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Simulation of operations on the production line as a tool for making the production process more efficient

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Abstract: For a company to make a profit and satisfy customers' needs, it must have the correct individual processes - the production process is one of the most important. This paper proposes a solution to eliminate the problem based on identifying the cause of the blocking - idle times in several workplaces of the production line. Another goal was to determine whether increasing productivity and the number of products on the given line is possible. At the beginning of the research, a system analysis of production operations was carried out. A simulation was chosen as a tool for solving the goals. Tecnomatix Plant Simulation creates the simulation model. The model was verified by a simulation experiment that simulated the current state, and the data obtained by the analysis were used. The experiment was performed for three simulated times: 8, 16 and 48 hours. After the verification of the model, experiments were performed on the models. The paper presents the results of three experiments for a simulated time of 48 hours. Based on the experiments, it was found that in the case of shortening the work cycle at critical workplaces No.5 and No.15, it is possible to make the process more efficient - to equalise the workload of individual workplaces and increase production by 25%.

1 Introduction

The mission of the manufacturing company is to achieve the best possible profit results by eliminating losses. It is necessary to satisfy customers' needs to fulfil the requirements as best as possible. For a company to make a profit and satisfy customers' needs, it must have the correct individual processes - the production process is one of the most important. The production process comprises a series of activities of different natures (processing, transport, assembly, inspection) performed on different machines and devices. It ensures the material flow from the input to the end of the production process. Discrepancy between these activities and equipment can result in downtime. However, idle time can also be caused by other factors, such as in the case of lack of material but also the case of accumulation of material at the workplace. Compliance with these facilities and activities impacts labour productivity, product quality improvement, production process efficiency increase, cost reduction, and ultimately, customer satisfaction. Inconsistencies between these activities and equipment can result in idle time.

Productivity in the industry itself is efficiency. Efficiency refers to the resources needed to achieve the desired results. These essential sources include the time during the facility's production process and the amount of funds and energy expended [1].

This article's research subject is a production line consisting of several workplaces. This paper proposes a solution to eliminate the problem based on identifying the cause of the blocking - idle times in several workplaces of the production line. Another goal was to determine whether increasing productivity and the number of products on the given line is possible. Simulation was chosen as an auxiliary tool for solving the goals based on the analysis of the current state. Simulation modelling is an excellent tool for analysing and optimising dynamic processes.

A simulation tool has become widely used since the 1950s [2]. Simulation is a research method where we replace the object of study with a model. We experiment on the created model to accumulate information and statistics and use them in the real system [3].

Simulation on real process models aims to obtain information, one of today's most valuable sources. Simulation eliminates the need for surplus financial resources from interventions in the real system. The information thus obtained is used to evaluate and improve the modelled system [3,4]. Computer simulation methods, especially discrete event simulation (DES), are the most universal and are widely used. Currently, researchers use many simulation tools for computer simulation: ExtendSim [5], Tecnomatix Plant Simulation [6], Witness [7], FlexSim [8], ARENA [9], and more [10]. Computer simulation can be used successfully to solve problems in various fields.

The simulation was used by several authors in the solution of transport in deep and surface mining [11]. The authors [12] presented the simulation study as an efficient tool for the analysis times and costs of underground haulage systems (railway and vehicles) that are used in the mining processes with ARENA simulation software. The study of the authors [13] describes the possibility of modelling the disconnecting process of mining wagons in the program Tecnomatix Plant Simulation using the SimTalk program.

Simulation is often used in logistics solutions: transport, handling, storage, delivery of parcels, packaging, and more. The authors present the simulation model for assessing the effectiveness of implementing a goods delivery process [14]. Software Tecnomatix Plant Simulation, paired with a genetic algorithm, was used for simulation in shipment and sorting processes to determine the number of workers needed to speed up the departure of shipments and optimise the workload of workers [15].

