The object of the study is Manufacturing Execution System. The relevance of the study is conditioned by the fact that the metallurgical industry has been demonstrating a high level of volatility in the global market over the past few years. The issue of the effectiveness of the metallurgical enterprise is directly related to ensuring environmental safety. The purpose of the study is to consider how the Manufacturing Execution System (MES) operates in the metallurgical industry and highlight its features, offering recommendations aimed at improving operational efficiency with the introduction of MES systems at enterprises of the metallurgical industry of the Republic of Kazakhstan. The following methods were used in the study: analysis, synthesis, comparison, graphical representation of data. Using the example of the Magnitogorsk Iron and Steel Works, the study examined the relationship between MES and APCS (Automated Process Control System), highlighted the requirements for the transition from individual management of particular cases of technological rules and restrictions to the digitization of general algorithms. It was defined that the advantages of a production system include its fast payback. Also, it was determined that the MES system allows automating production operations and information support, carrying out operational planning, accounting for production and quality of metal products, tracking the history of each product, managing equipment, and analyzing performance. In addition, the recommendations that can be used as a basis for creating an enterprise development program, increasing the level of productivity, therefore, reducing the cost of the enterprise's products, were developed

Keywords: integrated management system, software implementation in production, metal products manufacturing

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IMPORTANCE OF THE INTEGRATED MANUFACTURING EXECUTION SYSTEM FOR A METALLURGICAL ENTERPRISE

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1. Introduction

In practice, part of the production facilities put into operation for a long time is associated with the equipment of outdated automation systems that do not support integration with other systems. There is also a certain fragmentation of systems. MES (Manufacturing Execution System), which connects production resource planning, logistics processes, downtime monitoring, product quality management, and other links of the value chain in a single information space, is often built to satisfy the interests of one side of the technological process, but at the same time may not take into account the possibility of further integration and modernization of the system [1–3]. Considering the current demand for IT (information technology) from metallurgical companies, then, of course, most are already focused on digital solutions and services. However, digitalization cannot be carried out without ensuring the proper level of automation. In this regard, the introduction or modernization of MES is one of the necessary and obvious requirements [4, 5].

Digital technologies enable large metallurgical producers to form their own ecosystems that can unite the client network and contractors [6–8]. The MES system most often covers a wide range of tasks: installation and configuration of rational modes of operation of the enterprise and each of its individual technological processes; maintenance of proper operation of a given mode of activity of the enterprise; provision of the growth of the quality of the manufactured product by reducing costs, emergencies, downtime, etc.; distribution and monitoring of the status of resources; automation of dispatching of production processes; regular data collection, quality management, maintenance management, performance analysis; production scheduling; document control, human resource management; coordination of technological processes and tracking of finished products [9–11].

To implement the advantages of high-tech machines and effective processing strategies, compliance with all the conditions is required [12, 13]. The search for technical solutions in response to the ever-growing demands of modern metalworking is the basis for new developments, in particular, in the field of cutting tools. Thereby, the development of a tool based on the entire knowledge base and competencies, and digitization in formats convenient for both its consumer and the equipment manufacturer, is becoming a requirement of the time.

2. Literature review and problem statement

Digital transformation increases the competitive advantage of an enterprise that implements automation of production, thereby it allows ensuring productivity growth and improving product quality, reducing cost and losses. The paper [14] claims that production and sales conditioned by the introduction of digital technologies become more transparent, the impact of the human factor is reduced. Of paramount importance are the tools of digital transformation for metallurgy: the introduction of big data analysis, artificial intelligence and machine learning, the industrial Internet

of Things, predictive analytics, machine vision, virtual and augmented reality. The authors of [15] consider that it is important that all this be combined in one way or another into a single information system.

But there are still unresolved issues related to the digitization of equipment manufactured in the last century. Digitization of equipment manufactured in the last century is possible thanks to the use of modern sensors installed on the equipment and the transfer of this information to the system for monitoring and analysis. This is the approach used in the work [16], however, the authors are convinced that in steelmaking it is possible to use the latest technology to store the history of the melting parameters so that the result can then be predicted. Or, for example, as the work [17] showed, using machine learning, determine the initial composition of the alloy and the melting parameters in order to achieve a certain quality. This allows reducing the consumption of raw materials, optimizing the composition of elements, predicting the quality of products, etc.

