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Production Line Modelling in Accordance with the Industry 4.0 Concept as an Element of Process Management in the Iron and Steel Industry

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Abstract
Simulations are becoming one of the most important techniques supporting production preparation, even in those industrial sectors with atypical technological processes, such as in metallurgy, where there is a multiphase material flow. This is due to the fact that in the conditions of a market economy, enterprises have to solve more and more complex problems in a shorter time. On the basis of the existing production process and the knowledge of the flow characteristics in a given process, a model is built, which, when subjected to simulation tests, provides experimental results in the scope of the defined problem. The use of computer techniques also creates new possibilities for the rational use of the reserves inherent in each technological process. Taking into account the existing demand and the state of modern technology, the computer model can be a source of information for further analysis and decision-making processes supporting company management. At work a model of the logistic system was made on the example of a hot-rolled steel strip mill, on which simulation experiments were carried out to improve the effectiveness and efficiency of the analysis production line. The presented article aims to disseminate the idea of ??Industry 4.0 in Polish companies from the manufacturing industry sector, taking into account simulation techniques.

Keywords
Hot rolling mill, Logistic model of a mill, Steel, Strip, Stock management.

Introduction

The development of IT technologies and automation, and their implementation in production processes transforms the traditional industry and puts it on a new level of organisational development. The new paradigm used globally, i.e. Industry 4.0 or the Fourth Industrial Revolution, is discussed with the view of the optimal use of these technologies for considerable acceleration of production enterprise development and increased competitiveness in global markets (Ślusarczyk, 2018). The concept is used to describe phenomena of broad implementation of smart devices in production lines to communicate autonomously along the value chain. In this approach, machines and software collect information on an ongoing basis in order to automatically improve their configuration and supply significant ratios and calculation from the execution of the production process. The combination of production processes with IT technologies which develop on their own at a very fast pace makes the automation of production lines very flexible, merges logistics processes, and optimises the value chain.

The aim of of the work was to carry out on-line the process of rolling with specific technological and transport assumptions using data from various sensors, cameras, databases, web application, etc. For model purposes, due to the costs associated with the operation and reconstruction of equipment and production units as well as the cost of manufacturing the final product, which is a steel belt, the following was analysed:

- the influence of the parameters of technological and transport equipment on the time of production task execution,
- impact of technological and transport equipment parameters on production equipment downtime,
- the degree of use of technological and transport equipment for the execution of the production task.

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The program of the simulation tests carried out was presented on the basis of two characteristic cases. The first case assumes rationalization of the examined rolling mill on the basis of calculations and analyses. The second case, on the other hand, adopts actual assumptions that are currently applied and implemented in the production process of producing the finished product.

The innovation of this article is to show the possibility of using the Dosimis-3 graphic simulator as a tool to solve complex technological problems in industrial conditions. It is an interactive, object-oriented graphic simulator that enables the simulation of material flow processes and production systems in discrete time, which makes it helpful in making effective technological decisions at the level of operational planning and preparation of production in the surveyed company. It allows you to track the behavior of devices "step by step", and thus the possibility of eliminating any errors and obtaining the results necessary to make specific decisions in the field of supporting production planning processes. On the built model, it is possible to carry out research on the transport and storage system, cooperating with the adopted production subsystem. In the case of other steel companies, if work was carried out in these directions, they were not reflected in scientific publications.

Literature review

The first three industrial revolutions brought progress in the automation of production devices, electricity and distribution of labour, and in IT technologies (Kumar Mohd & Asjad, 2020, Hamrol et al., 2019) . The Industry 4.0 term means the fourth industrial revolution which is assumed to be the vision of smart factories built from smart cyber-physical systems. The implementation of this idea should enable the development of smart production systems which, apart from the mentioned autonomy, will have the properties of self-configuration, self-control or self-repair. Industry 4.0 is currently one of the most frequent topics among practitioners and scientists, and thus becomes a priority for many research centres and enterprises. The Industry 4.0 concept covers the areas of various technologies and related paradigms. The main elements closely connected with the idea of Industry 4.0 include industrial Internet of Things, cloud-based manufacturing, smart factories, cyber-physical systems or social product development (Lee et al,. 2018, Zhong et al., 2017).

