber-physical systems. The concept of a cyber-physical system was proposed in 2006 (first definition that can be found about cyber-physical systems (CPS) dates from 2006, during a workshop with the American National Science Foundation) [3, 4]. In the literature on the subject, the concept of a cyber-physical system is complex and ambiguous. For example, in [5, p.17] the author indicates that the essence of the cyber-physical system is the control of the so-called physical processes in the factory using a network of industrial sensors, as well as remote monitoring of these processes via a global digital network. *„Cyber-Physical Systems (CPS) are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet"* [6]. In turn, in the paper [7, p. 84], the authors of this paper emphasize that the cyber-physical system enables effective coordination of factors and means of production using information systems, as well as – more importantly – practically unlimited access to distributed industrial data. In relation to industry, a cyber-physical system can be seen as a solution integrating control systems for machines, devices and robots and intelligent information systems supporting operational and management functions. A cyber-physical system can also be considered as a solution integrating physical components, logical components and networks of industrial partners.

Cyber-physical systems are identified with smart manufacturing. The transition to technological solutions according to the concept of Industry 4.0 is also connected with requirements for new skills of workers [8]. According to the National Institute of Standards and Technology (NIST) smart manufacturing is a fully integrated, collaborative manufacturing system that responds in real time to meet changing demands and conditions in the factory, supply network and customer needs [9]. Kusiak, A. (2017) said that "smart manufacturing integrated manufacturing assets of today and tomorrow with sensors, computing platforms, communication technology, data intensive modelling, control, simulation and predictive engineering" [10]. The concept of smart manufacturing using a new generation of cyber-physical systems primarily covers the computerization of industrial process procedures. The currently used integrated MRP/ERP class information systems were developed for the needs of computer support of economic processes in the area of a single enterprise.

The smart manufacturing can be considered to be a new version of intelligent manufacturing that highlights the use of advanced information and communication technologies and advanced data analytics [11, 12, 13]. Smart manufacturing is based on data and information, largely the term 'smart' refers to the creation and use of data [12]. Technologies are equipped with advanced sensors, embedded software and robotics to collect and analyse data and enable better decision-making. Even greater value is gained when data from manufacturing operations is combined with operational data from ERP, supply chain, customer service and other enterprise systems to create a whole new level of visibility and insight from previously collected data. Transmission and analysis of data takes place in real time throughout the product life cycle with model-based simulation and process optimisation, creating "smart" to bring a positive impact on all aspects of production [11, 14, 15, 16]. According to Kang [17], the aim of smart manufacturing is to improve competitiveness using innovative ICT technologies for effective and accurate engineering decision-making in real-time.

In accordance with the paradigm of the "Industry 4.0" concept, cyber-physical systems will operate in a virtual and distributed environment, which will enable the cooperation of a group of independent partner enterprises integrated in the production process (integration of a network of industrial partners). These systems, in addition to functionality in the area of supporting typical process operations, are equipped with intelligent modules supporting decision-making based on expert knowledge bases, as well as forecasting functions (machine learning techniques) [18, 19, 20]. In smart manufacturing, the cyber physical systems (CPSs) handle interconnectivity between the physical assets and computational capabilities [21].

The part of the smart manufacturing are computer system: ERP, MES, and others. The ERP computer system covers the control and management of the most important resources and processes in almost every business area of the company: sales, finance, accounting, warehouse, human resources, procurement, production, etc. Its most important distinguishing feature is the work on one database. This means that data entered in one area of the system, e.g. in trade, is immediately visible to other users, e.g. the production manager, the accounting department or the warehouse. Historically, ERP system derived from MRP II systems are designed to manage a company's inventory orders, schedule production plans, and organize inventories. In addition to these functions, ERP system integrates inventory data with financial, sales, and human resources data to enable an organization to price their products, generate financial statements, manage the workforce, materials, and money efficiently [22]. The expansion of MRP II into ERP in the 1990s aspired to further improve resource planning by including the components of the supply chain in the scope of the planning phase. In Industry 4.0, according to Deloitte [23], ERP systems will still play a central role but it has to be evaluated how they should be used to maximize their potential for Industry 4.0. "Enterprise resource planning and the future of this concept will be well affected by this new transformation. It is obvious that some concerns are eliminated by implementation of the Industry 4.0 and related activities such as: (i) gathering data from the real production environment will be quite easier than manual data entering, (ii) more reliable data is acquired from the source at once, (iii) more amount of data can be handled and analysed by cloud and big data approached, (iv) decision capabilities of ERP software are increased by applying artificial intelligence techniques, and (v) future ERP systems are one of the key concepts that controls the bottom and intermediate data storage and analysis in the smart facilities [24].