Considering individual segments of metallurgical enterprises, the modernization of metallurgical industries entails the expansion of related IT projects. According to [18], with the introduction of technologies aimed at automating production, there is an increase in demand for information storage and processing systems, secure information transmission systems, and business process automation solutions. Particularly relevant are requests for ensuring the safety of corporate data – backup storage systems, copying corporate data to the cloud, data cyber protection technologies. In addition, the paper [19] noted that the need for security systems (especially access control and perimeter monitoring systems) and network technologies appears stable. The authors of [20] are convinced that customers are increasingly showing cautious, but noticeably growing interest in hyperconvergent infrastructures that combine storage, computing and network resources into a single system, which simplifies the processes of management, protection and scaling. In turn, the authors of [21] consider that a lot can and should be automated and digitized in metallurgy – starting from simple office operations, sales and logistics, ending with many complex production processes, but not all.

However, the problem of the functioning of the production management system in the metallurgical industry has not yet been investigated. This allows stating the expediency of conducting a study devoted to the introduction of integrated automation in the metallurgical industry. Also, recommendations aimed at improving the efficiency of work with the implementation of production management systems at enterprises of the metallurgical industry have not yet been created. Therefore, this work is an attempt to fill these gaps.

3. The aim and objectives of the study

The aim of the study is to consider how the integrated management system operates in the metallurgical industry and highlight its features. This will make it possible to offer recommendations aimed at improving operational efficiency with the introduction of MES systems at enterprises of the metallurgical industry of the Republic of Kazakhstan.

To accomplish the aim, the following objectives have been set:

– to analyze the experience of digitalization of industrial production and the advantages of MES systems;

– to study the features of introduction of MES systems at enterprises of the metallurgical industry of the Republic of Kazakhstan;

– to develop recommendations for improving the efficiency of work with the implementation of MES systems for enterprises of the metallurgical industry.

4. Materials and methods

The object of research is Manufacturing Execution System. The main hypothesis of the study: integration of automated enterprise management systems allows increasing the efficiency of production processes. Assumptions made in the work: due to the introduction of automated systems, the volume of metallurgical production is increasing; the MES system allows increasing labor productivity and reducing costs. Simplifications adopted in the work: MES is a common phenomenon in the Republic of Kazakhstan; there are enough qualified electronics engineers in the metallurgical industry who specialize in digital technologies.

The following methods were used in the course of the study: theoretical (analysis, synthesis, comparison); graphical representation of data. The basis for this study includes papers by researchers investigating issues related to the digitalization of industrial enterprises, namely in the metallurgical industry.

The investigation of this issue was carried out in three stages. At the first stage, the characteristics of the digitalization of industrial production were given, the principles of the information model were considered, the elements of industrial digitalization based on the concept of "Industry 4.0" were highlighted. Then the characteristic of MES was given, its result, what it is aimed at, what tasks it solves during implementation, what are the functions of this system. The advantages of the production system (MES), the problems of implementing the MES system, barriers to the implementation of digitalization projects and the introduction of MES systems, the functions of implementing the MES system in metallurgical production were also highlighted. In addition, as part of the first stage, the study considered an example of the introduction of an MES system in the metallurgical industry and at enterprises that work in it to solve problems related to the calculation of the metal balance. Within the first stage, the main technologies and approaches that were used in organizing the collection of data on the operation of equipment within the MES system (EUROMAP63, OPC DA and OPC UA, MODBUS ASCII/RTU/TCP) were highlighted.

The second stage was related to the investigation of the implementation of MES systems at metallurgical enterprises located in the Republic of Kazakhstan. In particular, it was highlighted how many customers, contractors, projects within MES systems were recorded in 2021. An analysis of the main processes within MES systems that were recorded at metallurgical enterprises of Kazakhstan was presented. The study analyzed the official statistics on the implementation of the MES system at metallurgical enterprises in Kazakhstan. In addition, as part of the second stage, the main standards of production data management during the life cycle were considered as part of the implementation of MES systems. The second stage also included the results of a survey among enterprises that have already implemented the MES system and who are thinking about implementing,

how effective this system is in their opinion. As part of the ongoing research, at the third stage, recommendations were proposed aimed at improving operational efficiency with the introduction of MES systems to enterprises of the metallurgical industry of the Republic of Kazakhstan.

