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EVALUATION OF ENGINEERING SOLUTIONS IN THE DEVELOPMENT OF THE PROCUREMENT SECTION FOR THE METAL CONSTRUCTION WORKSHOP

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Abstract. *Modern complex production requires approaches to improving production systems that create a comprehensive understanding of process-equipment-product interactions along the technological process chain, rather than focusing solely on individual processes. Any production system consists of separate but interconnected elements arranged in a certain sequence: reserve, workstation, operation workstation, working process. This document proposes an approach to support and improve the production system using these elements and establishing connections between them and their parameters. This allows process models of various complexities to be constructed, laying the groundwork for improving the production system. The article discusses the process of building a simulation model of a production system – a machining department for manufacturing semi-finished products from metal rods. In the model, each element of the production system is graphically represented, allowing the use of a flowchart for simulation modeling. The purpose of developing the simulation model is to optimize the operation of the machining department by identifying those workstations in the technological process where the longest idle time is observed during operations and optimizing the structure of the department. Additionally, this approach has been tested and implemented based on the scenario of using the simulation model in mechanical engineering production.*

Keywords: simulation modeling, production process, machine-building enterprises, downtime

OCENA ROZWIĄZAŃ INŻYNIERSKICH W ROZWOJU DZIAŁU ZAKUPÓW DLA WARSZTATU KONSTRUKCJI METALOWYCH

Streszczenie. *Nowoczesna złożona produkcja wymaga takiego podejścia do doskonalenia systemów produkcyjnych, które tworzy holistyczne spojrzenie i zrozumienie interakcji proces-urządzenie-produkt w łańcuchu technologicznym procesu, zamiast skupiać się wyłącznie na poszczególnych procesach. Każdy system produkcyjny składa się z oddzielnych, ale połączonych ze sobą pewną sekwencją elementów: rezerwy, miejsca pracy, funkcjonowanie miejsca pracy, proces pracy. W artykule zaproponowano podejście do utrzymania i doskonalenia systemu produkcyjnego z wykorzystaniem tych elementów oraz ustalenia zależności pomiędzy nimi a ich parametrami. Pozwala to na konstruowanie modeli procesów o różnej złożoności, tworząc podstawy do doskonalenia systemu produkcyjnego. Rozpatrzono proces budowy modelu symulacyjnego systemu produkcyjnego – miejsca zaopatrzenia w produkcję półproduktów z prętów metalowych. W modelu każdy element systemu produkcyjnego jest reprezentowany graficznie, co pozwala na wykorzystanie schematu blokowego do modelowania symulacyjnego. Celem opracowania modelu symulacyjnego jest optymalizacja działania wydziału obróbki skrawaniem poprzez identyfikację tych stanowisk pracy w procesie technologicznym, na których obserwuje się najdłuższy czas przestoju podczas operacji oraz optymalizację struktury wydziału. Dodatkowo podejście to zostało przetestowane i wdrożone w oparciu o scenariusz wykorzystania modelu symulacyjnego w produkcji inżynierii mechanicznej.*

Słowa kluczowe: modelowanie symulacyjne, proces produkcyjny, przedsiębiorstwa produkujące maszyny, przestoje

Introduction

As of today, simulation modeling is one of the effective methods for studying production systems. It is often used for developing projects to reconstruct enterprises by optimizing the schemes of their material flows, arranging warehouses in departments, as well as for optimizing the operation of technological equipment. The essence of simulation modeling lies in reproducing, using computers, the operation process of a production system over time, taking into account its interaction with the external environment [1, 11]. An interesting approach is discussed in materials [2], where the authors examine and then analyze the impact of workers on the productivity of the production line.

Another interesting researchis the research of Pawel Pawlewski [7] who proposes to use PFEP (Plan for Every Part) to automate the designing of production systems simulation models.

Modern simulation modeling allows determining the optimal type of technological line by identifying the best flow throughput and the amount of required equipment. This enables determining the most efficient production type for manufacturing products and factors influencing the final quality indicators of the product [3, 9, 10]. The article describes the development and verification of a digital twin of the workshop section for manufacturing metal structures.

Digital twins of workshop sections in metal structure manufacturing can significantly streamline the management and optimization of production processes, reducing costs on experiments and testing new strategies directly on the real system.