Authors often present simulations of production plants, processes, and lines in their works. The case study [2] carried out in a medium-sized company aimed to take the first step towards sustainable production development, eliminate bottlenecks in production and shorten the production process. The means to verify and evaluate the proposed solution was a simulation in the ExtendSim. Authors often use Tecnomatix Plant Simulation (TPL) for simulation in this case. The authors' work [16] presents a TPL simulation model consisting of five modules representing individual parts of the operation. The main module represents a complete production plant and, thus, the simulation model as a whole. The sub-modules are divided into production lines, warehouse, intermediate storage and output. Using the above modules, the authors kept the simulation clear and provided the possibility of more accessible work with individual sections or their modifications. TPL was also used in the case study to create a simulation model of the production process and test the energy consumption of selected equipment with a proposal of measures to increase the company's OEE (the overall equipment efficiency) [1]. The authors' work presents a case study on creating a virtual environment and optimising the production–assembly process in the TPL software environment [17]. The streamlining utilisation of the assembly line using TPL software was dealt with by [6]. The minimising risks in the workplace using TPL was dealt with by [18], too. The authors' work presents an integration of 3D objects into the simulation as part of the material flow [19].

2 Methodology

The simulation of the selected logistics activity consists of several steps [5]. These steps have been extended. The basic steps are described in the following points and shown in Figure 1, used in this case:

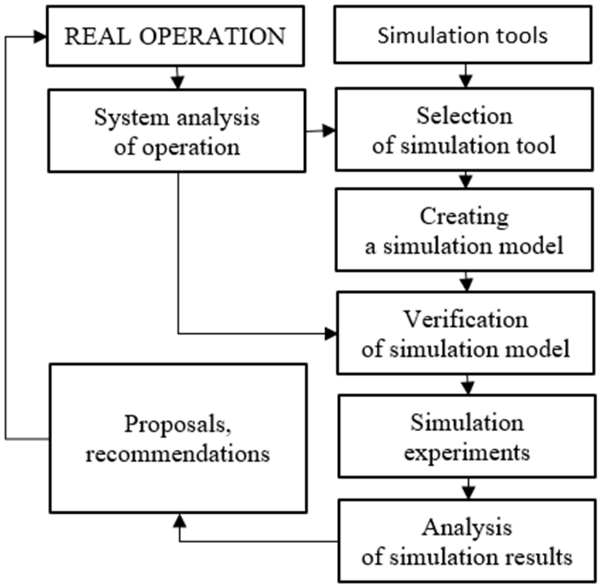

Figure 1 Steps of methodology

A: System analysis. System analysis is a suitable tool for analysing the state of the system. It examines its elements and the relationships and connections between them. Thanks to this, we can get to know the system's functioning in detail and derive individual results of observations and valuations from the research. This analytical method is used mainly in cases where we want to improve the given system or completely replace and create a new one [20,21]. The process of analysis represents the main activities: defining the problem of the production line, defining the elements and links of the production line and graphic representation, and collecting the necessary data - the observation method was used, and it is one of the time study methods and summary of findings including deficiencies. First, the observation method was used to observe the supply of the production line, individual operations, and the observation of operators. Subsequently, the method of time studies was used – “Operation snapshot” for each workplace. Operation snapshots are aimed at studying a work operation or a work cycle. To achieve reliable data, it is necessary to take the operation record several times to exclude random circumstances. The operation record is provided in several stages: preparation for monitoring and measurement, observation, measurement and recording of measured values, processing and analysis of named times - evaluation of the obtained data [22]. With the help of analysis of the system, we obtain data from operations: characteristics of the line, description of the activity on the production line, graphic representation of the sequence of activities on the production line, activity times, and definition of identified deficiencies.

B: Selection of a suitable simulation tool for creating a simulation model. Several simulation tools are currently available. Our workplace has several tools for simulating

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the problem: ExtendSIM10, Tecnomatix Plant Simulation, and taraVRbuilder. Their advantage is graphic symbolism, creation of statistics, 2D and 3D animation, and flexibility when changing the model and the input data.

C: Creating a simulation model of a real system by the chosen simulation tool. The construction of the simulation model is presented in the Results.

