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Production management system in a modern coal and coke company based on the demand and quality of the exploited raw material in the aspect of building a service-oriented architecture

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Keywords

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RESEARCH ARTICLE

Production Management System in A Modern Coal and Coke Company Based on the Demand and Quality of the Exploited Raw Material in the Aspect of Building a Service-Oriented Architecture

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Abstract

The paper deals with the implementation of the JSW Capital Group's (Poland) Demand and Quality Driven Production Management System (SPPJ – System Zarządzania Produkcją oparty na Popycie i Jakości) using a service-oriented architecture (SOA). The main components of the SPPJ architecture have been characterized, and the scope of their integration has been defined. The individual parts in the first area, i.e. quality management, have been described in detail. Due to the extensive nature of the issue, components in other areas, i.e. planning and scheduling, coal extraction and processing, coke production, as well as sales and logistics, have only been signalled. Results of the analysis of the implementation of particular components of SPPJ areas have also been presented. The development of the system and the way of implementation in a mining environment is important from the perspective of achieving the superior objective of the JSW Capital Group's Quality Programme, which is to increase the efficiency of management of the exploited deposit and the volume of commercial product supply.

Keywords: production quality management, quality strategy, quality management policy, geological modelling of deposit, production scheduling, IT systems architecture

1. Introduction

On 5 May 2021, the European Commission set out the foundations of the EU Industrial Strategy. The strategy was intended to enable a twofold transformation – green and digital, to make the EU industry more globally competitive and increase Europe's open strategic autonomy. The day after the announcement of the new industrial strategy, the World Health Organization announced the outbreak of the SARS Covid-19 pandemic [1].

The SARS Covid-19 crisis had a strong impact on the EU economy. The impact varied depending on the ecosystem and the size of the company. The crisis highlighted the interdependence of global value chains and proved that a well-functioning and globally integrated single market is essential. Out of the steel-consuming sectors, the automotive sector has been hit hardest by the Covid-19 pandemic. The number of new car registrations in the EU dropped in 2020 – by nearly 24% – this is the largest drop in the number of new car registrations since the start of such statistics.

It is important to recall that the main objective of the new EU Industrial Strategy is to support economic growth and prosperity in Europe. European industry provides 35 million jobs and represents 20% of total EU added value. Therefore, it is very important to maintain its global competitiveness, which cannot be achieved without access to critical raw materials [2], often also called strategic raw materials, from the civilisational development point of view.

The Critical Raw Materials List is announced periodically every three years by the EU. The

Abbreviations: Service-oriented architecture, (SOA); Demand and quality driven production management system, (SPPJ); Laboratory information management system, (LIMS System); Central register of quality test orders, (CRZJ); Central repository for quality data, (CRDJ),

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current list was published by the European Commission on 3 September 2020, and it includes 30 items. The first list published in 2011 contained 14 raw materials. During the next assessment in 2014, there were 20 [2]. After a review in 2017, the list was extended to 27 raw materials [3].

The European Union currently imports about 75% of the coking coal, which it uses from such distant countries as Australia, the United States, Canada, Mozambique and Russia. Currently, Poland is the only EU producer of this critical raw material. The largest producers of coking coal in the world are China, Australia, the United States, Russia and India, where about 90% of global production is concentrated. In 2022, Poland will remain the only coking coal producer in Europe, and, according to the author of the article, it should become a strategic guarantor of the safety of the European steel industry.

JSW Capital Group deals with extracting and processing hard coal, producing coke and using coal derivatives. For more than half a century, it has been intensively exploiting the richest coking coal deposits in Europe, to a large extent leading to their depletion. The need to reach parts of the deposit located on the edges of the current mining areas, which are more and more difficult to exploit and of poorer quality, has given rise to the need to build an Integrated Production Management System in the JSW Capital Group, enabling the management personnel at various levels to control the production process from the stage of excavation of the deposit underground, processing it into coke in the coking plant, to loading onto wagons or ships in a port, all with the aim of improving the economic performance of mining operations [4].

This article aims to present the functional assumptions for selected components of the target SOA class architecture developed for the Demand and Quality Driven Production Management System and to determine their place in the presented architecture, as well as the scope of integration with other components. Due to the breadth of the topic, the components relating to only the first area − quality management − have been characterised in the most detailed way. Components in other areas, i.e. planning and scheduling, coal mining and processing, coke production and trade and logistics, have only been signalled. The article also presents the impact of the research results on individual areas with respect to increased efficiency, which later impacted the order of implementation of individual components of the SPPJ system.

Prior to 2015, JSW Capital Group's mining plants independently tracked forecasts of qualitative and quantitative parameters of the exploited deposit (without the coordination of the Head Office) based on traditional methods of flat (two-dimensional) digital mining and geological maps, which were usually updated once every few months or even less frequently.

The heuristic architecture of the production chain management system, introduced by the author, provided the possibility of analyzing the profitability of JSW Capital Group's production process in the form of a drawn account in mining, processing and coking areas, ultimately increasing production efficiency by up to 20%.

This optimisation was only made possible due to the solution proposed by the author, unique on a global scale, introduced at the level of the Head Office. These related to the implementation of continuous quality forecasts, which allowed in real time to stimulate standardization and comprehensive management of production orders, track production and monitor the effectiveness of the whole process “from the deposit to sea”.

The introduction of such an approach to modelling and scheduling JSW Capital Group's production and the appointment of the coordinator of all activities related to the quality management of the extracted spoil, processing and the production of the final product has basically completed the claims, common until recently, that the instability of the quality parameters of Jastrzębie coaking coals is a natural factor, related to the variability of the quality parameters of coal deposits and the such state has to be accepted.

2. Business context of building a production process management system for a coal and coke group

One of the factors determining the growth in demand for coking coal is steel consumption and the volume of production in countries with low consumption rates and the highest population, with a high development potential compared to developed countries. In general, Asia is increasingly affecting the global market, being the largest producer and thus the largest consumer of raw materials for its production. It should be noted that in 2010, steel production in China represented about 44% of global production, and in 2020 this share grew to 58%. In the same period, Europe had, respectively 12% share in world steel production in 2010 and, in 2020 less than 8%. In the pandemic year 2020, world steel production fell by less than 1%, but this was mainly due to a 1.6% increase in Asia because other regions of the world saw significant declines, e.g. the European Union by nearly 12%. In Poland, steel production fell

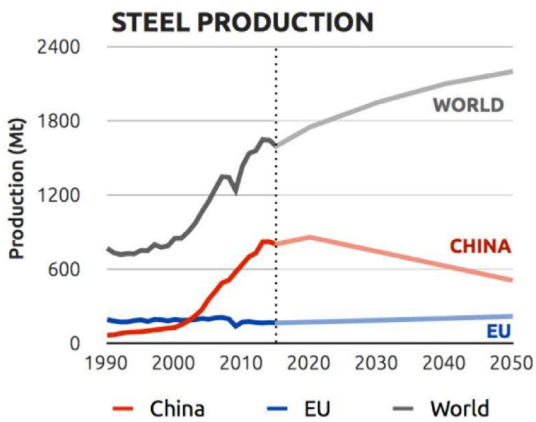

Fig. 1. Steel production worldwide and in China and the EU up to 2050 [6].

at the same rate as the European average, namely also by approx. 12% [5] (see Fig. 1).

In the coking coal market, business cycles typically last from one to several years, with varying price movements and production growth rates. Fig. 2 shows the volatility of the benchmark and spot coking coal price quotations from January 2016 to January 2021. In Q4 of 2021, Australian coking coal prices have significantly exceeded US$ 200/t, an increase of nearly US$ 100 per tonne since the beginning of the year.

When analyzing the volatility of quotations presented in Fig. 2, it should be remembered that in the economy of mineral raw materials, there is a phenomenon of a business cycle, namely fluctuations of the economic situation in periods of several years with a persisting long- or short-term trend of economic growth. The indicators most frequently used in business cycle research are investment expenditures, company inventories, GDP dynamics, employment level, capital market indexes and stock exchange indexes, and company profits. Raw material business cycles are clearly visible, especially in the most developed countries, and such fluctuations affect all non-isolated economies [8–10].