To achieve this aim, the following tasks were set:

1. Data collection. Gathering information about the real workshop section of the factory, including equipment parameters and its placement, technological processes in the workshop, and technological parameters.
2. Description of the model ontology necessary to transform any production system into a virtual representation. This ensures a structured data model for further creating a digital twin [8].
3. Building a virtual representation of the workshop section on the computer using the AnyLogic software environment, which includes modeling the premises with equipment installed, material flows, and work processes.
4. Developing strategies and improving the production system to achieve better productivity and efficiency by using the digital twin to implement various scenarios, as well as changing process parameters and equipment placement.

The article discusses issues related to the methodology of preparing models of objects in the production system for conducting simulation modeling. The subject of the study is the digital twin of the production system for manufacturing semi-finished metal rod products. The aim of the study is to create a simulation model of production, specifically the machining department of the metal structures manufacturing workshop, which can be used for analysis, improvement, and optimization of production processes without the need for direct intervention in the real system.

1. Materials and methods

Description of the model ontology. The purpose of developing the simulation model is to identify workstations in the technological process where the longest idle time is observed during operations. Additionally, it is necessary to determine how long workers will produce a specified quantity of semi-finished products in order to establish production delivery deadlines [6].

Analysis of the manufacturing process of semi-finished products by metal rods cutting.

The object of study is the process of manufacturing semi-finished products by cutting rods from different types of metal, which takes place in the procurement section for the metal structures manufacturing factory. The purpose of modeling was to identify workplaces in the technological process, where there is the greatest time spent on downtime in the execution of operations. In addition, it was necessary to determine how long workers will produce the specified number of semi-finished products to understand the timing of products delivery.

In the process of semi-finished products manufacturing, most of the operations are performed by two workers and two machines, that is, semi-automatic, when unloading oversized cargo, a beam crane is involved.

The process of cutting rods from various metals (type G, D, P) (figure 1) in the production of metal structures includes the following operations:

- Operation of delivery of metal rods in packages to the warehouse and their unloading by the worker with a beam crane.
- Operation of placing packages of rods from different types of metal in a corresponding rack cells in the warehouse.
- Search for rods from the required type of metal on racks by worker.
- Setting the machine on a rod cutting from the required type of metal.
- Cutting rods from a certain type of metal.
- Sorting semi-finished products and moving them for further storage.

Fig. 1. A sample of rods from which semi-finished products are made

During the work shift, in the workshop there are 2 workers, who work on the metal cutting machines, and 2 workers who work with unloading packages of metal rods during their delivery. Each of the rod cutting machines processes a certain type of metal.

The operation of delivery of rods packages to the warehouse is carried out under the following conditions:

- Metal for semi-finished products is delivered to the workshop in packs (packages), each of which contains from 100 to 360 metal rods. The number of rods in the package depends on the type of metal.
- For the manufacturing of semi-finished products, 3 different types of metal D, G, P are used.
- The length of the metal rod is 6 m.

For the operation of metal unloading using a beam crane, the timing of unloading was considered in accordance with the data provided from production. The average value of time spent for this operation was calculated. The unloading operation takes in average 28 minutes, if to fill all cells of the rack in the warehouse.

The operation of moving the rod packages to the warehouse and placing them in a certain rack cell must consider the zoning conditions. That is, packs of rods with a certain type of metal (D, G, P) are placed in cells that are closer to the cutting machine on which the rods of this metal type are processed.

The operation of finding rods of the necessary metal by the worker is the most difficult, because it should include several conditions. Depending on the invoice documentation, the worker should look for metal on the rack and in the pieces of semi-finished products. Accordingly, to fulfill each condition, the worker spends a different amount of time.

Parameters considered in the model:

1. Time: The primary parameter for the simulation model. Determined at each of the operations described above.
2. Different types of metal (types G, D, P).
3. Quantity of raw materials delivered in batches and semi-finished products manufactured.
4. Number of machines and workers.

Additionally, the simulation environment replicates the real dimensions of the premises, machines, and metal rods.

2. Results

Simulation model development.

The performed analysis of the production of semi-finished products allowed to develop a schematic model of the section for cutting metal rods. The created model includes 2 units of equipment on the pre-cutting procurement section, as well as their connection with the open warehouse (figure 2). The simulation model was developed in the AnyLogic software environment [5]. First of all, a plan of the rooms with work areas, racks and ways of workers movement has been developed. The virtual markup of space was applied, where zones of the basic operations performance for the metal rods cutting process, racks placement zones, trajectories of workers movement in the shop were highlighted.