The nest system – MES – allows users to export data to cloud-based big data structures to efficiently distribute operational data. MES was developed in 70s to assist the execution of production, with the concept of online management of activities on the shop floor. „It bridges the gap in-between planning system (such as ERP) and controlling systems (such as sensors, PLCs) and uses the manufacturing information (such as equipment, resources and orders) to support manufacturing processes. Like any enterprise information systems tool, MES too has evolved with time to integrate several extensions to perform various manufacturing activities using the sophistication of the computer technology advancements" [25, 26]. „In the past, production departments of many companies preferred tailor-made information systems for the shop floor and were locally collecting the production data in spreadsheets or other databases, which made it difficult for software maintenance and data consolidation. MES was developed with a purpose to integrate multiple point systems and consequently software providers were able to package various production execution functions in the form of MES software [27]. However, the next generation manufacturing is in the need for process improvement by further leveraging automation tools and real-time systems to completely avoid the paper work. This vision leads to the concept of smart factories (with industrial internet), where wireless technologies and mobile information & communication technologies (IT/ICT) become the key enablers for industrial internet. But such digitization in manufacturing is still at a nascent stage. In the future, companies will rely on real-time compliant software and IT/ICT, where MES will have a greater role in smart production than just providing information for manufacturing management [28, 29, 30].

As information systems develop, their functions change. The basic functions - planning, control and optimization of production processes and resources – are expanded with predictive and preventive activities. Information systems are components of cyber-physical systems with access to Internet of Things and cloud computing. Intelligent sensors installed on machines and technological processes provide more and more data, which creates a need for Big Data technologies. With access to Big Data, data analysis techniques and tools are developing. Among the data analysis methods, more attention is paid to prediction, simulation and modelling. Process visualization has also developed significantly. Discrete production involves the use of 3D models and the use of information embedded in them to visualize systems and simulate production processes. The digital factory model supports planning, analysis, simulation and improvement of the production of all types of products [31, 32].

Modern information systems and digital technologies connect processes within enterprises and supply chains. Internal and external logistics constitute a coherent whole, which in the era of industry 4.0 is called Logistics 4.0. A feature of this logistics is the integration of systems and physical solutions using IoT, digital platforms, cloud computing, big data analysis, blockchain technology and other pillars of Industry 4.0 [33].

METHODOLOGY OF RESEARCH

This part of the research (analysis) is the result of the expert knowledge of the authors of the publication and was created during the exchange of knowledge and experience on the implementation of IT/ICT systems in continuous production. The analysis was based on two sectors: coal mining and steel production. The research process was carried out using the deductive method. The input to the analysis included the processes of (1) coal mining, (2) steel production analysed at all levels of management. The transformation process involved grouping processes according to general criteria typical of continuous production. The MPM model was obtained as the output of the analysis.

By applying the obtained MPM model to this architecture of an IT system supporting continuous production (architecture of an existing system from coal processing plants), an architecture innovation project was created consisting of supplementation with elements of Industry 4.0 technology.

The research methodology consisted of the following steps: Step 1: Analysis of coal and steel process. Step 2: Define the research problem. Step 3: Design an integrated model of processes for continuous production (MPM model). Step 4: Design of universal information system architecture for support the continuous production according the concept of Industry 4.0.

Analysis of processes in coal and steel production

Analysis of processes in coal mining and preparation were realized in 90.ies and has been published in 1997 [34]. The diagram of the connection of processes in coal production from mining to the sale of the resulting products is shown in Figure 1a. The same analyse has been done for steel production (Figure 1b).