In March 2020, the developing 2020 global SARS Covid-19 pandemic caused a very large increase in coking coal prices in key markets. The coke market, which is heavily dependent on the steel industry, suffered severely from the reduction in global production. This is particularly evident in the automotive sector in Europe. Among the steel-consuming sectors, the automotive sector was hardest hit by the Covid-19 pandemic. New car registrations in the EU fell at a record pace in 2020 – nearly 24%, and it is the largest drop in new car registrations since such statistics began. All major car markets in the EU saw double-digit declines. The other key steel-consuming sector, i.e. construction, was less affected as projects were mostly ongoing but with significant increases in material prices. Now, after a period of declining coking coal prices and production in the

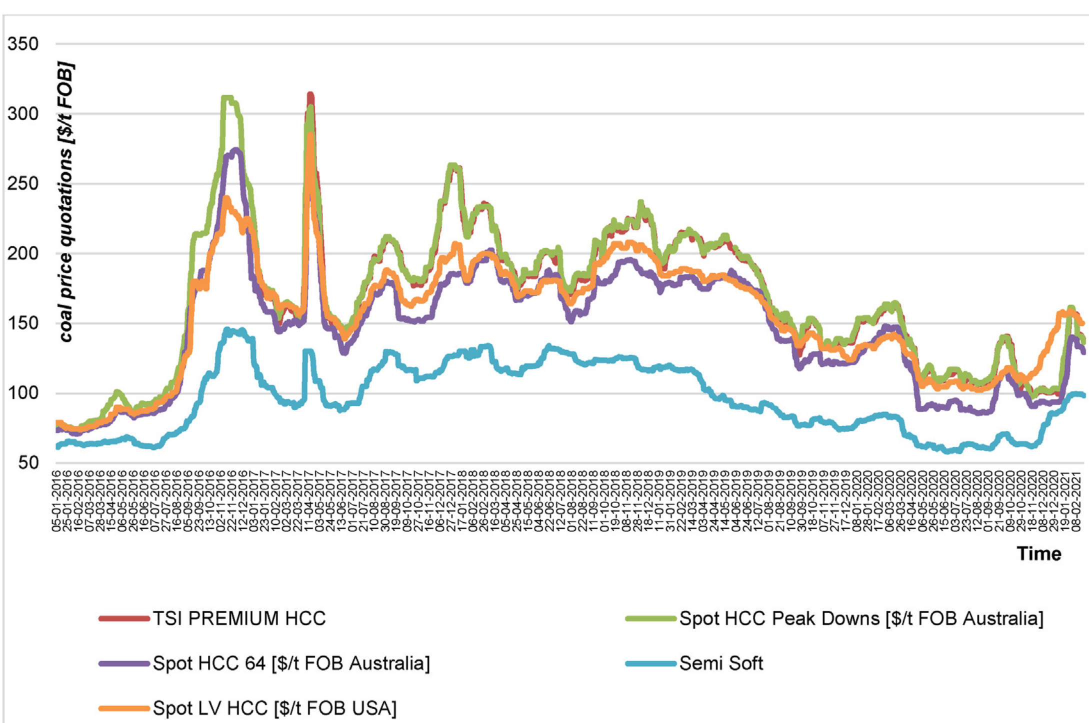

Fig. 2. Benchmark and spot coking coal price quotations [$/t FOB] in 2016–2021 source: own study based on [7].

second half of 2021, global economies have started to accelerate, and production rates have returned to pre-pandemic levels. The complement to the current business cycle is certainly the ongoing trade war between China and Australia, in which China appears to be emerging as an insurmountable power, as evidenced by the performance of the Chinese economy. China's crude steel production reached a record of over 1 billion tonnes in 2020, which is a result that is more than 5% higher than in 2019. China's economy grew by 2.3% in 2020, making it the only major global economy to achieve positive growth in a year of pandemics presented in Fig. 3. Metallurgy, an industry that is the pillar of China's economic growth, performed better than expected and steel prices rose for most of 2020; whether this trend will be permanent will be decided by China through its administrative decisions on steel production or raw material import policies and the scenario that the Covid-19 pandemic will determine in the future [11] (see Fig. 4).

Considering the cyclical nature of the mineral raw material market presented, especially metallurgical coal, the author of this article has attempted to develop a strategy to counteract the effects of such frequent and large fluctuations on the operation of a large European coal and coke company. Importantly, the developed strategy also took into consideration limitations associated with the Covid-19 pandemic, and defined objectives for key areas of responsibility − on the one hand, to reduce the risks and business challenges associated with them, and on the other, to maximize the opportunities arising from socioeconomic changes. The key element of the business strategy was the implementation of the "QUALITY Programme" which includes a number of actions to provide uniformity in the design and

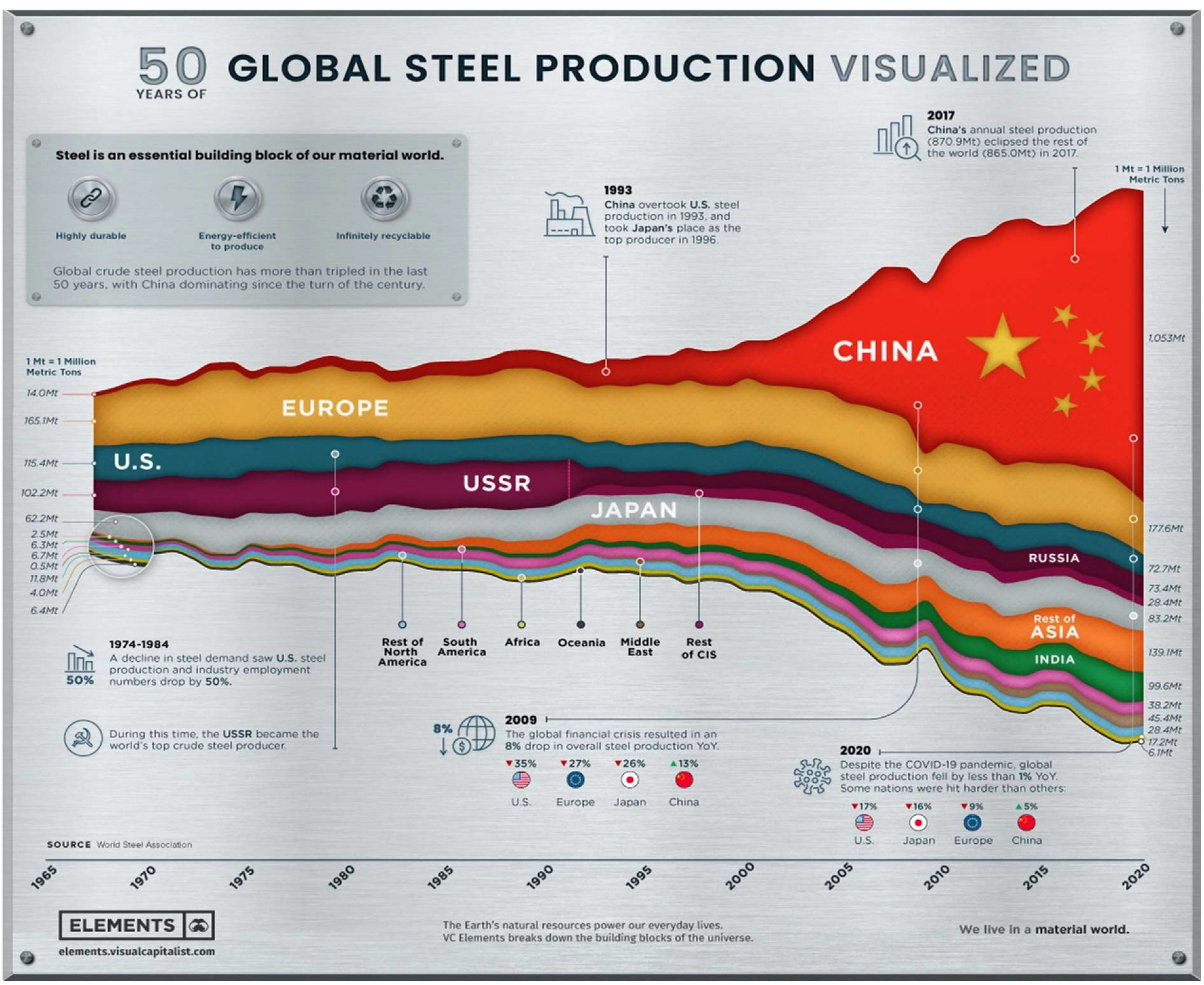

Fig. 3. Visualizing 50 Years of Global Steel Production − source: ELEMENTS [11].