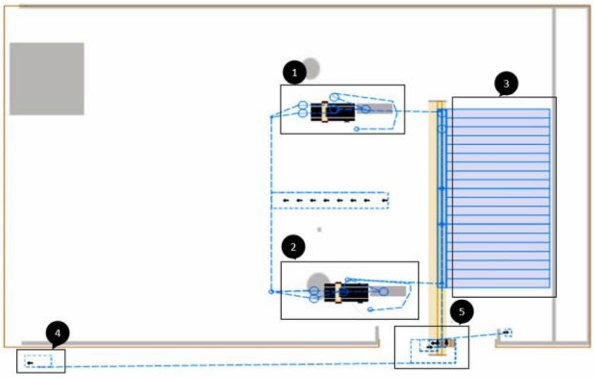

Fig. 2. Plan of the cutting metal rods section: 1, 2 – the metal cutting machines, 3 – rack, 4 – raw material delivery operation, 5 – raw material unloading operation, - - - – route of movement of equipment and workers

As initial data, we used the design data for one of the offered variants for the preparing production organization, namely a section for rods cutting for which statistical data on work of the technological equipment for rods cutting are selected. The creation of the section model was performed with the following requirements:

- Opportunities for step by step modernization.
- Preservation in the process of modernization of individual units of equipment for cutting rods.

The next step, after the virtual mark up, in the development of the simulation model is to create agents which will specify the rod metal type, its properties and quantity in the general package. Since there is provided cutting of three types of metal on the factory, respectively, these three types will be represented by three different agents in the model. In the window of the agent creating for each of three types of metal rods, the parameter has been generated to specify the number of rods in the package (figure 3).

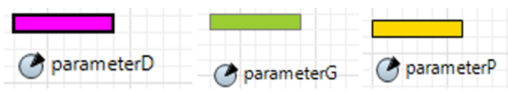

Fig. 3. Agents` model creation

According to the input parameters of the model, the parameters (parameter D, parameter G, parameter P) are responsible for the number of metal units in one package of a certain metal type. For metal type D parameter D will be 100 units, for metal type P parameter P will be 200 units, for metal type G parameter G will be 360 units. In the future, this parameter will indicate the rest of raw materials in the warehouse.

To fulfill the condition of placing each type of metal in its cell rack in the warehouse, we decided to divide the process diagrams. Thus, each type of metal has its own process diagram. In the future, this will simplify the writing of model scripts for each type of metal and will allow to add new types of metal to the model. In addition, the division of process diagrams by the metal type is due to their different input parameters and properties. In particular, such an important parameter as the search for metal by a worker on a rack, for each type of metal (P, G, D), has a different range of values.

The process diagram begins with a *Raw* agent that simulates the appearance of a metal package on a pallet in the unloading area [4]. To avoid collisions in the *Raw* agent settings, the arrival time of the agents is set for each type of metal. The number of arrivals simulates the number of packages of each type of metal.

Table 1. The Raw Agent Settings

Type of metal	Time between deliveries (seconds)	Time of the first delivery (seconds)	Deliveries quantity
Raw G	150	60	7
Raw P	250	150	7
Raw D	300	250	4

The next *Queue* agent simulates the queue formed when unloading metal packages. Next in the process diagram is a block that simulates the process of unloading a pallet with rods using a beam crane. From the pallet, the package of metal is being hanged to the crane hook and fixed. This operation is performed with the help of a worker and a crane. In the process diagram, this operation is performed by the *pickup agent*. The average execution time of this operation, according to the timing, is 4 seconds. After fixing the metal package, the crane transports it to the rack for storage. This operation is performed by the *moveByCrane* agent. The average execution time of this operation, according to the timing is 1.2 minutes. In the *moveByCrane* agent property settings, the pickup time and the drop-off time of the package should be specified. On average, it takes 1.5 seconds. The operation of dropping off the metal packaging by the crane is simulated by the *dropoff* agent.

The diagram of the process of arrival and unloading of metal rod packages is shown in figure 4.

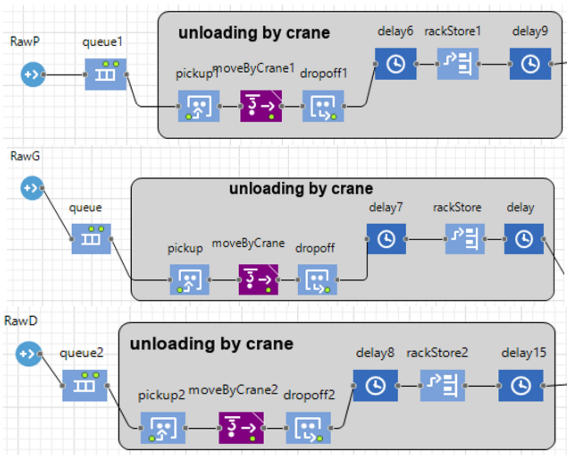

Fig. 4. The diagram of the process of arrival and unloading of metal (P, G, D)