The cyber-physical system (CPS) is the main technology of Industry 4.0 and it is defined as a combination of computational elements and physical processes. Most frequently, integration takes the form of embedded systems and networks to monitor and control physical processes. The control system of the manufacturing process functions in a feedback loop. In this case, physical processes are sources of data for the computation of a signal to control selected executive objects. CPS is developed in three stages: first-generation CPS – includes RFID identification technologies, second-generation CPS – systems equipped with sensors and actuators of limited functions, third-generation CPS – systems can store and analyse data (Mao et al., 2018, Nguyen et al., 2018). Devices are connected in a closed system, thus creating locally an embedded network system of a hierarchical structure. Thanks to CPS, intelligence is not centralised but dispersed at process stages, which also ensures greater stability and more flexibility in the execution of operations. Machines connected to cyber-physical systems should be characterised by a high degree of automation and application of AI algorithms. In the processing of controllable data, CPS systems are supported by cloud computing which allows for very fast data processing within secure systems. Cloud computing mainly comprises analytical and calculation systems. Thanks to the centralisation of data collection and processing, time and money can be saved by reducing headcount and equipment resources necessary for the functioning of the system (Kiepas, 2018, Rojek et al., 2021, Bysko et al., 2019).

The basic approach under Industry 4.0 is to develop plug-and-work systems in automatically configured modules based on information transferred from databases, ERP (Enterprise Resource Planning) systems and physical sensors installed on production lines. All this is to enable more dynamic and flexible options of the configuration of the final product. The basic aspect of such operations is to identify devices and processes significant within production systems of an enterprise which may be connected to the IT network structure and continue its functioning without interference in other system parts. The physical production process connected to the Internet and dispersed embedded intelligence is flexible and autonomous, and can quickly react to demands, changes and market restrictions.

One of the key elements of Industry 4.0 is the Digital Twin – a virtual replica of a physical object, process or product which is updated on an ongoing basis (Taliaferro et al., 2016, Gudanowska, 2017). A copy can be saved both for a single device and for the entire production line. Digital Twin consolidates data from many sources, such as data measurements in real time from IoT measures, CAD designs, reports

and documentation created during the product lifecycle. Enterprises can use this data in order to simulate production processes, manage them appropriately and optimise e.g. stock. With the data collected in one place, the response time is shortened and, as a result, enterprises may take action quickly enough in case of parameter change, which reduces the risk of downtime and limits material and financial losses. Through the combination of immense modern processing capacity and advanced algorithms, the Digital Twin enables fundamental changes in this aspect of knowledge.

Internet of Things is another important technology used in the Industry 4.0 concept. It allows for connecting the known and used devices to the Internet, and enables remote access to these devices and the possibility to control them from any place with Internet access. In practice, IoT allows for global functioning of enterprises which have innovative technologies but do not have an extensive distribution and service network (Ershadi & Menéndez, 2017). In technical terms, these phenomena are referred to as the Industrial Internet of Things (IIoT). One of the applications of IIoT technology are integrated monitoring networks – systems of wireless sensors which are safer and faster to implement on production lines, less invasive and cheaper than their wire equivalents. Just like in case of IoT, the idea behind IIoT is to collect large quantities of data. In the case of the Industrial Internet of Things, it is the collection of data from production processes and the sending of this data to data processing centres. IIoT includes industrial devices, such as sensors, robot actuators, production equipment (control systems of lathes, milling machines, drills or grinding machines), production line elements (PLC controllers, engines, pumps).

Social Product Development (SPD) is a relatively new concept in the world of product development. At present, there is no clear definition but it is assumed that it means involvement of a team of people inside or/and outside the enterprise in product development (a team of qualified employees). Technologies, social tools and media are used for this purpose so that users could have an influence on product lifecycle at all stages of design. It turns out that if a new product is released on the market and Internet users have participated in its development, it has a shorter development period and requires less investment than similar projects based on traditional design only.