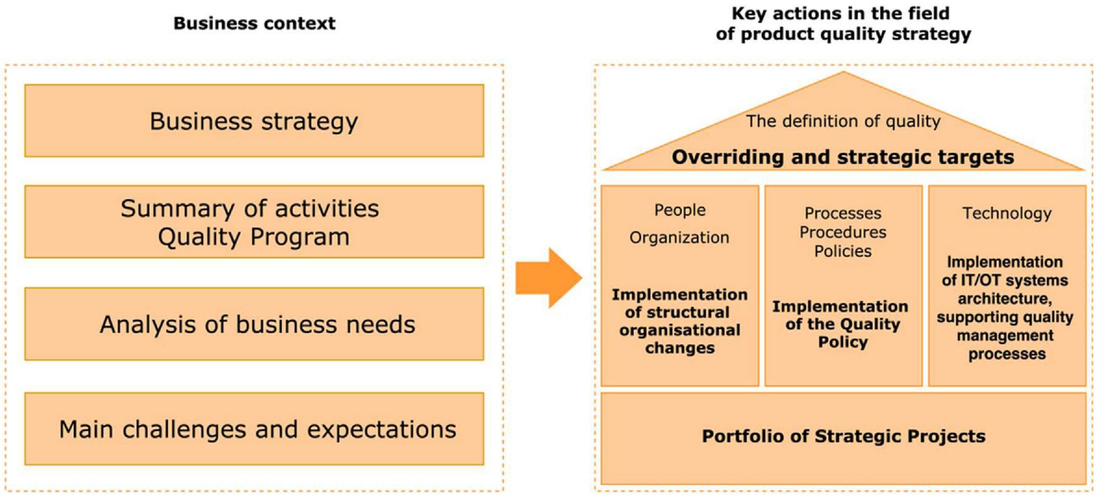

Fig. 4. Business context and crucial actions in the "Product Quality Strategy" project at JSW CG [8].

planning of production activities, deposit modelling, production scheduling and ongoing monitoring and supervision of the quality of the production process [12].

3. Strategy and policy for management of the production line of a coal and coke group in terms of testing the quality of the deposit exploited and the coke produced

The "QUALITY Programme from deposit to sea", which is the essence of the JSW Capital Group's strategy of 2018, which defines detailed objectives for key areas of responsibility, to reduce risks and business challenges related to them on the one hand, and to maximize opportunities on the other, resulting from socioeconomic changes.

The new strategy of the JSW Capital Group defined goals for key areas of responsibility, on the one hand, to reduce the risks and related business challenges and, on the other hand, to maximize opportunities resulting from social and economic changes.

The implementation of the "QUALITY Programme" was made the key element of the JSW Capital Group business strategy, comprising several actions enabling the ensuring of a uniform procedure for designing and planning production actions, deposit modelling, production schedules planning, as well as monitoring and production quality supervision on a current basis, including:

- geological databases of six mines have been built and ordered
- IT tools for scheduling and deposit modelling have been implemented
- geological models have been developed for strategic deposits, resource parts, and mining levels of all JSW CG mines
- strategic production schedules have been developed, linked with deposit models
- central strategic scheduling model has been developed, enabling the integration of mine schedules at the level of the JSW CG Management Board Office
- operations to build a central database, aggregating deposit models and production schedules, are planned at the level of the JSW CG Management Board Office

Much effort was devoted to selecting and training appropriate employees in the surveying and geological departments of all JSW CG mines. It is enough to say that in relation to the system development needs, the JSW CG signed appropriate agreements with the AGH University of Science and Technology, employing 17 young mining geologists, managing inter alia the entire scientific circle, involved in geo-statics and modelling parameters describing the hard coal quality at the Department of Geology of Mineral Deposits and Mining Geology of the Krakow AGH [12].

The development of Teams was accompanied by an equally complex process of providing the staff with measuring equipment to acquire the data for deposit modeling, and with modern IT systems, enabling automation of measurement processes and data visualization. To this end, "Smart Weighers" and "Neutron Analyzers" implementation projects were started, allowing to control continuously the quantity and quality of the mined coal transported by conveyors to coal preparation plants.

Prior to carrying out studies on the development and implementation of the system for deposit modelling and production scheduling, the IT environment of the Group consisted of dispersed systems, among others, Geoslip and ArchiDeMeS, which were used for charting individual seams in the mined and planned to mine deposit (that was nothing more than developing 2D models for individual coal seams). In turn, in the area of production planning, the CAD environment was used (via overlays to the AutoCAD software). Spreadsheets were used in production scheduling, and after the entire process completion, the results were transcribed to the THPR module of the SZYK2 system. The SZYK system is a System for Mine Management Support. Its second generation, SZYK2, has been used in the Polish mining industry since the beginning of the 21st century. The THPR module was used, e.g. for settlements and control of mining plans, schedules, and progress of development work; it allows to record elementary data on the carried out and planned mining operations. In practice, the deposit management and scheduling of its mining was carried out with a low share of IT systems support. The majority of operations related to production management and scheduling were performed in a dispersed way in tools (.dwg,.xls files) without the possibility of automatic data exchange or even files import. In addition, all these operations were carried out on the level of individual mining plants. A decisive majority of operations were performed manually and in a decentralized way.

The main limitation, related to the lack of integrated production planning and scheduling system, consisted in a very long time necessary to collect and standardize the data needed to build an effective mining strategy. The process of strategic plans development, using the dispersed tools, lasted from three to six months, which practically limited the possibility of updating it more often than once a year during the development of a technical and economic plan. It made it impossible to operate quickly and update the mining strategy between the planning periods, e.g. in the case of macro-economic changes or other factors related to mining and geological conditions [12].

The second important limitation consisted in directing the production planning and scheduling at the quantitative planning, at a small use of information on quality, which made increasing mining effectiveness impossible.

The dispersed IT systems used for planning, due to the adopted simplifications, in many places, required providing the data of various degrees of accuracy and granulation, which resulted in a very large amount of labour to reconcile the final data.

The fourth equally important limitation consisted in the missing possibility to monitor, on a current basis, the deviation from plans in the field of qualitative deviations.

Because of that, it was important to carry out studies and to take actions, to comprise the entire process related to deposits modelling and production scheduling in centralized IT tools.

The update of JSW Capital Group's business strategy, prepared since the beginning of 2020, whose aim is primarily to provide the safety and continuity of the Group's production, led to the adoption of the Company's necessary regulations preventing the mines from filling up with coal stored above the level safe for the mining plant's operation and to secure itsstrategic storage sites so that, if necessary (for example, when rail traffic stops due to the pandemic), it will be possible to safely deposit the coal extracted by the mines at a time when the mines' storage sites are dangerously close to 75% fill. All these activities implemented in the area of production volume optimization: ongoing analysis and monitoring of production capacity, research and forecasting of quality and sales opportunities based on the demand of the internal and external markets (exports and domestic sales), along with the establishment of the new Quality Management Office, made up the "Product Quality Strategy for the JSW Capital Group for 2020–2030" adopted by the Management Board and the "Quality Management Policy for Deposit and Product Testing in the JSW Capital Group" enabling assurance of the desired level of qualitative parameters of coking coal and steam coal, as well as the rules for forecasting the level of qualitative parameters of steam coal [8] – Fig. 5.