5. Results of studying the implementation of digital technologies into the production of metallurgical enterprises

5. 1. Features of the digitalization of metallurgical enterprises and advantages of the Manufacturing Execution System

Currently, most enterprises of the Republic of Kazakhstan have started to introduce digital technologies into manufacturing processes. The factors that hinder the introduction of digital technologies into the production of metallurgical enterprises are as follows: a shortage of financial resources, qualified personnel, lack of standards and underdevelopment of regulatory requirements. In addition, each enterprise has its own understanding of "digital transformation", since there is no single definition of "Industry 4.0" and technologies that would correspond to this concept.

Digitalization and its transformation into production introduce new characteristics of high-tech production, the foundation of which is the information model (IM) of digital production. IM implies the transition of existing production facilities to digital and high-tech processes coordinated by intelligent systems in the temporal aspect and interacting with the external environment, creating a new organizational level of production and management throughout the life cycle of products. IM is based on a large-scale study of production and information flows, information processing algorithms, automation elements to ensure the improvement of the information system by selecting technical means and uses the following principles (Fig. 1) [3].

MES in metallurgy can be defined as an information system aimed at maintaining the execution of all functional tasks for planning, monitoring, accounting, and analysis of the entire production process at all its stages and focused on achieving the maximum economic effect from the production activities of a metallurgical enterprise [5]. The MES system is the first step towards the introduction of world-class production standards. MES systems (Manufacturing Execution System, production process management system) consider functions, tasks, advantages, and disadvantages [5]. Operational management of the company's production through the tools available in MES allows [5]:

– tracking inventory of each category (raw materials, products of intermediate stages of production, finished products) with accuracy to one;

– managing the sequence of production orders, tracking readiness statuses;

– optimizing the processes of distribution and selection of raw materials or components and their shipment to production;

– ensuring the management of the workforce and production processes directly by drawing up and controlling the execution of a detailed production schedule.

The ISA-95 standard, developed by the International Association of Automation, is a well-established standard that defines the functionality of MES. The standard defines the integration of IT systems of general and operational planning, management, logistics, etc. This standard corresponds to the European standard IEC 62264. In addition, there are a number of standards that define to some extent the tasks of production process control systems. Part of these standards defines the description of requirements for production management systems, for example, in terms of ensuring the safety of food production, pharmaceutical products (FDA 21 CFR Part 11, etc.). It is also worth highlighting the manual on production management systems of the German Association of Engineers (Verein Deutscher Ingenieure) VDI 5600, which contains a functional description of MES. A brief description of the functions adopted in various standards is given in Table 1.

Table 1

Manufacturing Execution System functionality in various standards

MESA	ISA-95	VDI
Operational/detailed planning	Detailed production planning	Detailed planning and detailed control of the production schedule
Status monitoring and resource allocation	Production data collection	Operational resource management
Document management	Management of production resources	Materials management
Dispatching of production	Product history tracking	Personnel management
Performance analysis	Dispatching of production	Data collection and processing
Personnel management	Production process management	Interaction management
MRO management	Production efficiency analysis	Performance analysis
Process management	Managing definitions	Quality management

Source: [11]