MES system in the Industry 4.0 concept

The contemporary production industry is not only the production system of an enterprise but it also includes basic production machines and facilities, robots or industrial manipulators as well as further surroundings taking the form of logistics systems, resources and customer service. In accordance with the Industry 4.0 concept, all these aspects should be strongly integrated and communicated, programmable, reconfigured, managed, and they should be flexible. Various integration levels of the mentioned systems can be encountered in production enterprises. Considerable differences in the levels of technological advancement result in the absence of a single scenario of the implementation of the Industry 4.0 concept in enterprises. Every implementation of the Industry 4.0 in a production company should be considered individually.

Responsible management of production processes is a key element affecting the stabilisation and development of the enterprise on the market. This need has led to the creation of a new class of industrial software – Manufacturing Execution Systems (MES) (Hansen et al., 2017, Łukasik & Stachowiak, 2020).

MES systems have always been an important element of production functioning. The following five major areas have been affected by the Fourth Revolution in this aspect: communication/mobility, cloud and advanced analysis, decentralisation, vertical and horizontal integration. MES systems allow for supporting tasks associated with the optimisation of production processes, easier access to documentation or production path. They also help keep up with the changing requirements of recipients. This is possible thanks to the collection of data in real time directly from machines. The obtained information is really valuable thanks to its high level of detail. This, in turn, allows for quick identification of potential problems and active action to increase the quality of production and to reduce costs. Such software also enables the control of the flow of production processes and the verification of their compliance with the technological and quality specification, and appropriate response to changes both within and outside the organisation. The implementation of the advanced system to support manufacturing enables better use of the enterprise's resources by, for example, applying comparative analyses. The solutions which can be found in MES systems are used irrespective of the production environment in which they function. Only emphasis on individual functions can be spread differently. For example, for a production environment where there is no large assortment of goods and there are relatively simple and constant production processes and production batches of high volumes, data regarding the process performance, its parameters and deviations from the standard will be important so that, after slight modification, the management of robot operation will be possible in future. In case of

a production environment characterised by a high individualisation level of products and low production volumes, easy access to documentation, adaptation capacity of processes or automation in the sphere of machine refitting will be very important. Industry 4.0. combined with the MES system makes the production market more dynamic (Nogalski & Niewiadomski, 2020, Liszka et al., 2019, Perzyk et al., 2019, Zawadzki & Żywicki, 2016). Decentralised logic of the new MES system must take into account updates among businesses, suppliers, sub-manufacturers, and distribution partners.

Essence of simulation modelling

Modelling and simulation methods are used when it is too complicated or impossible to achieve the solution using analytical methods and direct experiments on a practical (physical) model are too time-consuming, dangerous and costly. Modelling is also used when other methods do not provide the required assurance that the actual production system will operate as assumed in the theoretical (virtual) model. The modelling and simulation of production processes allow for their analysis and tracking of the functioning of a selected object (position, operation, procedure, action, transport, warehouse stock, disturbances, etc.) which sometimes lasts a few years in several minutes only. It enables the verification of the assumptions prior to their practical application and defining irregularities which may occur in the course of operation, in particular weaknesses of the designed or realised production system. The modelling and simulation of the production process involve the creation of a virtual model of an actual production system on which experiments are made. As a result of simulation, a set of reports is created which are later used to agree on the further course of action. For example, an organisational form of production stations or kind and number of means of transport are chosen; also, the scheme of changes to be made to the existing system to achieve the assumed target, e.g. production capacity or shortened production cycle. The analysed model of the production system can be improved and subsequent simulations can be conducted for its various variants and settings, e.g. different quantities of goods, capacity of inter-station warehouses, forecast disturbances and interruptions related to e.g. maintenance and repairs of machines and their failures, etc. with the Industry 4.0 concept taken into account (Luscinski & Ivanov, 2020, Lola & Bakeev, 2020, Kosacka-Olejnik, 2019, Cyfert et al., 2021).