The author's research shows that only the correlation of forecasts in the area of demand (the expected volume and quality of the product depends on the business cycle) and supply (extraction volumes), i.e. production and planned investments enable to fulfil the assumed production plans make it possible to achieve the greatest economic effect in the period of price increases, with simultaneous control of costs enabling to remain above the profitability threshold in the period of economic downturn [13].

Therefore, according to the author, a holistic approach to issues related to appropriate planning of production volume, its quality and demand based

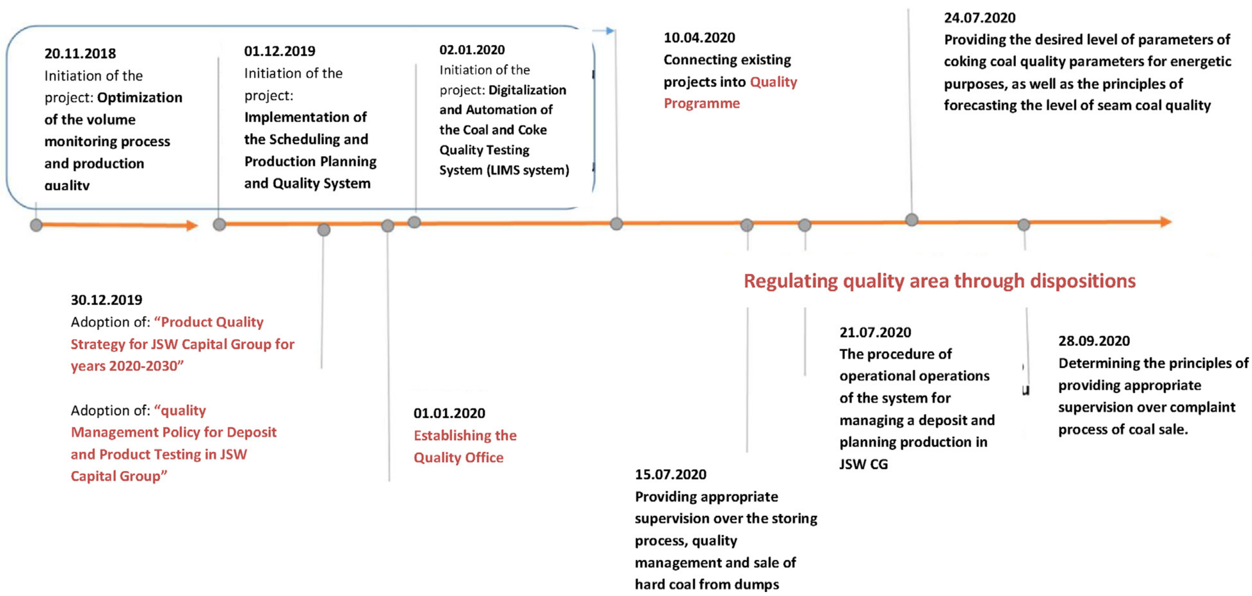

Fig. 5. Schedule of actions taken to develop proactive production control and stabilization of commercial coal parameters in JSW CG — Source [own study].

on monitoring all key operational indicators related to the ongoing production process is very important. Currently, mining companies lack systems that would enable such an approach. Therefore the author proposed to establish a production planning and settlement system controlled by demand, especially by the quality of mined coal in the entire JSW Capital Group, which would integrate previously dispersed domain systems using the SOA architecture [14].

The development of the system concept began with the arrangement of the quality management area, considering the results of scientific research [10,15–21], which confirm that the implementation and operation of the quality management system bring many benefits. Internal benefits include, among others, current monitoring of quality, predictability of production quality, improved efficiency of action, ordering of activities in the organization, employee involvement in shaping the quality of products or services, economic benefits, supervision, and improvement of processes in the organization, the assignment of entitlements and responsibility to appropriate employees, motivation for improvement and innovation, better and faster circulation of documents and information flow, improved communication within the organization, fewer complaints and higher employee motivation. On the other hand, external benefits, among others, include increased quality of manufactured goods and services, increased satisfaction of external customers, standardization of procedures for dealing with customers, image change — shaping a pro-quality orientation of the organization, increased sensitivity to customer expectations, easier access to local and international markets. It should also be emphasized that a quality certificate builds credibility and trust in the organization, is a confirmation of the organization's development, and is often a condition for participation in business negotiations [22–27].

JSW Capital Group, which produces coking coal, has been conducting research for several years to implement a Demand and Quality Driven Production Management System (SPPJ). The company's overriding objective was to increase efficiency in the management of deposit quality recognition and product quality. This may be enabled by a comprehensive approach to the quality management process, according to which monitoring and supervision of product quality should take place at every stage of production to increase the production potential and stabilize the quality of the coal.

This article aims to present functional assumptions for selected components of the target architecture of the Demand and Quality Driven Production Management System and to define their place in the presented architecture and the scope of integration with other components. Due to the comprehensiveness of the subject, the components relating to the first area — quality management — were characterized in the most detailed manner. Components of other areas, i.e., planning and scheduling, coal extraction and processing, coke production, and trade and logistics, were only indicated. The article also presents the results of research on the influence of individual areas on increasing efficiency, which later influenced the order of implementation of individual components in SPPJ areas.

4. Current and target status of the production process management system based on the demand and quality of the performed production process

An analysis of the current status of quality management in JSW Capital Group has allowed concluding that, in practice, the potential of IT systems was used to a small extent. Most activities related to production management and scheduling were performed in a non-standardized manner, often using spreadsheets, without the possibility of automatic data exchange at the level of the Group's individual mines. Planning was predominantly performed in a manual and decentralized manner, with data aggregation occurring only at the very end of the process. This made it impossible to conduct the process quickly and to respond on an ongoing basis to changing market conditions or the macroeconomic environment. With such a process, it was impossible to create scenarios in order to choose the most effective solution [12,27].

Currently, quality data in JSW Capital Group is processed in multiple systems. Among other things, the Group has at its disposal data on resources, production and quality plans, parameters controlling production processes that affect product quality, readings from production and production quality monitoring systems and the results of quality tests. In many cases, the data was not recorded and archived in an organized or systematic way in a centralized solution. It was not standardized or synchronized. It should be emphasized that the quality data comes from different sources and has a different nature, frequency of recording (unit readings or continuous readings) and non-unified data model (planning data, unit reading data, continuous reading data, parameter data controlling production processes, contract data, quality test results, etc.).

Therefore, the prerequisites were developed for an appropriate production management system in the JSW Capital Group which would allow, among others, to develop a coherent data model, centralize and fully computerize deposit and product quality management processes, and orchestrate the process of acquisition and analysis of quality data. This would directly translate into increased quality and effectiveness of quality research and related processes, such as collecting, storing, processing, providing access to data, etc., in the full production cycle.

The basic principle of business should be based on responses to the changing market environment, especially at the time of large economic fluctuations. The pursuit of change and the desire to catch up with the market may lead to neglecting the preparation of appropriate corporate and IT architecture. In JSW Capital Group, in an effort to prepare a solid foundation for its operations, not only an operating model was prepared, specifying the general requirements for the integration and standardization of individual business units, but also a draft of the corporate architecture covering, inter alia, the quality management process, which is correlated with the planned development directions [9,13].

This architecture indicates the company's key processes and the data integrating the main forms of activity, which made it possible to cover the foundation of activity with digitalization, thus treating the management system, driven by demand and quality, as a basic element of management.