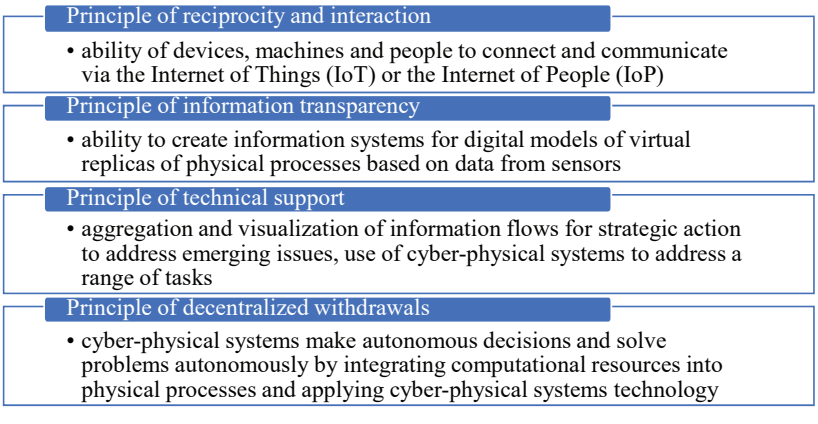

Fig. 1. Principles of the information model

The advantages of a production system (MES) include its fast payback. Reducing the number of defects, increasing productivity without attracting additional labor and increasing production capacity, optimizing work schedules,

including schedules for the continuous operation of equipment – all this ultimately helps to increase profits [7]. The integration of automated enterprise management systems (MES) allows increasing the efficiency of production processes. This procedure is aimed at accelerating the work of processing centers, increasing the overall productivity of the enterprise [1].

The advantages of MES systems are shown in Fig. 2 [2].

1. • Ability to control technological processes
2. • Ability to move from manual to automated data recording operations, thus avoiding errors and inaccuracies
3. • Rapid provision of information to production staff regarding stock levels and raw material status
4. • Ability to collate, analyze and distribute information and documents in a structured manner
5. • Ability to reduce training and system maintenance costs

Fig. 2. Advantages of Manufacturing Execution Systems

MES is a relatively new phenomenon in the Republic of Kazakhstan, since such systems can often be confused with production ERP (Enterprise Resource Planning). The essential differences between MES and ERP systems are as follows: focus on solving first of all production, and only then administrative and economic tasks; broader functionality that reflects the production process in more detail; providing the opportunity to make adjustments to the production schedule at any time and as many times as necessary [2].

5. 2. Peculiarities of the introduction of Manufacturing Execution Systems at enterprises of the metallurgical industry of the Republic of Kazakhstan

Considering the implementation of the MES system at metallurgical enterprises in Kazakhstan, as of October 2021, there were 14 customers, 8 contractors, and 14 projects [12]. The analysis of the experience of implementing MES systems was carried out at 9 enterprises related to metallurgy. Table 2 presents a general description of the main processes within MES systems [12]. Speaking about how many enterprises have effectively implemented the MES system and how they work with it at metallurgical enterprises in Kazakhstan, the study concluded that 3 enterprises provide for personnel training costs in the field of digitalization; 9 enterprises have implemented the system and software; 6 enterprises have their own service that is directly responsible for digitalization; 6 enterprises have fully automated business processes [12].

Due to the introduction of automated systems, Taraz Metallurgical Plant increased the production of ferrosilicon manganese by 91 %. The plant is an integrated producer of ferroalloys, anode paste, and phosphorous products. The industrial zone is 632 hectares – these are melting shops, administrative buildings, warehouses. The infrastructure allows servicing 13 furnaces with a total capacity of 400 thousand tonnes of alloys per year [10].

Due to the introduction of the MES system, the volume of ferroalloy production at the Temirtau Electrometallurgical Combine increased by 1 %. The main activity of the company is the extraction of manganese ore and limestone, the production of ferroalloys and calcium carbide from them and their sale. Having its own raw material base and production facilities, the plant has created a full production cycle of raw materials – production – finished product. According to the results of the implementation of the MES system, ArcelorMittal Temirtau AO has seen an increase in steel production by 2.1 %. The company specializes in the production of flat and long products, and also produces agglomerate, iron ore and coal concentrate, coke, cast iron, steel and related products of blast furnace and coke chemical industries. In non-ferrous metallurgy, there is an increase in production volume by 6.6 %. In turn, Kazakhmys Corporation TOO increased the volume of gold bullion production by 52 % and silver granules by 33 %. In Tau-Ken Altyn, there is an increase in the production of refined gold by 4 % and refined silver by 46.7 % [10].