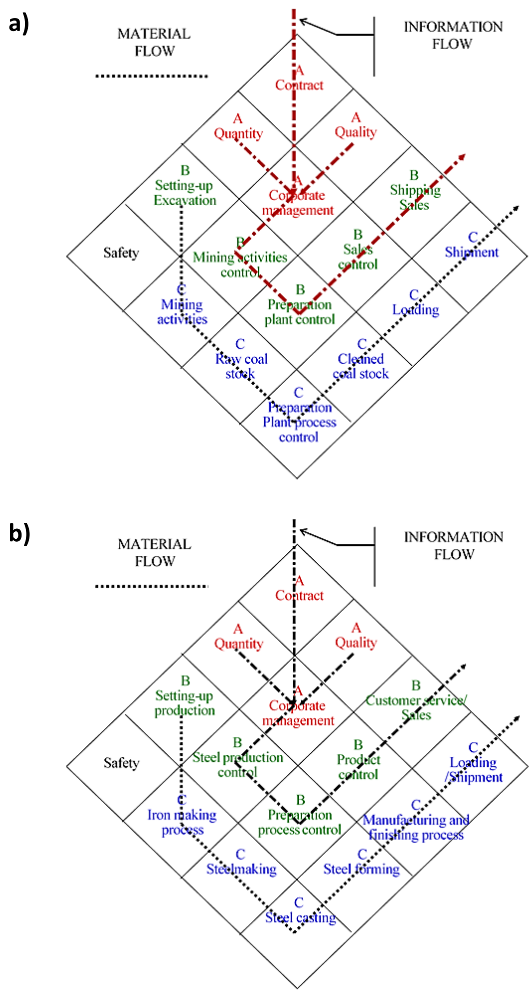

Fig. 1 a) Control subsystems in the coal production, b) Control subsystems in the steel production

The scheme shows material and information flow through processes with logical division according control level. This scheme proved its universality during subsequent implementations of information systems in OKD (hard coal mining company in Czechia) not only in the nineties but also in other generations of these systems In a production of brown coal, the process schema is similar. Only the differences are less importance of coal preparation of processes and different quality parameter (e.g. more important is sulphur content).

In steel industry (case study – Poland) changes in steel processes accelerated after the sector's restructuring in the 1990s. [35]. At that time, many countries in Europe changed their economic systems, which affected the development of the steel market. Open hearth furnace technology was discontinued in the Polish steel sector in 2002. Since then, two technologies have been used BF+BOF (Blast Furnace-Basic Oxygen Furnace) and EAF (Electric Arc Furnace). These technologies determine the steelmaking processes, which over time have been supported by computer technologies and systems [36]. The key components of the computer system for process support were presented in Fig. 1b.

If the information flow and material (raw material) flow is added to Fig. 1a and Fig. 1b, there is a logical differentiation of production control and quality control into following control levels:

- Operational control level (marked with the letter "C")
- Tactical (dispatching) control level (marked with the letter "B")
- Strategic (management) control level (marked with the letter "A")

The management control level (strategic management) is further stratified to higher control levels; however, its nature does not change compared to the process and dispatching levels.

The naming of the control levels is based on the degree of human involvement in the control process. The stratification into control levels does not have a direct relation to the architecture of the implemented control systems in terms of configuration of technical tools or to the structure of the programming of the control systems.

The operational control level is related directly to a technological process. Human participation is limited to supervision and setting of control parameters. This is primarily direct control of technological nodes in distributed control units and automated data collection.

The centre of tactical control of the preparation plant is the control room, dispatching, loading control or shift foremen's worksite. Users have at their disposal information about the progress of the controlled process.

The strategic (management) control level is usually allocated to the company management level and is connected with long-term planning, balance reporting and production/sales analysis.

Problem definition

The existing information systems for processes control in the hard coal preparation plants in the Czech Republic are conceptually more than ten years old and do not reflect current developments in information technologies, such as the connection with a solution based on the Internet of Things, the application of the ideas of the Industry 4.0 initiative, support for cloud solutions, Big Data analysis, etc. In contrast, the steel sector, which was analyzed in Poland, significantly accelerated the development of process support IT systems at the end of the first decade of this century, when strong foreign capital appeared in the Polish steel market. The largest steel company in the Polish market introduced WCM standards, achieving a leadership position in this market [37]. In the case of I 4.0, the same enterprise, within the capital structures, adopted the startegy of Industry 4.0. Technologies woven into IIoT and M2M communication with increasingly strong autonomous decision-making processes are moving towards smart steel manufacturing [38, 39, 40].

With differences and similarities between these two continuous production processes we found need for developing common integrated information system based on common processes and activities. The aim of this research is to prepare background for design a universal information system supporting continuous production and including technologies connected with concept of Industry 4.0. So integrated universal information system have to be modular and flexible to allow easy adapt new technologies in plants.