The Demand and Quality Driven Production Management System comprises the following key business areas implemented in the JSW Capital Group:

— quality management area
— planning and scheduling area
— the area of coal extraction and processing
— coke production area
— the area of trade and logistics (coal and coke)

In all business areas defined above, the prepared SPPJ architecture concept adopted a unified approach to defining the system architecture based on the following components:

— source data
(e.g. samples, sensors, scales, analyzers)
— business process support systems
— integration
— Central Quality Management System
— data repository
— analysis and reporting (Business Intelligence)

The proposed SPPJ architecture assumes the use of data from the currently used IT systems supporting key operational processes, i.e. primarily the ERP systems and systems containing data on resources (3D Deposit Model System) integrated with the production planning and scheduling system (Production Planning System), as well as the implemented systems monitoring production processes, while their full integration is planned to be performed using microservices.

Additionally, it is assumed that the system will be fully integrated with the currently implemented system for comprehensive support of laboratory processes in quality testing of solid fuels (coal), coke and other elements, subject to quality testing processes (LIMS System – Laboratory Information Management System). The developed SPPJ architecture concept [12,13] assumed that it will be necessary to prepare, implement and integrate the additional components in individual business areas presented in Table 1.

The objective of SPPJ implementation is effective management of production processes in the JSW Capital Group, including the quality of coking coal and coke product, which will translate into maximization of the margin obtained from sales of products and reduction of operating costs associated with optimization of production processes of the product with the required quality level. Fig. 6 presents a map of SPPJ architecture layers with marked components in business areas [28–30].

It has been assumed that SPPJ will be used mainly by the management and employees of the Quality Office, Production Office and Trade Office, as well as by employees of other operational offices responsible for supporting planning processes and production management from the point of view of its quality [12,14].

4.1. Building the architecture of the JSW Capital Group's production management system based on demand and quality using the service-oriented architecture (SOA) paradigm

In recent years, changes to software architecture have tried to keep up with the rapidly increasing complexity of IT systems. However, due to the pace of this growth, traditional patterns have not been able to cope with current challenges. A need arose to react quickly to new business requirements, expectations for further reduction of IT costs, and above all, the needs related to the rapid integration and absorption of new business areas [31,32]. Service-oriented architecture has emerged as a new architectural solution [33], separating the application layer from the user by means of web services. This solution enables easy integration of the functionalities of various systems without making major changes to these systems. Due to its flexibility, such an approach has been widely recognized by many scientists and practitioners as appropriate for implementation in organizations [34]. However, during its development, this architecture was repeatedly criticized due to doubts as to its real value [12].

The service-oriented architecture introduces the concept of integration of various systems using separate services and the division of application functionality into services.

The main features that characterize the services, among others [35] are as follows:

- Service interface – contains information about the rules of communication, input and output data, and methods that are made available by a given network service
- Service description – contains only basic information about the service outside the provided contract. It completely hides how a given functionality is implemented
- Usage logic – services contain shared logic among themselves; with logic division, it is easy to reuse the re-created functionality
- Autonomy – each service is autonomous, and the website's liability is limited to the functionality it provides
- Statelessness – it minimizes the use of resources, not storing information about the client or previously performed operations
- Discoverability – designed for use in distributed systems, services are supplemented with metadata with which they can be effectively discovered and interpreter
- Composition – they can consist of several functionalities implemented through other services, i.e., create complex services that divide the task among themselves

It is clear from existing definitions and models that service-oriented architecture is commonly viewed as architecture or a way to build and orchestrate an organization's information

Table 1. Components in individual business areas – source [own study].

Area	Component
Quality management	Quality Integrator Central Repository for Quality Data (CRDJ)
Planning and scheduling	Production Planning Integrator Central Planning Data Repository
Extraction and processing of coal Coke production	Production Data Integrator
Trade and logistics (coal and coke)	Trade and Logistics Data Integrator Warehouse Quality Map

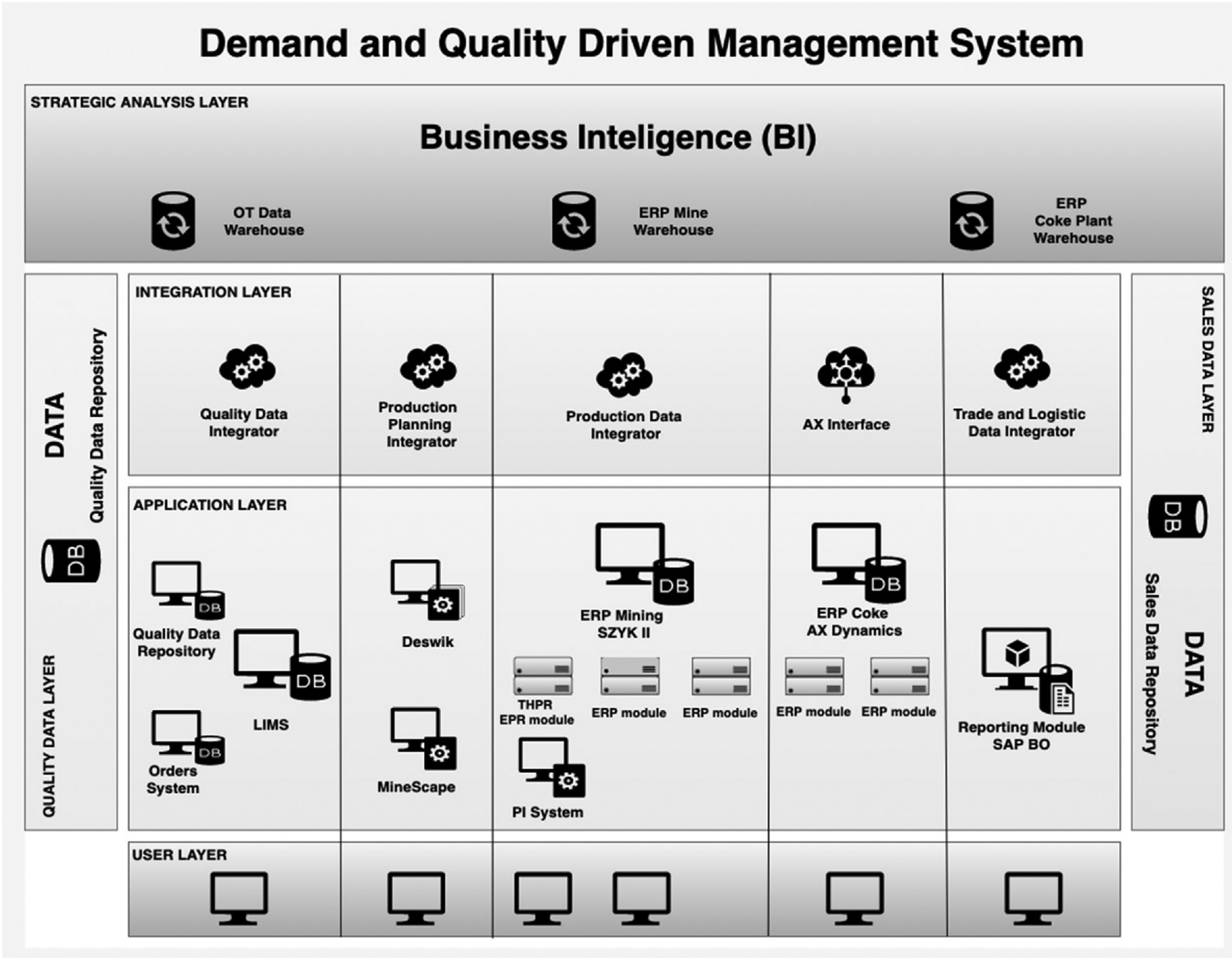

Fig. 6. Map of SPPJ architecture layers with components — target condition — source [own study].

infrastructure. As such, SOA is not a technology in itself: it is a way to organize data flows or integrate other technologies to perform a variety of other tasks. This naturally leads to the problem of multiple SOA definitions, as many relatively similar service structuring is possible. Many SOA definitions also indicate that the layout and relationships between services should be loosely coupled, not tightly coupled. This allows oneto customize services to his needs and do it on demand rather than building a predetermined structure [15].