The use of computer modelling and simulation techniques is one of the methods which contribute to faster design of new production systems and verification of existing systems during the period of a competitive market and constant aspirations of businesses to reduce production costs. It leads to shorter time of project development and enables experiments on various variants of the virtual production process. It also makes it possible to trace the effects of changes before making final decisions. This reduces the risk of failure which may be very costly. Furthermore, it increases quality ratios of the technology to choose the most favourable variant in the actual conditions of application which is being currently developed and which will be used in future (Buer et al., 2018).

Dosimis-3 as a modelling tool in accordance with the Industry 4.0 concept

The application of simulation techniques for the solving of complex technological problems in industrial conditions requires an efficient simulation tool such as Dosimis-3. It is an interactive object-based graphic simulator which enables the simulation of the flow of materials and production systems in discrete time. Thanks to this, it is useful when making effective technological decisions at the operational level of production planning and preparation in a given enterprise. The software enables the tracking of device operation "step by step" and the elimination of all errors. It provides results necessary for making specific decisions with regard to the support of production planning processes. Typical structure of a simulation model: introduction and placement of elements in the viewport, determination of simulation parameters and data entering, conducting of simulation, analysis of simulation results, model validation. The user can also enter various parameters which describe the functioning of individual system elements, e.g. duration of the run cycle of devices (flow of materials), duration of technological operations, object dimensions, strategies of flow control, duration of the reconstruction of process equipment, duration of device repairs, and duration of disturbances in system operation. An appropriate database (Internet of Things, MES applications) which describe individual system elements (production and transport equipment, and storage sites) is required for system modelling. These elements include (Wyrzykowski, 2020): transportation time of materials using transport equipment (overhead cranes, conveyors), duration of technological operations, dimensions of objects (length of transportation routes, capacity of warehouses), time of transportation equipment refitting, duration of system disturbances.

The following are the parameters compared with characteristics of the actual object: production capacity of a mill, extent of use of transport and production equipment, average duration of the cycles of production and transport equipment, assortment of ordered ready goods, time of passage of the material through the system – lead time.

One of the more important values describing system operation is the ratio of the use of process equipment and the utilisation of production and transport equipment. System simulation modelling integrated with processes facilitates and helps streamline decisions, thus contributing to better utilisation of resources of the enterprise and increased system capacity. The preview of model operation is a considerable advantage of the software. The model can be previewed in the course of animation execution. Thanks to this, errors caused by improper selection of the priority of model inputs and outputs can be eliminated and this may lead to the blockage of simulation even if correct data is entered. It also enables the analysis of the condition of material, i.e. whether it is transported or processed, or waits for transport or processing.

Materials & Methods

The following was performed during the simulation:
- an algorithm of conduct for the construction of a simulation model has been developed based on literature analysis and author's research,
- graphic models for research experiments using the technology proposed by the Industry 4.0 concept have been built based on the actual empirical data from the rolling process, with the use of simulation methods, in order to reduce the production cost of the final product depending on the executed rolling scheme,
- after model construction, the results of these experiments and their conformity with actual data from industrial conditions have been evaluated.

The scheme of simulation involved simulation of the functioning of a production system whose structure and attributes correspond to the structure and attributes of the real system. Simulations are performed on production equipment and assemblies possessed by the mill, starting from the furnace through preliminary and finishing roller assembly, to coiling machines. Data for the model construction was generated in accordance with the technical specification of individual equipment with which the mill is equipped. The graph is given in Figure 1 and Table 1 which present historical data regarding the period of random fifty rolling campaigns in the mill during the period from 2018 to