Project of integrated model of processes for continuous production

Integrated Management Information Systems (IMIS) are modularly organized IT systems that support all areas of enterprise activity, from marketing, planning and supply, through technical preparation of production, management of the manufacturing process, distribution, sales, repair management, to financial accounting work and human resources management [37, 38, 39, 40]. Benefits of using IMISs:

- User with his own workstation is able to use every function of the system,
- Users use a universal interface throughout the system,
- Data is entered into the system in real time and automatically updates the system status and is visible to all dedicated users.
- Basic features of modern systems [41, 42, 43]:
- Functional comprehensiveness (the scope of the system covers all spheres of the organization's technical and economic activity),
- Integration of data and processes, referring both to the exchange of data within the facility and with its surroundings,
- System flexibility (maximum adaptation of hardware and software solutions to the needs at the time of system installation and its dynamic adaptation to changes occurring during operation),
- Modularity of systems (systems with options for additional modules in line with the specifics of continuous production processes),
- Openness (scalable architecture, ability to expand the system with new modules and connect with external systems),
- Advanced autonomy (in order to provide full IT support for information and decision-making processes, systems can be equipped with learning/self-learning algorithms),
- Standardization (guarantees compliance with current hardware and software standards and a basis for further development),
- Legislation (compliance with regulations and standards),
- Ensuring safety and security.

The main challenges for software producers are related to combining physical technological processes with information systems and augmented or virtual reality. Systems must keep up with the development and autonomy of production means, creating integration interfaces between machine software and information streams of production planning systems. In this respect, we should expect the development and adaptation to the open standards in the field of communication between means of production, production planning software and data exchange between cooperating enterprises.

Searching for common features of processes in various types of continuous production is important for designing a modular general management support system at all levels of the organization. The description of the processes and their management at all control levels in coal and steel production, presented in Fig. 1a and Fig. 1b, is summarized in Table 1.

First of all, common features were sought to rebuild a general common process model. The aim of the project is to define the general part of the model (system), it is immediately expected that the differences and specific features of a specific implementation of technological processes will be resolved in a special software layer that will be implemented in each implementation project.

Based on analyses of processes (Table 1) a universal integrated model of processes common for coal and steel production has been designed as it is shown at Figure 2.

At the strategic control level long-term contracts are collected, that define requirements for production quality and quantity. This is a source for tasks in the strategic corporate management to achieve company goal – maximalisation of a profit. From the strategic control level short-term production plan is created for tactical (dispatching) control. On the tactical control level quantity and quality management is also crucial tasks, and these are included in production/product processing management.

Table 1
Analysis and comparison of processes in coal and steel production

Name	Control Level	Coal Production	Steel Production
Market Contract	A	Management of long-term contracts with crucial customer	Management of long-term contracts with crucial customer
Quantity	A	Management and planning of quantity requirements specified in long-term contracts	Management and planning of quantity requirements specified in long-term contracts
Quality	A	Achievement to compliance of quality parameters with customer requirements	Setting of the key quality parameters with customer requirements
Corporate management	A	Achievement of business goals	Achievement of business goals
Optimalisation (KPIs)	B	Achievement of KPIs in planning processes	Achievement of KPIs in planning processes
Production Management	B	Control of technological processes on dispatching control level in short-term period according particular orders.	Plan and control of technological processes according customer orders.
Product processing management	B	Control of coal preparation technological processes to achieve required quality of products.	Achievement both of steel products quality parameters and processes optimalization.
Orders and logistics management	B	Control requirements for quantity and quality of coal in short-term period according particular orders. Control the cooperation with transporting companies to ensure requirements for logistic of sold products.	Plan and control of raw materials. Order control. Logistic control according to process flows.
Balance reporting	B	Monitoring and reporting of production parameters and KPIs.	Monitoring and reporting of processes parameters and KPIs.
Resources control	C	Monitoring of production flow in real-time.	Monitoring of production flow in real-time.
Production control	C	Control of technological processes in real-time.	Monitoring of used resources.
Technological nodes control	C	Control of technological nodes and devices in real-time.	Control of technological parameters of used process technologies. Control of technological processes in real-time.
Warehousing	C	Monitoring and control of bins or storages with raw and clean coal.	Warehouse management using QR codes.
Loading and transport (distribution)	C	Loading of coal to the wagons or lorries include anti-frozen prophylaxis activities. Processing of transport documents.	Product tracking and lifecycle management using QR codes.