Analysis of research conducted in the field of mining data processing showed that there are limitations (barriers) in the field of data exchange related to the client-server architecture, so far commonly used in the Polish mining industry. The solution to this problem was the use of an SOA architecture that improves data integration processes [36].

4.1.1. Reasons for using SOA

Software development methods are constantly changing, and they also change the architectural paradigm. These changes were made in part to help deal with the higher level of software complexity and partly to enable rapid and painless integration of applications with parts, components, or services.

The service-oriented architecture enables the design of systems that deliver services to other applications through published and discoverable interfaces, and where those services can be called over the network. The use of service-oriented architecture with the use of network technologies and services means taking advantage of such a way of building applications, where it is possible to reduce maintenance and development costs, as well as mitigate the risk of implementation [15,35].

4.1.2. Differences in the use of SOA in open and closed systems

One of the components of SOA is the service registry. The use of SOA technology in the closed network architecture of an enterprise limits the use of SOA solutions such as service detection for the use of the Register of services already defined by the entrepreneur in the central Register of services or distributed in the registers of services in individual departments of the concern [18].

4.2. Quality management area — functional assumptions

The quality management area includes the following components, the first two of which are currently operating:

— LIMS system (Laboratory Information Management System), a central system to support qualitative research processes
— Central Register of Quality test orders (CRZJ)
— Quality Integrator - understood as an integration layer/set of interfaces, connecting the new LIMS system with other elements of IT/OT architecture in the JSW Capital Group
— Central Repository for Quality Data (CRDJ)

The target architecture of the integrated components will allow for full digitization and orchestration of the data transfer process, both during the recommendation of quality sample tests as well as the feedback of obtained test results.

4.3. LIMS — Laboratory Information Management System

The LIMS system is a new system that comprehensively supports the work of the JSW Capital Group laboratory. It supports the registration, introduction, and archiving of laboratory results and their analysis.

The scope of implementation includes the digitalization of laboratory service processes in the administrative area and supporting processes, as well as integration with measuring devices. The system will ultimately be used to manage laboratory work and all types of quality tests performed in the main laboratory [28,30].

Qualitative studies are to be conducted in the following laboratories:

— solid fuels laboratory
— laboratory for gas and dust samples
— the coke lab
— environment and work environment laboratory
— the microbiology and genetics lab

The LIMS system will eventually replace the current IT system, which in its current functional scope, is only used for qualitative research for coal samples.

4.4. Central Register of Quality Test Orders

The rationale for developing the Central Register of Quality Test Orders was that currently, in the JSW Capital Group, there is no unified process for preparing and monitoring quality test orders. The processes of preparing orders, ordering samples, and processing test results are often performed in a manual or semiautomated manner. The test results for the coal samples are recorded in electronic form in the laboratory system and transferred directly, in electronic form, from the IT system to the analytical and reporting system. For other types of quality samples, test results are transmitted manually via batch files. There is also no unified model for assigning unique identifiers for different types of quality samples except for carbon samples, for which unique identifiers are assigned in the relevant module of the ERP system. For other types, there is often no unified method to assign identifiers. The scope of functioning of the Central Register of Quality test orders includes [37,38]:

— covering all types of quality samples, i.e., coal, gas, dust, work environment, coke, etc.
— providing automatic two-way integration between the CRZJ and the LIMS system, providing paperless workflow
— providing the possibility of parameterization and management of Registers, Dictionaries, and Catalogues of quality tests (e.g., according to types of samples and functional groups of tests) with the possibility of automation of the selection of necessary parameters while generating an order
— providing the ability to present operational and cost parameters associated with sample ordering for different types and ranges of quality testing
— providing the ability to generate a unique quality sample number (when creating a quality test order) and sample identifier
— providing integration with marking systems/giving samples, e.g. barcodes/QR codes, in order to increase work efficiency and control over the completeness of samples and quality tests performed
— providing online monitoring of order status, sample criteria being met, test completion status, and anticipated study completion date
— providing integration with CRDJ

4.5. Integrator of the quality data area

The Quality Integrator is designed to provide automatic integration of all input and output data to/from the LIMS system. The implementation and integration of the LIMS solution are taken to provide the full implementation of the electronic data flow concerning the sample and the quality study: from the generation and registration of the order, through the processes of the quality study execution, to the preparation and release of the report with the study results. The quality integrator is understood as a set of interfaces connecting particular elements of the quality management system architecture. The key supported processes and major functional requirements include the following:

— preparation and implementation of a single data model for the quality area
— covering all types of quality samples, i.e., coal, gas, dust, work environment, coke, etc.
— providing automatic integration of all input and output data into/out of the LIMS
— covering with the scope of integration all processes related to customer service in the areas: Pricing and Offering, Contract Parameters Management, Customer Monitoring, Complaints
— eliminating paper workflow between units in the Group in the full range of sample workflow (orders, sample collection, sample marking and coding, sample registering, status preview, test results approval and authorization, test reports, etc.)
— providing integration in the scope of data exchange from Registers, Dictionaries, Tests Catalogues
— providing integration to enable the use and transmission of a unique numbering of quality samples
— providing integration with generation and marking systems (e.g. assigning barcodes/QR codes to samples and reading them) in order to increase work efficiency and control over the completeness of samples and performed quality tests
— providing online monitoring of order status, sample criteria being met, study completion status, and anticipated study completion date
— exchanging information between all systems about the testing status of a particular sample, activities on a sample and the results of tests on samples
— providing access to the test results of the sample immediately after testing,
— providing automatic transfer and storage of data on performed tests and obtained results in the Central Repository of Quality Data
— providing integration and automatic transfer and storage of data on performed tests and obtained results to the Central Repository of Quality Data, Central Quality Management System and analytical and reporting system

4.6. Central Repository for quality data

The Central Repository for Quality Data (CRDJ) is the place where quality data will be sent and then collected. Thus, the main task of the CRDJ will be to collect and store particular types of data in a uniform repository and synchronize them with other operational and quality data. CRDJ will feed the Central Quality Management System and/or the analytical and reporting system as the primary and unified source of quality data. The functional scope includes the following:

— covering with the scope of data processing all types of data collected in the full scope of the so-called “from deposit to sea” processes, i.e. in the areas of quality management, production planning and scheduling, monitoring of coal and coke production processes and commercial and logistic processes
— ultimately, data collection and processing, not only for planning and monitoring, but also for controlling and optimizing production processes
— providing data supply from individual functional areas, i.e. Quality Integrator, Production Planning Integrator, Production Data Integrator (for both coal and coke production), Trade and Logistics Data Integrator (for both coal and coke)
— providing integration with the Central Quality Management System and/or the Analysis and Reporting System as a unified data source
— the possibility of adopting a hybrid service-oriented architecture, using as components the technological solutions currently used in the Group (SAP Business Objects/MS Reporting Services/PI Systems), integrating them by means of microservices
— orchestrating integration between the CRZJ and LIMS system, providing the ability to go paperless for the full range of sample workflows while maintaining the ability to view/print prepared orders, sample labelling and coding, sample log, view status, etc.

4.7. Scope of required integrations

The most important task for successful enterprise architecture is to define processes, data, technologies and interfaces (also for users) so that all key resources and their compliments are optimally used. To prepare the target system architecture, the Master Data Model was implemented as a link between the business and technical layers, resulting in a unified approach to data and related processes, treating this as part of a broader data management strategy. The master data model provides consistent data from each key business area of an enterprise, excludes the creation of duplicates, and guarantees the availability of sensitive data while providing easy integration with data warehousing, analytical and transactional systems. In order to achieve a specific data orchestration, a model of the required integration and data flow between the key processes has been developed, namely:

— exploration of a deposit
— coal mining
— coal preparation
— sale of coal
— coke production
— sale of coke

In order to illustrate the processes that must be carried out by the system, as well as to synchronize data exchange between individual components, a data flow and integration diagram was prepared, which is presented in Fig. 7. This allows illustrating the network of connections between individual components of the system and their functions [39,40].