The next operation performed in the process diagram is the placement of the metal package in the required rack cell. One of the conditions for designing the "rack" unit was a clear zone of metal placement. As there are two metal-cutting machines in the shop and they are placed parallel to each other, it was necessary to place a certain metal type closer to the machine that processes it. We decided to create a system of racks for each type of metal. Thus, 4 racks work in the system. This simplified the task of placing the metal. The process of storing metal on the rack simulates the agent *rackStore.*

The next operation, according to the scheme on picture 1, there is a search for the workpices of necessary metal type by the worker on the rack or in pieces of semi-finished products.

This is the most difficult element for simulation because it includes several possible scenarios for the model. The parameters that affect the course of the model script are:

- Metal type.
- Quantity of the rods needed for production of semi-finished material.
- Physically, a worker can only take 2 rods at a time.

Depending on the rod metal type and the amount that needs to be processed, the worker may spend different amounts of time. To do this, the agents flow was divided in the process diagram for each of the three metal types. Depending on the number of rods that the worker takes from the rack, he spends a different amount of time. Because, under condition: "find and pick up 8 rods", the worker must go to the rack 4 times and spend more time on it, which in turn will affect the time of the products batch manufacture.

In the process diagram, this situation is simulated by the *selectOutput* agent, which divides the agents flow into several, depending on the number of rods that the worker needs to take. Thus, the model considers the different probabilities of the scenario. The operation of finding and collecting metal is shown in figure 5.

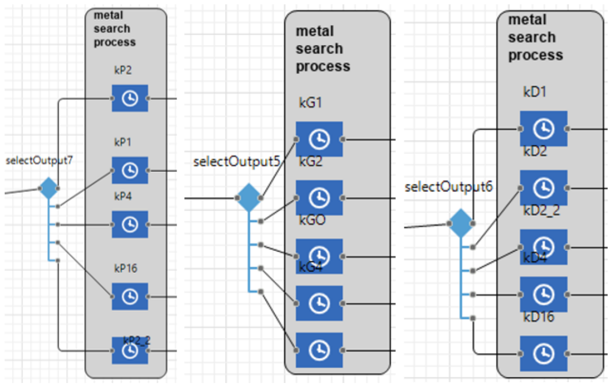

Fig. 5. Part of the diagram for metal search process (P,G,D)

Table 2 shows several scenarios that are executed in this simulation model.

Table 2. Scenarios for Rods Search

	Type of metal (G,P,D)	Quantity of metal rods needed	Time spent for search (seconds)
Worker 1	G	1	50-70
	G	2	50-70
	G	6	130-360
	G	8	200-250
Worker 2	D	1	50-70
	D	2	130-360
	D	6	200-250
	P	1	50-70
	P	2	100-300
	P	5	144-354
	P	8	300-350
	P	10	200-240

The next operation in the process diagram is the placement and adjustment of the metal workpiece on the machine. In the process diagram, this operation is simulated by agents *nG1*, *nG2*, *nG6*, *nG8*, which are responsible for the number of rods. Accordingly, for each agent *nGn* the setting time will be different, it ranges from 14 to 234 seconds and depends on the number of rods.

After adjustment the worker carries out rods cutting. This operation is simulated by agents *rG1*, *rG2*, *rG6*, *rG8*. The time that a worker spends for metal rods cutting ranges from 1 to 24 seconds. This time is the same for all types of metal rods. During cutting on the process diagram, new agents are created, which in further simulate the finished semi-finished products and off cuts.

According to the timing table of the cutting operation from a certain number of rods, the specified number of semi-finished products and segments can be got. Simulation of the operation of creating a new quantity of semi-finished products is performed by agents *splitG_1*, *splitG_2*, *splitG_4*, *splitG_6*, *splitG_8*, *splitG_36*, *splitG_48*.

After cutting the worker sorts the obtained semi-finished products and cutoffs. In its turn, the cutoffs can be reused for semi-finished products manufacture (figure 6).

This is considered in the model and is singled out to the separate Cutting operation. The end of the technological cycle is the sorting of semi-finished products and their placement in special carts for further transportation to other shops.