D: Verification of the created model based on values obtained from the operation.

E: Simulation experiments to eliminate the problem on the production line. Simulation of experiments, in which the input parameters of the simulation model are changed. The task of the experiments is to see changes in the output parameters of the system.

F: Analysis of simulation results. Outputs from individual experiments (statistical parameters, performance parameters and graphical outputs) are used for analysis and behaviour of the system under changed conditions. These results need to be interpreted and used correctly.

G: Proposals, recommendations to eliminate the problem.

3 Result and discussion

3.1 The results of the system analysis

The mentioned methodology was applied to improve the efficiency of the production line. The production process consists of several technological and assembly operations on the production line at different workplaces. The selected line consists of 15 workplaces, four fully automated. There is also one preparatory workplace on this line. There are 12 production operators on the line and one worker in charge of running and servicing all four automated workplaces. This line operates in two shifts thanks to the high demand for the product.

A counter is placed at each workplace of the production line, which shows how many pieces were produced at the workplace and how many pieces should be produced at the given time according to the standard. Each workplace is equipped with a computer on which the work process at a particular workplace is displayed.

Small materials, such as screws and gaskets used in production, are placed on the worktable in small crates. Aluminium parts are stored in large crates at the workplace. More extensive materials are stored in cardboard boxes on pallets or gitterboxes along the production line. Each position includes a conveyor belt along which the product moves and a lifting device to lift the product. Each workplace has a red crate, which is intended for non-conforming material [23,24].

The sequence of workplaces where individual operations are performed is shown in Figure 2.

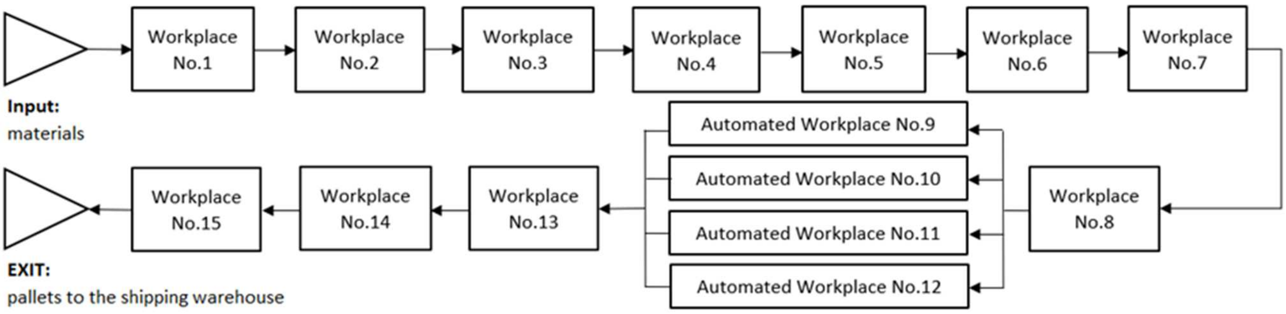

Figure 2 The sequence of workplaces

The production process on the line starts at workplace No.1 and ends at workplace No.14. The primary input material is the bare frame, on which other input materials are gradually mounted at individual workplaces. Each workplace is supplied with different input materials, except for production workplaces No. 9, No.10, No.11, and No.12, which are arranged in parallel. Here, automatic tests of manufactured products are carried out. The finished product is packed at workplace 15, loaded on a pallet and taken to the warehouse of finished products.

Assembly operations are carried out at workstations No.1 - No.7. Workplaces No.8 - No.12 are test workplaces. The assembly operation is carried out at workplace No.13, and the worker at this workplace also performs the preparatory operation for workplace No.14. At workplace No.14, the last assembly operation is performed, as well as the electrical test, which is used to check the electrical parts. Product production ends at this workplace. Workplace 15 is a packaging workplace, as mentioned above.

One of the tasks of the system analysis was:

- to observe the operation of the input material line,
- to observe individual operations on the production line,
- to record the operating times of individual operations,
- to record idle times and other irregularities,
- and, based on the observation, to define the identified deficiencies.