Due to the adopted basic data model, it was necessary to define the scope of required integration in the area of quality management between particular system components. The definition of requirements concerned the indication of the source component for data, the components processing the data, and the scope of their use. Owing to such an approach, the data entered in one system component is available in all the connected components, so there is no need to duplicate it; it also gives the possibility to use the data simultaneously. The described operation also provides data consistency, which reduces the risk of errors and duplicates. A well-designed integration facilitates access to particular elements of the system, as SSO (Single

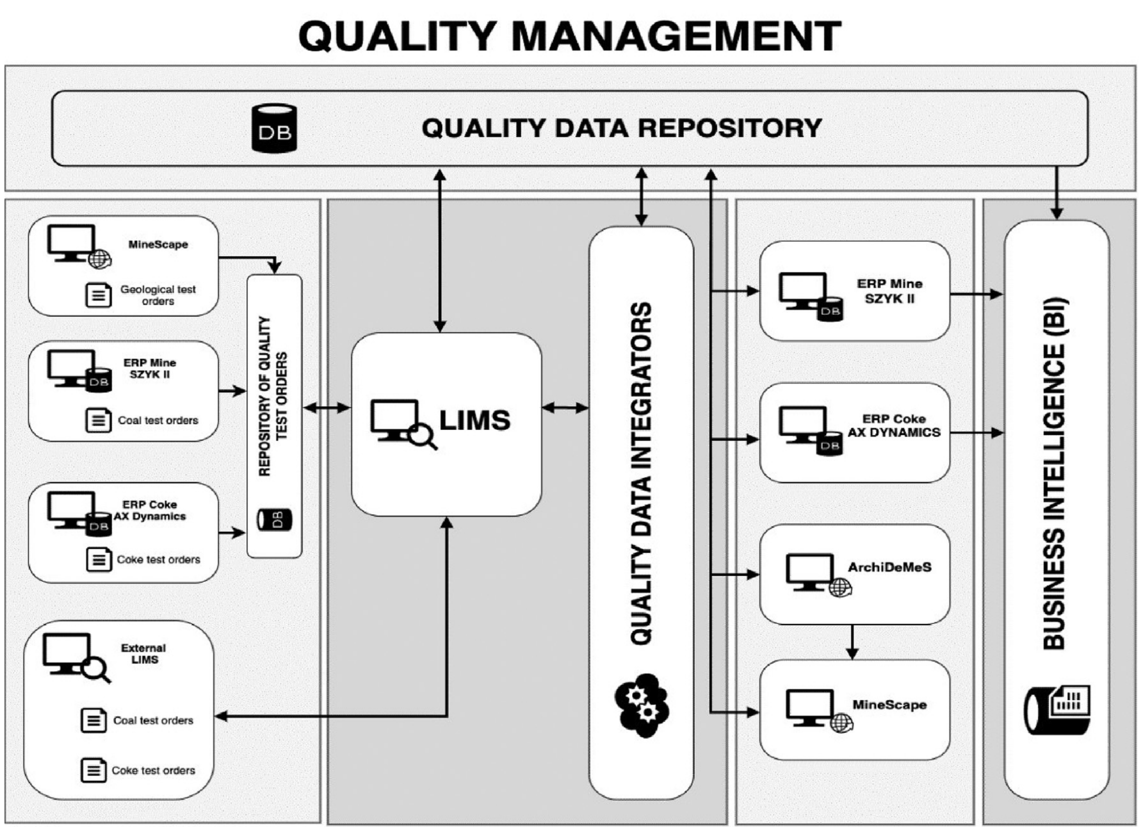

Fig. 7. The scope of required integration in the area of quality management source [own study].

Sign On) technology can be applied, owing to which a user, after logging in to any of the system components, can obtain access to the whole system. The key interfaces required to design and implement the elements of the SPPJ architecture in the quality management area are presented in Table 2.

It has been assumed that within the area of planning and scheduling, it is plausible to implement the following two components: Production Planning Integrator and Central Repository of Planning Data. The target architecture of the components will make it possible to integrate the processes of production planning and scheduling of mining works, assuming the possibility of dynamic updating of plans, simulation and the creation of multiple variants with creation of current Quality Plans based on the same source of data – based on a geological model of a deposit, describing structural and qualitative features of the extracted mineral, maintained in the 3D Map of the Deposit system and the Production Planning system. This approach will also eliminate the dualism of entering identical data between the Production Planning system and the Group's ERP system module [12,14].

In the area of coal mining and processing and coke production, Production Data Integrator was developed to provide automatic integration of all data collected from infrastructure sensors and IT/OT systems in the following production processes: mining, processing and coking. In order to enable proactive planning of supply quality and product quality management in trade and logistics processes, the following components of SPPJ architecture were implemented in the area of trade and logistics (coal and coke): Trade and Logistics Data Integrator and Warehouse Quality Map. Such solutions will enable appropriate balancing and management of product streams adequate to the realised quality requirements of a given customer – on the one hand, flowing out of the preparation plants and, on the other hand, from the storages (heaps) in a continuous mode.

5. Implementation of individual components of the production management system based on demand and quality of the production process

Implementing SPPJ in JSW Capital Group requires substantial expenditures and the participation of many resources. It is a long-term process, very complicated in organizational, financial and technical terms, requiring the involvement of the management, employees and stakeholders of JSW Capital Group. Due to the very wide scope of implementation, this article shows one of its stages – namely, the determination of priorities for the implementation of individual components.

In the research, the MoSCoW prioritization method was applied, which is based on prioritizing the required functionalities so that those that will bring the best business benefits were implemented first. It is often applied in management, business analysis, project management, and also in software development processes [17,40].

The term MoSCoW itself is derived from the first letters of the four priority categories described in A Guide to the Business Analysis Body of Knowledge:

— M – MUST (must be present): a necessary requirement that must be met in the final solution, often treated as a criterion for implementation success
— S – SHOULD (should be present): a high-priority requirement, but not necessarily to be delivered in the first stage of implementation

Table 2. The scope of required integration in the area of quality management source [own study].

Component 1	Component 2	Component 3	Description
Central Register of Quality test orders	Quality Integrator	LIMS system	Qualitative research assignments
LIMS system	Quality Integrator	3D Deposit Mapping, Production Planning System	Results of deposit tests for geological samples
LIMS system	Quality Integrator	ERP	Test results for coal production samples
LIMS system	Quality Integrator	ERP	Test results for coke production samples
LIMS system	Quality Integrator	Central Repository for Quality Data	Data on quality tests assignments and results obtained
LIMS system	Quality Integrator	Central Quality Management System	Complete data for resource, production and product quality management
Central Repository for Quality Data	Central Quality Management System	SAP Business Object	Statistics and reporting on the quality management process in the Capital Group
Central Repository for Quality Data	Central Quality Management System	MS Reporting Services	Statistics and reporting on the quality management process in the Capital Group

— C – COULD (can be present): a desired requirement, implemented if time and resources permit
— W – WON'T (will not be present): a requirement that will not be implemented in a given implementation but may be considered in the future

The analysis began with an inventory of all systems in the planned deployment area, while identifying overlaps in functionality or gaps in coverage of business processes by IT systems. This made it possible to reduce the number of systems used and support the creation of the master data model. Subsequently, the leaders of the individual areas were identified, including, among others, coal production, deposit exploration, and quality management. On the basis of questionnaires, interviews and workshops conducted with the leaders, target areas of the system were identified, as well as key actions to be taken. In the research, the following classes of priorities for the implementation of particular architecture components were assumed [41,42]:

— Urgent priority (must be present) – the component necessary to be implemented in relation to other implementation projects currently underway or critical from the point of view of the quality and availability of information for quality management processes. The component must be implemented and integrated, regardless of other components, to enable the automation of key processes.
— High priority (should be present) – the component is important in terms of processing key information in the quality management processes. The component should be implemented to streamline processes and improve information quality.
— Medium priority (could be present) – a component the implementation of which complements and enhances the SPPJ architecture. The decision to implement a component may be postponed if there are budget constraints/in the case of a lack of organizational or implementation capacity.