2020. This data provides key information on the quantity and type of ingots as an entry buffer for a given model.
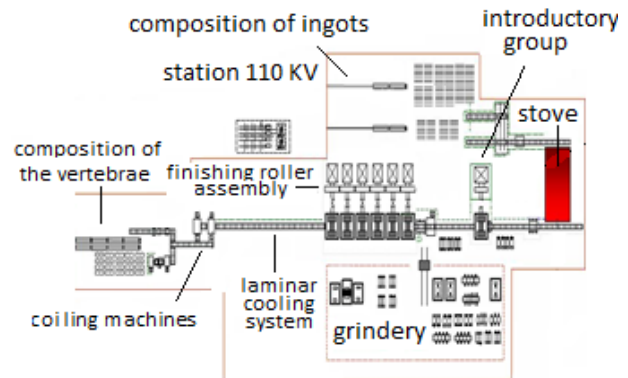

Fig. 1. Arrangement diagram for hot strip mills
$L = 2100$ mm

Table 1
Example of a rolling mill campaign

No.	Campaign no.	Number of ingots
0	1	3
1	1	3
2	2	2
3	2	2
. . .	. . .	. . .
1450	123	6

Each element entering the system has a number of parameters that determine its further flow in the system. These parameters are:
- campaign number: this is the consecutive number of the campaign from the list of historical data, at the same time it determines the type of object entered into the system,
- order number: this is a unique order number submitted by the customer,
- number of ingots: a parameter which determines how many ingots are made within the current order / rolling campaign.

The creation of the model required the collection of parameters concerning the total material flow based on Industry 4.0 tools, starting from the flat ingot storage facility to the finished goods warehouse. The following data had to be collected to model the individual devices:
- warehouses and landfills – capacity, size, transport equipment and its parameters, work history,

- transport equipment – paths of loading and unloading routes, loading and unloading times, minimum and maximum speeds, equipment dimensions,
- production facilities – times of materials passing through the plant, conversion times, process times for individual materials,
- material – types and dimensions of materials, material weight, assortment,
- planned repairs and failures of production and transport equipment.

The following characteristics of technological and transport devices were assumed as the input parameters for the analysis (Wyrzykowski, 2020):

1. Composition of ingots:
   - storage capacity: 40,000 Mg.
   - number of cranes: 5,
     - bridge travel speed mv = 0.7–1.5 m/s,
     - transport path distance L = 6 m,
   - dimensions of ingots: 220–250 × 700–2100 × 6000–11000 mm,
     - the mass of ingots: 35 Mg.
2. Walking beam furnace:
   - ingots heat treatment time: 180 minutes,
   - furnace efficiency: 450 mg/h,
   - ingots unloading maximum temperature: 1250°C.
3. Descaling agent:
   - roller table speed: 0–1 m/s,
   - transport path distance l = 2 m.
4. Initial cage:
   - rolling speed: 0–6.5 m/s,
   - total length of strip: 90 m,
   - number of roll passes: 7,
   - transport path length: l = 20 m.
5. Drum shear:
   - cutting speed: 0.35–1.50 m/s,
   - transport path length: l = 72 m.
6. Finishing cage assembly:
   - rolling speed: 20.40 m/s,
   - transport path length: l = 12 m.
7. Laminar cooling system:
   - transport path length: L = 112.5 m,
   - cooling system roller table speed: 0.4 m/s.
8. Coilers:
   - coiling speed: 21.76 m/s,
   - transport path length: L = 8 m.
9. Coils warehouse:
   - storage capacity: 2000 Mg,
   - number of cranes: 2,
     - bridge travel speed mv = 0.7–1.5 m/s,
     - transport path distance L = 15 m.

The following assumptions were adopted to create the model, collected with the use of tools based on technology according to the Industry 4.0 concept:

- The rolling mill operates on a 24/24 basis;
- On the basis of the technological tests carried out, it was established that in order to obtain the correct rolling temperature of 1250°C, the charge in the walking beam furnace is on average 180 minutes, instead of the actual 220 minutes;
- In cages 5 and 6 of the finishing assembly, the currently operating high chromium cast iron rollers were replaced by other rollers made of a new generation of high speed steel, which showed higher strength parameters in metallurgical research;
- The use of changed rollers increases the productivity of the rolling mill, so that the mandatory conversion of rollers takes place not after every finished campaign, but after seven completed rolling campaigns;
- Rolling is continuous – there are no downtimes due to the lack of orders;
- The number of equipment failures caused by the breakage of the rollers, which cause an obligatory stoppage of the mill, has been reduced;
- The batch ingots for all campaigns are delivered to the warehouse at the start of the simulation (taking into account the maximum storage capacity).