The analysis revealed:

- 11 input materials are used in the production of the product,

- workplaces are supplied along the marked route by a service vehicle approximately once every 40 minutes, i.e., 12 times in one shift,
- the length of work operations at workplaces No.1-No.4, No.6-No.8, No.13 and No.14 is 3 minutes and 20 seconds on average,
- the length of the work operation at workplace No.5 is 4 minutes,
- the length of the work operation at workplace No.15 is 4 minutes and 9 seconds,
- the length of work operations at workplaces No.9 - No.12 is 5 minutes, automated workplaces arranged in parallel,
- during one shift, an average of 96 pieces of finished products were produced on the production line,
- relocation of finished products from workplace No.15 is carried out using a forklift. 16 pieces of the finished product are placed on one pallet, pallets with products are transported to the output warehouse six times during one shift.

The analysis revealed the following deficiencies:
- during production, there were idle times of workers and accumulation of semi-finished products in front of workplaces No.5 and No.15 (difference in operating times),
- there were objects in the workplaces that were not necessary for the operation,
- the material and work aids used by the workers during production were not marked and did not have precise location or arrangement, the operator sometimes has to search for these aids and materials, and thus, the work cycle is extended,
- the work cycle also extends if an operator who was assigned to the workplace from another workplace works at the workplace.

Creating a digital model using simulation was possible based on the production line analysis.

3.2 *Selection of a suitable simulation tool*

The Tecnomatix Plant Simulation was chosen to simulate the production line. As mentioned above, we have three tools available at our workplace: ExtendSIM10, Tecnomatix Plant Simulation, and taraVRbuilder. We decided to use the Tecnomatix Plant Simulation tool from the available tools for two reasons. The first reason, we have experience in creating models in this tool, e.g., versus taraVRbuilder. The second reason is the easy-to-understand available 3D spatial visualisation and animation of material flow during simulation compared to the ExtendSIM10 tool. Based on this 3D spatial animation, it is possible to identify inconsistencies in the material flow quickly.

Tecnomatix Plant Simulation software enables the simulation, visualisation, analysis and optimisation of production systems and logistics processes. Using Plant Simulation enables optimisation of material flow, resource utilisation and logistics for all levels of plant planning, from global facilities and local plants to specific production lines. Tecnomatix Plant Simulation is object-oriented, hierarchical modelling based on dedicated object libraries for fast and efficient discrete and continuous process modelling. This software tool has many built-in tools and graphical outputs to assess production system performance, including automatic bottleneck detection, throughput analysis, etc.

3.3 *Simulation model*

The following chapter describes how to create a digital model. The simulation model (Figure 3) is created from blocks from the "Material Flow" library, the "Resources" library, the "Information Flow" library, the "User Interface" library and the "Tools" library. Blocks are interconnected using a "Connector".

The first block in the model is the "EventController", which starts, stops, resets and controls the speed of the simulation. It is the starting block without which the model cannot be run.

The input materials in this model are "Source" blocks in 11 pieces (11 input materials), representing the input material warehouse.

The central part of the model is the production line, which contains 15 workplaces. A conveyor belt transports material between individual workplaces comprising the "Conveyor" block. During the production process, the main (input) component is transported along the conveyor belt, where the required operations are gradually performed. Workplaces 1 to 8 and 13 to 14 form the "AssemblyStation" blocks, representing assembly operations (assembly of additional components into the main component). Workplaces 9 to 12 form the "ParallelStation" block. The "ParallelStation" block was used because no other parts are directly assembled at this workplace, but the product is automatically tested. These four workplaces are the same. Workplace 15 also consists of the "AssemblyStation" block, representing product packaging and storage on a pallet. At workplaces 1 to 8 and 13 to 15, a "Workplace" block represents a worker performing his activity. These workers are generated from the "WorkerPool" block and are managed using the "Broker" block. The supply of workplaces occurs along a marked route, represented by the "Track" block. A service vehicle follows this route. This vehicle will load the necessary material from the inbound warehouse. Loading is done using the "Method" block. The block is programmed where and under what conditions the material will be loaded. Next, the vehicle continues along the marked route to workplace No. 1, where it is unloaded using another "Method" block under certain conditions. The vehicle performs these actions at each workplace, and after completion, it returns to the input warehouse, where it starts its cycle again.