Due to the wide scope of the project, the necessary involvement of key personnel, and the high costs, the definition of low-priority components (will not' be present) was abandoned. The final prioritization was agreed with stakeholders under the implementation of the "Quality Program", taking into account the following factors:

— criticality to achieve the assumed objective, i.e. the ability to manage the business based on planning based on demand and product quality
— costs of implementing individual actions, launching the expected functionalities
— the time needed for implementation
— the state of progress of projects already launched that have an impact on or are part of the system

The adopted analysis method indicated a number of urgent priorities, and the lack of a clear, standardized justification did not allow one to rank the activities actually indicated for implementation in the first place. Therefore, it was decided to identify a critical path for the implementation of the system, enabling the start of the full quality management process. Table 3 presents a list of activities to implement the given component in particular business areas and the corresponding priority.

6. Summary

The overriding objective pursued by the JSW Capital Group of the "QUALITY Program" is to increase the efficiency of deposit and commercial product quality management. The article presents the assumptions of the Demand and Quality Driven Production Management System (SPPJ) implemented at JSW Capital Group, which supports effective management of production processes, including the quality of the coking coal and coke product, which in turn translates into maximizing the margin obtained on sales of end products and reducing operating costs associated with optimizing production processes for a product of the required quality level.

The Demand and Quality Driven Production Management System at JSW Capital Group is a solution that allows for a real increase in the effectiveness of quality management of both the selected deposit and the commercial product offered to end customers.

The system is the central element of the entire process of controlling mining production carried out in real time by the Quality Bureau and the JSW Advanced Data Analytics Center, especially established for this purpose by the Company's Management Board, all in terms of stabilizing and improving the quality of the extracted material.

Currently, there is no similar solution in the world to control the production process on such a large scale (seven mines, six processing plants and two coking plants) and in such complex mining and geological conditions to control the production process in the aspect of stabilization and improvement of the quality of the extracted ore and

Table 3. Implementation prioritization results for particular components. Source [own study].

Area	Component-specific action	Priority	Critical path
Quality management area	• Implementation of LIMS System • Provide integration within the Quality Integrator (LIMS – Quality Integrator – SPPJ - SAP BO) • Implementation of the Central Register of Quality test orders • Construction and implementation of the Central Repository for Quality Data (CRDJ) • Implementation of SPPJ in Quality Management in the form of analytical and reporting functionality	Urgent Urgent Urgent High Urgent	YES YES YES
Planning and scheduling area	• Implementation of the Production Planning Integrator between the Production Planning system and ERP; enabling the generation of Production Plans on the basis of data from the Production Planning system • Development of the Central Repository for Planning Data (CRDP) • Implementation of SPPJ in the area of Planning and Scheduling, enabling automatic generation of Quality Plans in SPPJ on the basis of data from the Production Planning system in the form of analytical and reporting functionality • Development of a Resource Planning module outside the ERP system and changes to the Manufacturing Resource Planning module	Urgent High Urgent Medium	YES
Area of extraction and processing of coal and coke production	• Implementation and commissioning of automatic Scales and Analysers at key points in the coal production line • Implementation and commissioning of automatic Scales and Analysers at key points of the coke production line • Expansion of the Central Repository of Quality Data to include the area of production process monitoring and production balancing • Implementation of SPPJ in the area of coal extraction and processing and coke production in the form of analytical and reporting functionality	High Medium Urgent Urgent	YES
Trade and logistics area	• Implementation and commissioning of automatic Sampling and Analysers in the area of coal trading and logistics • Implementation and commissioning of automatic Sampling and Analysers in the area of coke trading and logistics • Implementation of Warehouse Quality Map functionality • Providing integration within the Coal Trade and Logistics Data Integrator • Trade and Logistics Data Integrator • Expansion of the Central Repository of Quality Data to include the area of Trade and Logistics • Implementation of SPPJ in the area of trade and logistics in the form of analytical and reporting functionality	High Medium High Medium Medium Urgent Urgent	

maximize the economic effects of the production process.

In the years 2018–2020, the construction of the Demand and Quality Driven Production Management System in JSW Capital Group was the world's largest implementation of tools for modelling and scheduling mining production.

Thanks to the production launch of the Demand and Quality Driven Production Management System in 2020, JSW Capital Group is currently creating automatic operating variants, which are analyzed in any time frame, thanks to the possibility of choosing any calendar of mining works. This can be, for example, a monthly calendar divided into days, an annual calendar divided into months, but also a daily, five-year, and twenty-year calendar, and even until the mine resources are exhausted. Thanks to the constant updating of information in the database and the possibility of its quick use and modification, the design process (both in the case of access, preparation and operational works) is streamlined and accelerated many times compared to "manual" traditional methods, which allows:

— planning (short- and long-term) of operation and technical design

— design of access, preparatory and operational works
— execution of the schedule of designed works

The built digital model of the deposit quality allows for the automatic and integrated calculation of the quantity and quality of excavated material and gangue in selected time intervals. After the simulation is completed, a forecast is automatically generated for all parameters related to the mining project, such as quantity of excavated material, amount of gangue, quality parameters, etc. Thanks to the implementation and integration of systems in the area of quality management, the following possibilities exist:

— modelling of production management and forecasting and its key parameters in order to achieve a stable level of production quality for coking coal customers and coke producers
— planning and management of preparatory and mining work to obtain and maintain the required levels of physicochemical parameters of the product
— implementation of selective extraction by controlling the quantity and quality of excavated material − introduction of control of spoil with various parameters and the process of selective enrichment
— separation of product streams in terms of its quality, based on established key quality parameters and market demand, in order to maximize sales prices − in 2020, increases in the prices of coal supplied to strategic suppliers were obtained, thanks to maintaining a stable level of coke oven parameters of the produced coking coal
— elimination of purchases of low-phosphorus coal from outside the JSW Capital Group

Prior to 2015, JSW Capital Group's mining plants independently tracked forecasts of qualitative and quantitative parameters of the exploited deposit (without the coordination of the Head Office) based on traditional methods of flat (two-dimensional) digital mining and geological maps, which were usually updated once every few months or even less frequently.

The heuristic architecture of the production chain management system, introduced by the author, provided the possibility of analyzing the profitability of JSW Capital Group's production process in the form of a drawn account in mining, processing and coking areas, ultimately increasing production efficiency by up to 20%.

This optimization was only made possible due to the solution proposed by the author, unique on a global scale, introduced at the level of the Head Office. These related to the implementation of the continuous quality forecasts, which allowed in real time to stimulate standardization and comprehensive management of production orders, track production and monitor the effectiveness of the whole process “from the deposit to sea”.

The introduction of such an approach to modelling and scheduling JSW Capital Group's production and the appointment of the coordinator of all activities related to the quality management of the extracted spoil, processing and the production of the final product has basically completed the claims, common until recently, that the instability of the quality parameters of Jastrzębie coaking coals is a natural factor related to the variability of the quality parameters of coal deposits and the such state has to be accepted.

Most importantly, along with the implementation of the system at JSW Capital Group, there is a clearly noticeable mental change of the elites managing the mining process, requiring to ensure that the process of coal mining achieves specific quality parameters.

The author of the article personally learned how important this is for the safety of operation of a modern coal and coke concern during the beginning and duration of the first wave of the Covid-19 epidemic when the newly implemented Demand and Quality Driven Production Management System became the main tool to increase the situational awareness of the JSW Crisis Staff in the process of managing the production and logistics of the JSW Capital Group's mines and coking plants.

Ethical statement

The author states that the research was conducted according to ethical standards.

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Conflict of interest

The author declare no conflict of interest.

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