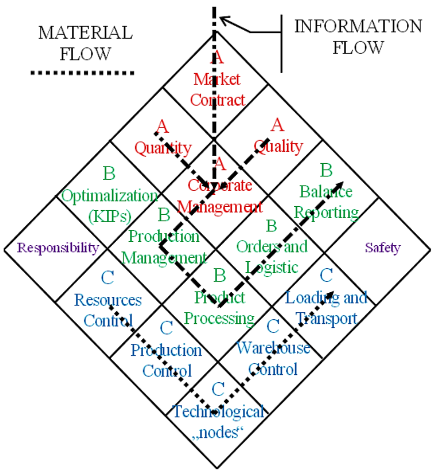

Fig. 2 Integrated model of processes for continuous production

At the strategic control level long-term contracts are collected, that define requirements for production quality and quantity. This is a source for tasks in the strategic corporate management to achieve company goal – maximalisation of a profit. From the strategic control level short-term production plan is created for tactical (dispatching) control. On the tactical control level quantity and quality management is also crucial tasks, and these are included in production/product processing management.

Tasks at strategic and tactical control level are almost the same for all types of continuous production processes. The biggest difference has been found at operational level due different character of particular technological processes, e.g. coal production has no critical input raw material supply comparing with steel production, where this is a crucial.

In this model there are two blocks – safety and responsibility – that are interlinked to all control levels and all processes (Fig. 3).

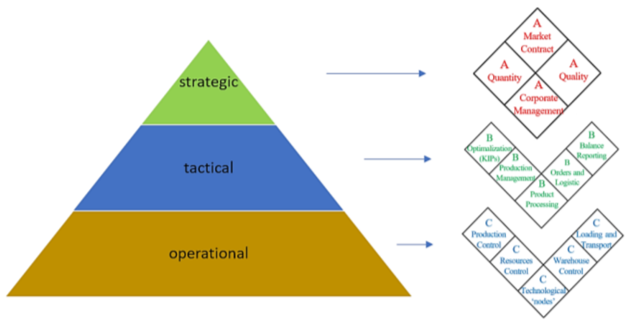

Fig. 3 Control level and Process Model

In the continuous production safety is crucial for eliminate all disturbing that can cause production stop. Responsibility is quite new as this mean fulfilment with strategy, vision and concept of sustainability according to European and local law. Demand for coal is recently decreasing due to idea of decarbonisation of industrial production.
Decarbonisation (deep) will also affect the steel sector. In this transformation, BF+BOF technologies will be replaced by electric furnaces (EAF) [44]. These changes are already happening, such as at the Ostrava steel plant and other EU countries.

DESIGN OF UNIVERSAL INFORMATION SYSTEM FOR CONTINUOUS PRODUCTION IN INDUSTRY 4.0

Physically, the information system software is implemented by means of a set of services. The core is the "data collection" service converting raw data from the sensors to its physical interpretation; simultaneously, it executes technological calculations and checks or data verification within the production line context, evaluates limit states and, if need be, provides for rising of alarm. It is possible to distinguish three generation of information system for production control. First generation serve as a monitoring tool only. In the second generation of information systems, implemented in nineties, production became depend on functions of the information system. Technically there is a move from central monolithic software solution to the system with layers and configurable modules. A core of the system usually was a mainframe server with operating systems like VMS or IBM OS/400. In a third generation of the system that comes to the market about 2000-2005, standard software means was used with emphasise to a distributed solution. Figure 4 shows the core structure of information system for continuous production [46].
The concept of modularity is based on the principle that the operation of a specific technological node is monitor by a separate software module. This makes it possible to add new modules for a new technology or modify existing ones in the event of technological changes in production and to flexibly adapt to these changes without the need for interventions in the system architecture. Technological modules are parts of the system that are dependent on the specific implementation of the system and must adapt to the topology and used technological processes, which may differ in each enterprise. In the case that the system should be used to control a technology other than common production processes, it is necessary to develop a new technological module. Other components of the system do not depend on the topology of production and used technologies.
There are three core modules. First is a data collection subsystem, that collect data from various types of sensors, do data verification and preprocessing. To achieve maximum data processing speed, data is written to a memory-resident database. To ensure dispatch control of technologies in real time, the key module is the alarm subsystem, which works exclusively on the resident database. The data from the memory-resident database is then written to a regular relational database to record the production history. This is essential to ensure the quality management requirements of ISO 9000. The third essential subsystem is the visualization layer. It consists of two subsystems – real-time data display (reports, SCADA system) and balance reports over historical data.