Other technological and transport parameters reflect the actual industrial conditions prevailing in the analysed mill (Niekurzak & Kubińska-Jabcoń, 2014):

- The structure of the identified real object is reflected in the simulation model,
- The parameters of the transport equipment correspond to the devices in the actual subsystem,
- The length of transport paths corresponds to the actual dimensions of the paths,
- The relations between the entry and exit of the real object and the computer model are identical,
- The quantity and processing times of materials of the actual object are consistent with the data provided in the model,
- The characteristic parameters of the production units are consistent with the actual data of the equipment in the rolling mill system,
- The operating parameters of the devices entered into the model are identical in value to those of the devices in the real object.

These assumptions are reflected in the model of the hot-rolled steel strip rolling system, shown in Fig. 2, made in the Dosimis-3 graphic simulator.
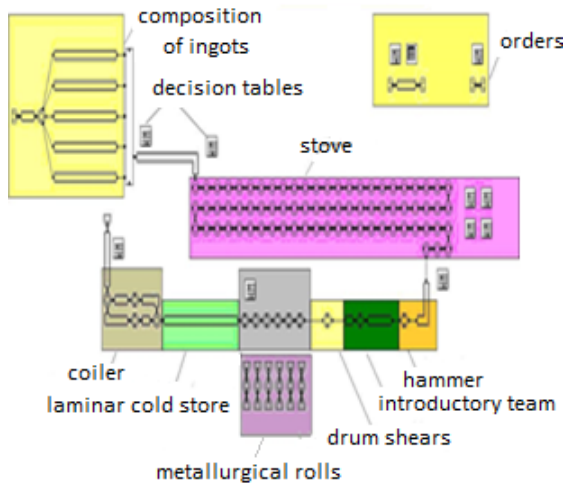
Fig. 2. Logistic system model for a steel strip rolling mill

Results

The following three indicators were taken into account as simulation results for the analysed cases:

- The time the steel strip remains in the system, i.e. the time counted from taking ingots from the warehouse to the final completion of the rolling process, i.e. rolling the strip into a coil and putting it back to the warehouse storage. This indicator is intended to provide key information on how the assumptions made in the model will affect the time of execution of given orders,
- The time the ingot stays in the furnace, which is counted from the entry of ingots into the furnace chamber to the exit to rolling table for the rolling process. This indicator aims to identify bottlenecks in the system,

- The times of roll conversions after a rolling campaign, which is counted from the moment the last strip from a given campaign is rolled into a coil until the roll conversions are completed. It is aimed at verifying the correctness of realization of the assumed assumptions for a given model.

The results of the simulation according to the assumptions made in a given hot-rolled steel strip mill are shown in Figures 3–5.
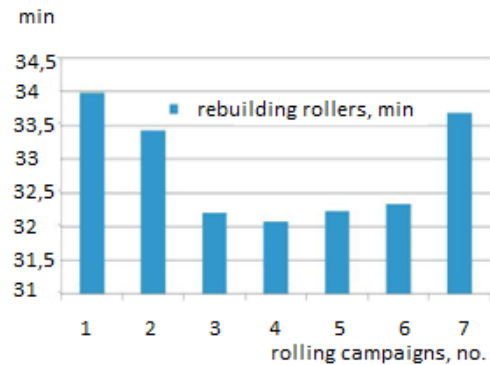

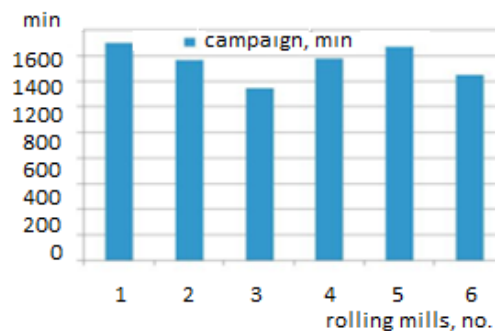Fig. 4. Times of rollers conversion after rolling campaigns