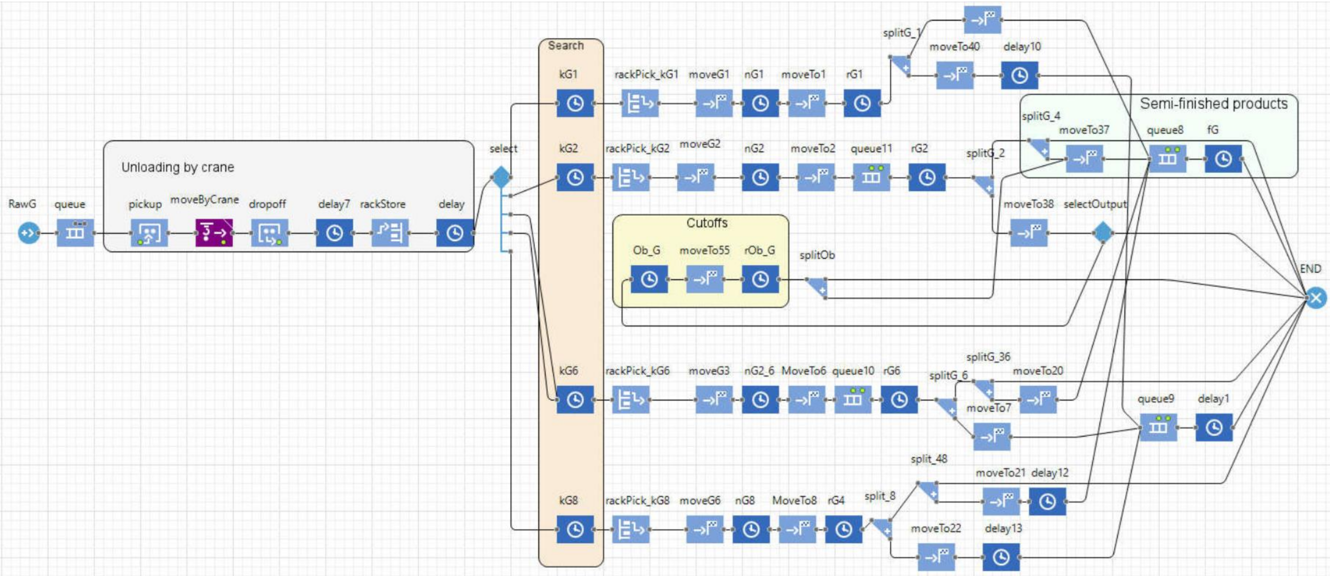

Fig. 6. The part of process diagram for G metal type rods cutting

3. Discussion

The created model supports the adjustment of the following parameters:

- Model time period.
- Distribution of rod lengths.
- Distribution by material types of rods.
- Operating modes of equipment for cutting rods.
- Duration of transport operations in connection with the warehouse.
- Number of staff.

The duration of the experiment is 31254 seconds (520 min). Initial parameters entered:

Rods quantity in the package:

- Metal type G – 360 pieces.
- Metal type D – 100 pieces.
- Metal type P – 200 pieces.

The number of rods that each of the workers takes from the rack for cutting:

- Metal type G – 33 pieces.
- Metal type D – 15 pieces.
- Metal type P – 33 pieces.

To develop the model, several values of time spent on a single operation were selected. According to the results of timing of operations in production conditions, it was found that for each operation the execution time is different, and the most time-consuming operation is the search for metal on the rack, the least time consuming – a rod cutting (one cutting takes 2–5 s.). The metal rodtype does not affect the time of the operation. But the number of rods that a worker needs to produce semi-finished products affects, that is when searching or cutting 10 rods, time will be spent more than for one rod.

When analyzing the unloading operation with the help of a crane, the model considered the time during which the entire rack will be filled with rolled metal, which is about 28 minutes. That is, the model was set the condition of filling the entire rack. At this total time, it was included the hanging of each package with rods to the hook of the beam crane by workers (according to the production data it takes 2-3 minutes) and replacement of the package by the crane to the rack cell. If to specify smaller number of packages in the input parameters, the unloading time will be reduced accordingly. The diagram shows the maximum, average and minimum time spent on unloading for 1 package of metal.

The operation of searching metal on the rack is characterized by the fact that the worker can physically take 1 time 2 rods from the metal package. The package, depending on the type of metal can contain 360, 100, 200 rods, which are then cut by the worker. The process diagram in the model identifies several scenarios, according to the number of rods that a worker needs to take to perform his task. It can take 1, 2, 6, 8, 10 rods (the table shows the time spent by the worker to find and select rods). That is, if the worker must take 6 rods then he needs to go to a rack 3 times that accordingly will increase expenses of time which will be defined as 615 second. The diagram in figure 6 shows the maximum, average and minimum time for which the worker finds the rods. The search time is specified for one approach of the worker to the rack. Accordingly, to find 10 rods, the time will be maximum (1800 second).