The "Chart" block in the model shows the percentage utilisation of individual workplaces. The "ShiftCalendar" block in the model serves to specify the working time of individual shifts. Workers' breaks during the work shift are also set in this block. The last part of the model is the output warehouse, to which the finished products from the packaging workplace No. 15 are moved using a forklift.

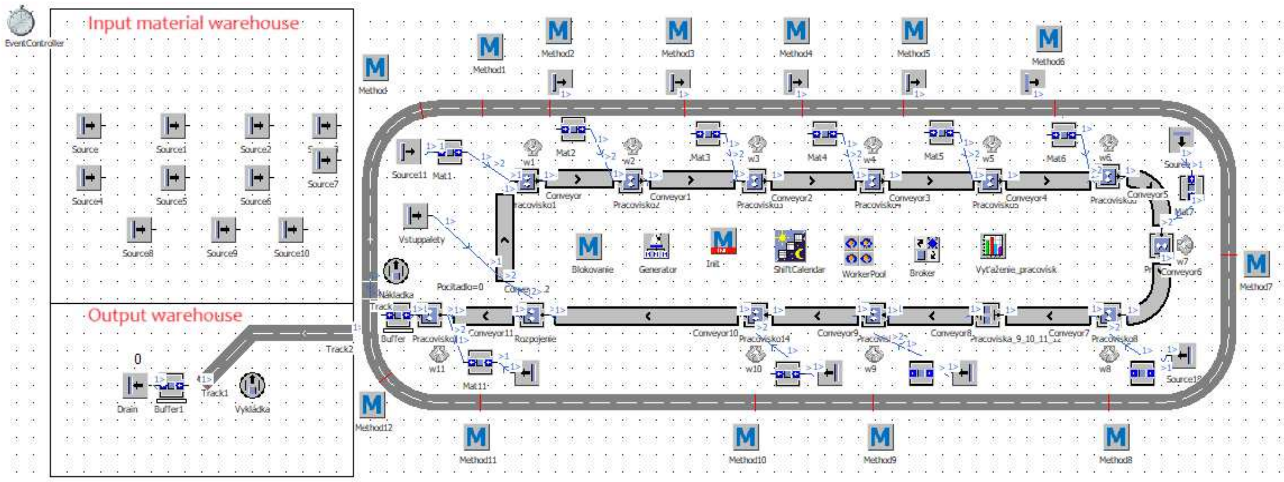

Figure 3 The model print screen

3.4 Verification of simulation model

The verification of the model was carried out by a simulation experiment that simulated the current state. In this experiment, the data obtained by the analysis were used. The experiment was performed for simulated times:

A: 1 shift, 8 hours,
B: 2 shifts, 16 hours,
C: 2 days, 48 hours.

From the simulation experiment for simulated time A, the following results were obtained:

- 96 pieces of finished products (6 pallets) per shift were brought to the output warehouse,
- 97 products were packed at the packaging workplace (Workplace No.15) (6 pallets, 7 pallets contained only 1 box with the finished product), and one product was in the process of being packed,
- the first product was packed and placed on the pallet in less than 45 minutes, and in 1 hour and 53 seconds, 16 products were loaded and taken to the warehouse.

From the simulation experiment for simulated time B, the following results were obtained:

- 192 pieces of finished products were brought to the output warehouse (12 pallets), which represents 96 products per shift,
- 195 products were packed at the packaging workplace (Workplace No.15) (12 pallets, 13 pallets contained only 3 boxes with the finished product), and one product was being packed.

From the simulation experiment for simulated time C, the following results were obtained:

- 384 pieces of finished products were brought to the output warehouse (24 pallets), which again represents 96 products per shift,
- 391 products were packed at the packaging workplace (Workplace No.15) (24 pallets, 25 pallets contained only 7 boxes with the finished product), and one product was again in the packaging process.