Kazakhstan Metallurgical company Casting increased the volume of copper cathode production by 19 %. The company produces a wide range of products from ferrous and non-ferrous metals: steel billets, grinding balls and rods, reinforcing bars, cathode copper and copper products, bronze, brass, aluminum and lead alloys [10]. Evraz Caspian Steel plant in Kostanay increased the volume of reinforcing bar production by 8 %. Reinforcing bar products are manufactured in accordance with state standards. The steel department of the company continues to implement a large-scale project to modernize automation systems of 0, 1, 2, 3 (MES) levels for accounting of manufactured products. Currently, the implementation of the first phase of this project is being completed in several workshops of the metallurgical combine.

Using the example of the Magnitogorsk Iron and Steel Works, it is proposed to consider the relationship between MES and APCS (Fig. 3).

As part of the ongoing research, a survey was conducted among businesses that have already implemented an MES system and who are thinking of implementing it, how effective they think the system is. The survey results are shown in Fig. 4 [19].

MES – APCS	APCS – MES
• Synchronization of normative and reference information in the APCS and the corporate system. • Cross-cutting identification of production units and workpieces. • Production task. • Production charts. • Information on the workpiece and finished product. • Formation of accounting information based on data from the APCS.	• Item-by-item tracking of metal movements in production units in relation to unit number and processing time in the unit. • Collection of information from process sensors in the form of data series that are required to generate a process report and product data sheet. • Information on product labelling and identification. • Collection of information on equipment operation, shutdowns and process interruptions, including their duration.

Fig. 3. The relationship between Manufacturing Execution System and Automated Process Control System on the example of Magnitogorsk Iron and Steel Works

Table 2

General characteristics of the main processes in the framework of Manufacturing Execution Systems

Business processes (automated)				
Electronic document management	Financial resource management (budgeting, payment calendar)	Equipment maintenance management	Personnel management	Production accounting
4	–	–	1	1
Information systems (implemented)				
APCS (Automated Process Control System)	ECMAS (Electricity Commercial Metering Automated System)	ERP (Enterprise Resource Planning)	MES (Manufacturing Execution System)	MRO (Maintenance, Repair, and Overhaul)
7	8	6	2	2
Level of digitalization				
Digitalization strategy			Level	
Obtained	No.	Planned	Above average	Average	Low
2	4	2	1	2	5

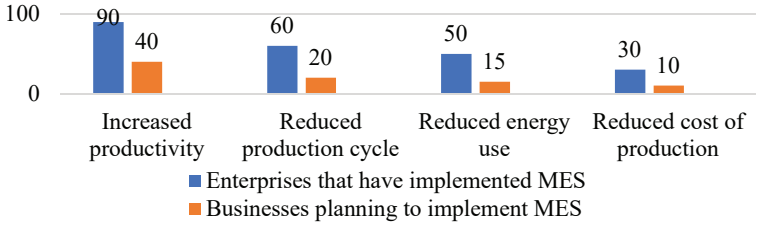

Fig. 4. The results of a survey among enterprises that have already implemented the Manufacturing Execution System and who are thinking about implementing, how effective this system is in their opinion

According to Fig. 4, it can be seen that both types of enterprises indicate that this system allows increasing productivity, which is one of the main indicators of the successful operation of the enterprise, regardless of which industry it belongs to. In addition, this system allows reducing the level of costs, reducing the production cycle, and lowering the energy consumption, which is a positive factor in the development of any industrial enterprise.

5. 3. Recommendations for improving the efficiency of work for enterprises of the metallurgical industry

As part of the work to improve operational efficiency with the introduction of MES systems, the following recommendations can be offered to enterprises of the metallurgical industry of the Republic of Kazakhstan:

– to ensure the improvement of the innovation and R&D management system to identify, develop, and implement new technical solutions designed to help improve business;

– to ensure compliance with requirements for the MES functionality (issuance for execution in MES and loading of the results of execution: schedules for the operation of aggregates, recommendations for loading warehouses (zone/stack), schedules for the shipment of metal products, schedules for transport needs, schedules for reconfiguration of equipment, schedules for the need for replaceable equipment (rolls), schedules for the need for materials (zinc, paint, tin), sampling and testing schedules, quality improvement/restoration schedules, issuance of PtW/order specifications for certification, assignment and reassignment of metal to order);

– production accounting should be carried out based on AS for current calendar planning;

– violations of the production schedule should be recorded;

– the numbering of planned batches should be carried out in the AS for current calendar planning;