The cutting operation, depending on the number of rods, can last from 5 to 35 seconds. Cutting of one rod is 2–5 s. The worker can also cut 2 rods at the same time.

The simulation results: in 31254 seconds (520 min) – 2 workers produced:

- Semi-finished products from metal G – 207 pieces.
- Semi-finished products from metal D – 40 pieces.
- Semi-finished products from metal P – 156 pieces.
- Cutoffs 5 pcs.

The time spent on each operation is shown in the figure 7.

To work with the model in the simulation environment AnyLogic, the graphical interface was developed that allows to the user to track the workload of production equipment for cutting rods during the experiment, to adjust the basic parameters and modes of operation area (figure 8).

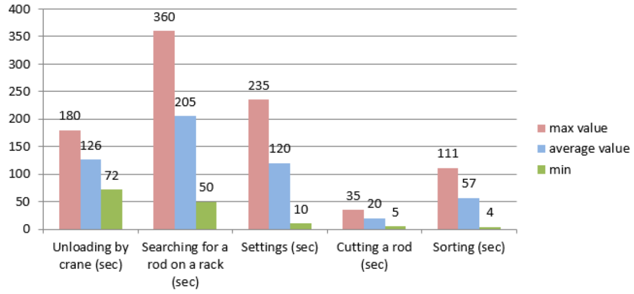

Fig. 7. The time spending for operations of the manufacturing process of semi-finished products

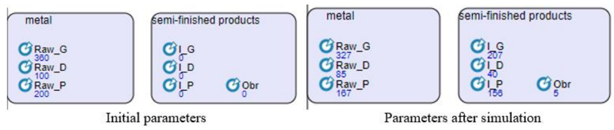

Fig. 8. Simulation modeling parameters

4. Conclusions

The proposed approach to improving the real production system involved combining modern simulation modeling concepts with planning and operational procedures in manufacturing systems in the machinery production industry. In the developed simulation model of the machining production department, the values of production parameters can be determined, which, under traditional approaches, are determined only by simplified methods of direct calculation using normative and design documentation and without considering various types of disturbances. The application of the simulation model allows for increased accuracy in determining the production parameters of the department because, on the one hand, all previously collected statistical data and engineering expertise are used, and on the other hand, all changes in the project are promptly taken into account, and new project execution options are worked out.

In addition, the model allows integrating various solution modules of department elements to support the overall quality of the production system for manufacturing metal structures. A digital twin of the metal cutting workshop has been developed in the AnyLogic software environment. The model consists of process diagrams, virtual layout of space replicated according to the real dimensions of the workshop, and 3D visualization of the production process.

Applying the concept of a digital twin in the example of metal fabrication has demonstrated that the developed simulation model and corresponding workshop structure can improve the existing production system. Through modeling, the following findings were established:

1. Operations in the production process that consume the most time. Particularly, the longest delays occur during the search for metal rods of the required type on the racks. To overcome these delays, it is proposed to implement zoning of the racks and place colored markers on the ends of the racks corresponding to specific types of metal (figure 9 mark 1, 2).
2. The placement of machines in the workshop requires review. To reduce the time spent by workers on moving to the racks, the layout of the metal cutting machines in the workshop has been altered. This resulted in a 12% reduction in time expenditures.

Clearly, addressing efficiency improvement issues in production systems enhances the understanding of the production system. This is achieved through the integration of simulation-based approaches into existing production system management processes.

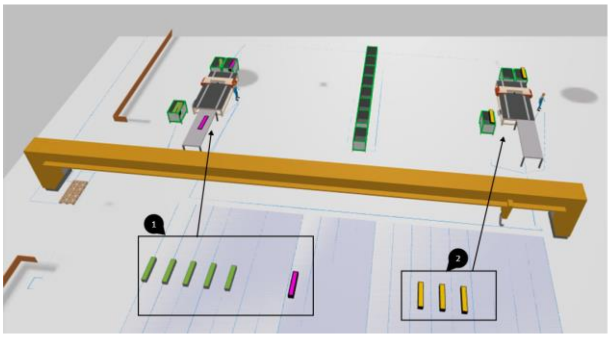

Fig. 9. Modernized planning of the procurement section for cutting rods

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