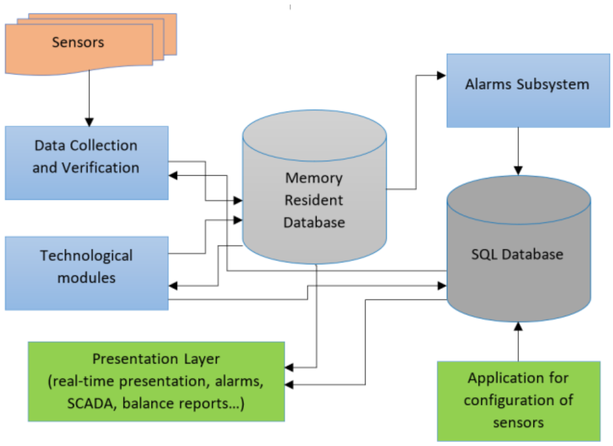

Fig. 4 Basic subsystems of the information system for continuous production control

The architecture of the information systems described here was actually used in the design of the information systems of the coal preparation plant at OKD in the Czech Republic and was deployed in five preparation plants.
Based on the analysis, there were identified the following requirements for system innovation, reflecting the current development of IT/ICT technologies and also Industry 4.0 concept as is shown at Figure 5.

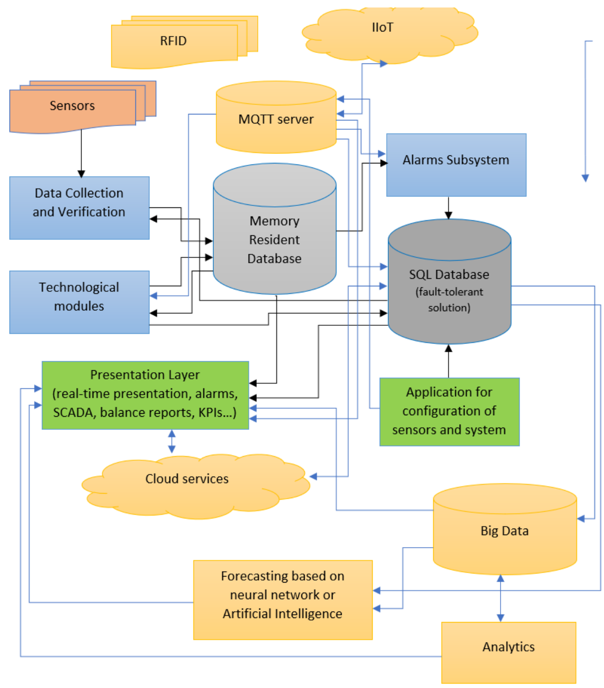

Fig. 5 Subsystems of information system for continuous production supplementing with Industry 4.0 principles

Based on analysis, the authors suggest increasing the information system for continuous production with following modules and extensions:

- The possibility of connecting sensors and action elements (regulators) via industrial buses using the OPC (Open Process Control) standard;
- Support for data collection using IIoT (Industrial Internet of Things) modules, including the possibility of wireless communication. IoT makes it possible to connect distributed systems and topologically separated workplaces;
- Support for material transport monitoring using RFID technology mainly applies to identification of wagons or materials on conveyor belts and in bins [47];
- There is still a requirement to provide a fault-tolerant solution (controlled operation is of the 7x24 type, no IT/ICT maintenance worker is available during night shifts and weekends);
- Requirement for the availability of production balance sheets and a view of the current status of production processes online using web applications;
- Analysis of the volume of data leads to the conclusion that it is not necessary to deploy big data technologies;
- Deployment cloud services to simplify maintenance of the systems;
- Supplementing the system of prediction functions using neural networks or artificial intelligence.