– production accounting should exclude the intersection of numbers; control of the balance between ingredients and products should be carried out in MES, taking into account planned consumption coefficients;

– information about the products produced and/or used semi-finished products should be received with a delay of no more than 15 minutes;

– correction of accounting information is not allowed retroactively;

– to provide an opportunity to create a virtual center of digital competencies to identify, study, and implement opportunities relevant to metallurgical enterprises;

– to provide an opportunity for the replication of the MES system in terms of the balance of metals at enterprises in Republic of Kazakhstan;

– to provide an opportunity to create a venture fund on the basis of the Astana International Financial Centre to promote the development of new types of businesses;

– to provide additional funding for technology start-ups that create new technological solutions for industrial enterprises.

The implementation of the proposed recommendations will be aimed at improving the work related to the digitalization of production, which will simplify the solution of many tasks related to this process. These proposals can be implemented not only at metallurgical enterprises, but also at enterprises operating in other industries not only in the Republic of Kazakhstan, but also in other countries.

6. Discussion of the results of studying the implementation of digital technologies into the production of metallurgical enterprises

The growth of global competition in the industry will cause changes associated with the transition to more environmentally friendly production, changes in equipment and the quality of technological processes [18, 19]. According to experts' estimates [20–22] and forecasts based on them, production will become more automated and robotic. Individual working professions will be reduced and their place will be taken by universal equipment operators.

Fig. 2 and Table 2 show that MES systems provide an opportunity to collect, track information, and simulate production processes, from placing an order to sending it

to the recipient; implementation of projects to digitalize all production processes. In connection with the introduction of MES, Magnitogorsk Iron and Steel Works has received the following positive results: digitization of the entire pool of technologies and restrictions with the possibility of automatic use in arbitrary combinations; seamless integration of all automation systems; support for a convenient environment for operational updating of content adapted for each user group (Fig. 3). Peculiarities of the obtained results (Fig. 4) indicate that a number of metallurgical enterprises in Kazakhstan are actively implementing digital economy tools. In particular, projects are being implemented in the field of using drones to monitor traffic on the tracks, virtual reality technology is being used for industrial training, big data is being collected and processed about the operation of equipment and coordination of the supply system, predictive diagnostics of equipment is being carried out. The industry lacks automation specialists, qualified electronics engineers versed in robotics and digital technologies. Nowadays, these professions are the scarcest and most in-demand on the world labor market.

A limitation of the presented research is that the impact of COVID-19 on the digitalization of metallurgical enterprises in Republic of Kazakhstan was not studied. In addition, the main disadvantage of the study is that the specifics of the operation of the production management system in the metallurgical industry of other countries were not studied. Thus, this is the perspective of further research.

7. Conclusions

1. The advantages of a production system (MES) were provided. It was determined that the main advantage of an MES is its fast payback. It was stated that MES programs are an important component of the corporate system. With their help, the management, service personnel and controlling units of the organization can get reliable information about the quality and quantity of products, about the state of production as a whole.

2. Based on the data of metallurgical industry enterprises in the Republic of Kazakhstan, the study analyzed the technologies they use in their work and identified the following: additive technologies (3D printing), collaborative robots, self-optimized equipment, quality assurance technologies, automated vehicles, automated internal logistics, advanced analytics, predictive maintenance, machine learning, artificial intelligence, cloud technologies, simulation, digital modeling, digital "twins" of factories, data integration, digital and virtual engineering, virtual equipment commissioning, industrial Internet, sensorized materials and autonomous components, data exchange technologies, system status monitoring. The types of digital support systems for MES systems at metallurgical enterprises in Kazakhstan were shown. The achievements of a number of large metallurgical enterprises located on the territory of the Republic of Kazakhstan as positive examples of the introduction of automated systems were considered.

3. The recommendations for enterprises of the metallurgical industry of the Republic of Kazakhstan were offered. It was stated that in order to improve the business, it is necessary to ensure the improvement of the innovation and R&D management system, as well as to ensure compliance with the requirements for the functionality of the MES. In addition, it is important to provide additional funding for technology start-ups.

Conflict of interests

The author declares that he has no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data will be made available on reasonable request.

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