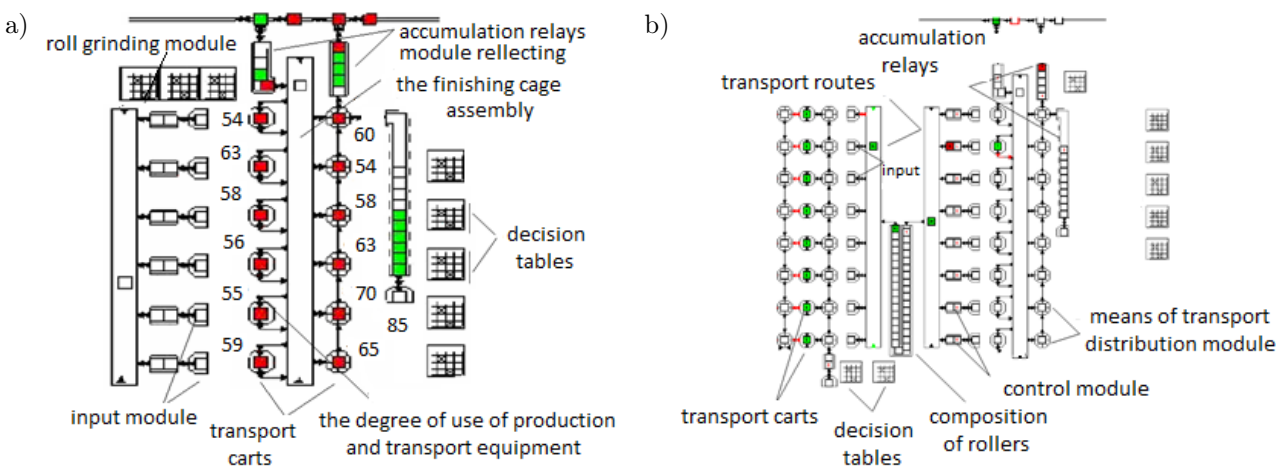Fig. 5. Durations of individual rolling campaigns

Fig. 3. Average occupancy of one of the subsystem elements a–b

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Discussion

The use of simulation techniques with the available technology of Industry 4.0 allows for a precise recognition of the relationship between individual technological and transport equipment. This makes it easier to properly identify the production system. The improvements made to the model on the basis of the industrial research carried out and with the use of process simulation techniques, allowed, according to the adopted assumptions, to obtain, among others, the following production system improvements:

- The use of production assemblies on the basis of the assumed assumptions is 100% for production at the level of 2.4 million Mg/year.
- The rolling campaigns were carried out in a rhythmic manner, i.e. during the simulation, there was no blocking of the furnace by the charge waiting in the equalisation zone for the rolling process. Thanks to this solution, the rolling mill: avoids unproductive furnace operation, the batch has the desired rolling temperature at all times, so it is ready for the production process at any time, using the correct furnace capacity, the rolling mill reduces the cost of the final product manufacturing.
- The use of rollers with greater durability in the finishing unit causes, among others:
  - the increase in the rolling capacity about 12%,
  - the reduction of the time the charge stays in the furnace about 9%,
  - the reduction of the time it takes to convert the rollers about 8%,
  - the reduction of the duration of a single rolling campaign about 10%,
  - the reduction of the duration of the entire technological process about 14%.
- The continuous six-clamp unit of rolling mills has a decisive influence on the occupancy of all the devices used. The rolling time is so long that, with the low cost of the means of transport, it blocks these means.
- As can be seen from the analysis performed, the times they draw are drawn from a visit in the past, repair the old database by 330 minutes. It is connected with the work on the design of the final product production by the department. Increasing, predicted gases by 3,093.75 GJ and electricity about 227 700 kWh in the analysed 2-month research period.
- The average duration of a single rolling campaign with the actual technological assumptions pre-vailing in a given rolling mill and with the use of production aggregates at the level of 63% is approximately 28 hours.
- The implementation of 50 campaigns for the actual rolling process showed that the total process of their implementation lasted 1352 hours 4 minutes. During this time, 608,400 Mg of strip was rolled, consuming about 760,500 GJ of gas and 55,972,800 kWh of electricity.