DISCUSSION

Initiated in the Third Industrial Revolution, the development of digital technology and process support information systems has accelerated in the Fourth Industrial Revolution. This strong progress in IT systems is caused by the emergence of new, broader possibilities of using the Internet. New technologies such as the Internet of Things, cloud computing, RFID and others have radically changed the IT environment for production support. The impetus for change is Big Data and Analytics, which enable the processing and availability of huge amounts of data in real time. Process optimization has become possible in real time. With the development of IT, systems are becoming more and more autonomous. The multitude of goods streams (raw materials, parts, semi-finished products, finished products, etc.) and information streams that intersect and complement each other has been organized according to many criteria of the management process. A human cannot understand Big Data without the use of highly advanced technology. The challenge for managers is the ability to effectively use IT/ICT and their integration with the organization's technical environment. The technologies available in Industry 4.0 are tools that ensure far-reaching cooperation and integration of the most important internal and external functions and processes of the enterprise, starting from supply, through production, logistics, to marketing and distribution at all levels of management (strategy, tactical, operational).

The paper presents the current model systems for steel production and coal mining processes. The form of production in both sectors is continuous production. Information systems used to support this production in the era of Industry 4.0 must evolve towards smart manufacturing. Against this background, an attempt was made to answer the questions: (1) to what extent the currently used solutions can be organized and generalized so that they can support the implementation of the Industry 4.0 concept (2) n what direction, in the era of today's revolution, IT system producers should develop systems supporting the management of continuous processes.

One of the necessary conditions for properly functioning information system modules is the integration of data and processes relating to both the exchange of data within the facility and with its surroundings: B2B (*Business-to-Business*), C2C (*Customer-to-Customer*), C2B (*Customer-to-Business*), B2E (*Business-to-Employee*), G2C (*Government-to-Citizen*), B2G (*Business-to-Government*), B2P (*Business-to-Public*). Other conditions include: comprehensive approach to processes, flexibility of solutions, data transparency, technology cooperation, data openness, real-time data analysis. For the systems to be useful, there must be algorithms focused on ubiquitous process optimization. Process optimization in the era of Industry 4.0 is a key feature of smart manufacturing [48].

Companies, including mining and steelworks are embracing change as actively as discrete manufacturing companies. The authors of this publication confirm with their research that mines and steelworks are starting to transform towards smart, and mines are moving towards smart mining and coal processing, respectively [49] and steelworks towards smart steel manufacturing [50]. Traditional industry, which includes mining and metallurgy, has already undergone radical changes in the countries of Central and Eastern Europe, which were introduced at the stage of accession of the countries from the socialist bloc to the EU after the transformation of their economies. Radical repair programs carried out in mines and steelworks in the 1990s ended in success for some plants, failure for others (plant liquidation). Steelworks and mining operations operating in a market economy, after years of experience, have learned the principles of a market economy. Currently, steelworks and mines are facing further challenges resulting from deep decarbonisation. The climate policy of the world and Europe is heading towards net zero, so the technologies used today in mines and steelworks, as well as the processes implemented, will be radically changed. It is assumed that digital technologies and computer systems will support new steel production technologies [38, 51, 52, 53, 54], as well as new functions of mines, which, apart from mining and coal preparation, have to prepare for a methane management [55] and revitalization of areas affected by mining.

The model prepared by the authors can support the construction of new system solutions in which some processes will be removed, e.g. BF+BOF (ang. Blast Furnace + Basic Oxygen Furnace) in steelworks, and others will be developed, e.g. energy production from renewable sources or CO_2 storage [44, 45]. The core of management, planning and controlling processes will remain, but with changes in technology and a strong orientation towards green smart manufacturing, the directions of process optimization need to be significantly changed.

CONCLUSION

The authors proposed a model resulting from comparing continuous production processes (coal and steel) with the aim of finding common general features. Based on this, it is possible to design an information system supporting such production, which will be able to easily adapt a specific technology in a specific enterprise, with only minor adjustments and additional programming of specific functions (technological modules).

The next part of the work presents the architecture of the information system modules to support continuous production, which has already been used in the continuous production industry (Fig. 4). Starting from the MPM model presented by the authors, the architecture diagram was supplemented with further elements that are necessary to develop the functions of such systems according to the Industry 4.0 concept.

In the next stage of the research, the authors plan to adapt IT systems in continuous production to the requirements of the Green Deal [56], the concept promoted by the EU. On the other hand, with the popularization of the Industry 4.0 concept, the intelligence will increase the autonomy of machines and process support systems[57]. In addition, with advances in technology, work in steel mills and mines will not be burdened with as high a risk to humans as it was just a few decades ago. Technologies are increasingly focused on warning and detecting hazards, as well as improving working conditions. These trends are changing processes and therefore the computer systems that support them [58].

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