The assessment of the model adequacy was based on the comparison of indicators and parameters obtained during the conducted research and simulation with indicators and parameters that could be determined as a result of identifying the real object. The aim of the results compared during the verification tests was to determine:

- the influence of the parameters of the production units on the rolling mill downtime,
- the rolling mill's production capacity,
- the degree of utilisation of production facilities,
- the average duration of production equipment cycles,
- the average times of the production task, etc.

Conclusions

Analysis and simulation of material flow performed in the work in a hot-rolled steel strip mill, allow the following conclusions to be drawn:

- Modelling and simulation of production processes using the Dosimis-3 package with which it is possible to analyse in just a few minutes and trace the functioning of a selected object (station, operation, procedure, action, transport, warehouse stock, disturbances, etc.) for the period of even several years. This allows for the verification of the assumptions formulated before their practical application and for defining irregularities which may appear during use.
- The existing transport system in the rolling mill is designed with a large excess of implementation possibilities, which results in incomplete use of means of transport, at the level of 33%.
- As a result of the simulation, it was found that the load of the production unit is 97%. The percentage occupancy also increased for trolleys transporting tools, i.e. metallurgical rolls. Comparing the simulation values without taking into account the time for the delivery of tools, an improvement in the use of the effective working time of the production unit can be noticed from the initial 63.4% to 84.7%.

- Comparison of the simulation model with the real model shows a clear improvement in the technological process, in which there were, among others: reduction of the ingots' residence time in the furnace, reduction of roll reconstruction times, reduction of the duration of a single rolling campaign, reduction of the ingot residence time throughout the entire process technological.
- The result of this improvement is the total reduction of the implementation time of 50 considered rolling campaigns by an average of 25 hours and 38 minutes, thanks to which, among others:
  - the rolling mill efficiency increased by an average of 11 700 Mg of strips,
  - there has been a significant reduction in the production costs of the final product by saving 14,625 GJ of gas and 1076,400 kWh of electricity,
  - with optimization assumptions, technological units fully use (100%) their production capacity,
  - the quality and technological conditions of the obtained tape have not changed.
- The implementation of 50-rolling campaigns with the applied improvements in the production system was shortened from the actual 58 to 52 days, which in the scale of the full year gives the profit of an additional 38 days. During this time, you can:
  - fulfill orders from additionally obtained 36 rolling campaigns,
  - efficiently and economically optimize the storage area and load of individual production units, warehouses for finished products and semi-finished products,
  - use the obtained additional days for repairs and maintenance of production units, without reducing their productivity,
  - savings from utilities can be used to modernize the plant or laboratory tests that will improve the quality of the steel strip obtained, contributing to increasing the plant's position on the market of steel products, etc.

The basic relationships between the elements of the hot-rolled steel strip system result from the material flow process and the timing of the logistics task. System simulation modeling integrated with management processes facilitates and helps to optimize decisions made, thus contributing to better use of resources in the enterprise and increasing the efficiency of the entire system or a selected process.

The model proposed in the paper may be helpful in controlling the flow of materials in a given rolling mill in order to optimally use the production equipment and transport, as well as to determine the time of order fulfillment and the production costs of the finished product. The use of the Dosimis-3 simulator makes it possible to evaluate the use of the existing means of transport and production units, which may be useful in a possible modernization of the subsystem. A similar solution can be transferred to other production plants, taking into account their technical specifications of the machine park.

In the future, work on the Industry 4.0 concept should focus on further operational aspects of the elements of production systems and monitoring of their efficiency in all characteristic areas: agile production, interaction of executive systems, modularity, ease of programming, and safe use.

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