Figure 4 shows the utilisation of workplaces. Figure 4 shows in green the utilisation of individual workplaces during two working days (4 working shifts). At workplaces that precede workplaces No. 5 and No. 15, the blocking of the given workplace is shown in yellow. This blocking is caused by work-in-progress products having to wait at workplaces until they are gradually moved to the following workplace, and queues of work-in-progress products are formed. The light blue indicates when the production line is not in production. Production only takes place on the line after the end of the afternoon shift at the start of the morning shift the next day. Breaks during the production process are shown in dark blue (lunch/dinner break).

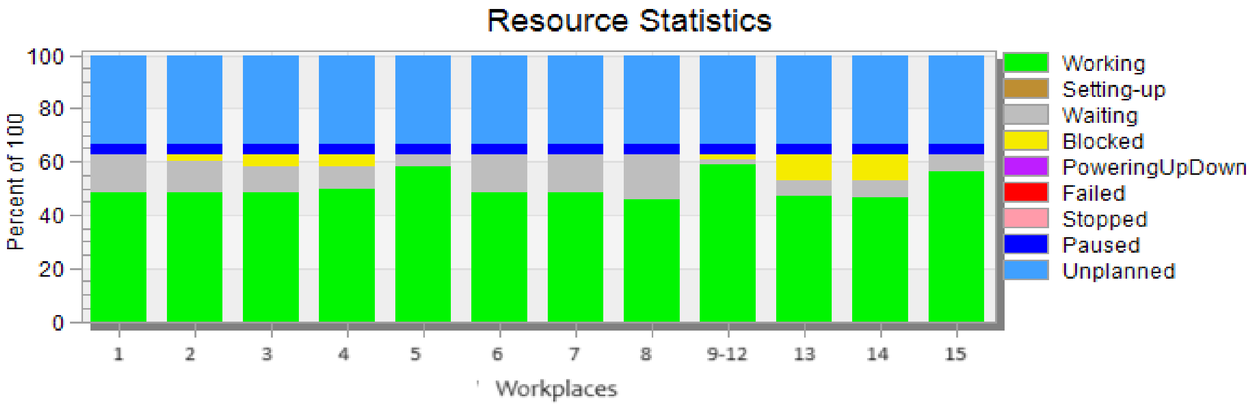

Figure 4 The utilisation of workplaces

The results prove that it is possible to produce 96 products in one working shift on the given line under current conditions. The model is verified, and the values obtained by simulation are identical to those from the analysis.

3.5 Simulation experiments and simulation results

Experiments were performed on the verified model. The main goal of the experiments was to eliminate the blocking of workplaces, to equalise the performance of workplaces and to find out whether it is possible to increase the production of finished products as well. The simulated time in these experiments was two working days, as in experiment C. Experiments were performed:

D: In this experiment, the work cycle time at critical workplace No.5 was adjusted from the original value of 4 minutes to the average time of the previous workplaces, to 3 minutes and 20 seconds. This experiment removed the blocking of workplaces in front of workplace No.5. Blocking workplaces in front of workplace No.15 was not removed. The result of this experiment is the same number of products produced as in the current state.

E: In this experiment, the work cycle time was modified at critical workplace No. 15 from the original value of 4 minutes and 9 seconds to the average time of previous workplaces of 3 minutes and 20 seconds. By adjusting the time, the production of finished products increased from 96 to 103 pieces per shift, i.e., by 7 pieces. The blocking of workplaces in front of workplace No.15 and front of workplace No.5 was not removed.

F: In this experiment, a time adjustment was made at critical workplaces No.5 and No.15 for 3 minutes and 20 seconds. In this experiment, the blocking of workplaces in front of workplaces No.5 and No.15 was removed, and the workload of workplaces was equal, figure 5. The production of finished products increased from 96 to 120 pcs per shift, representing an increase of 24 pcs/shift.

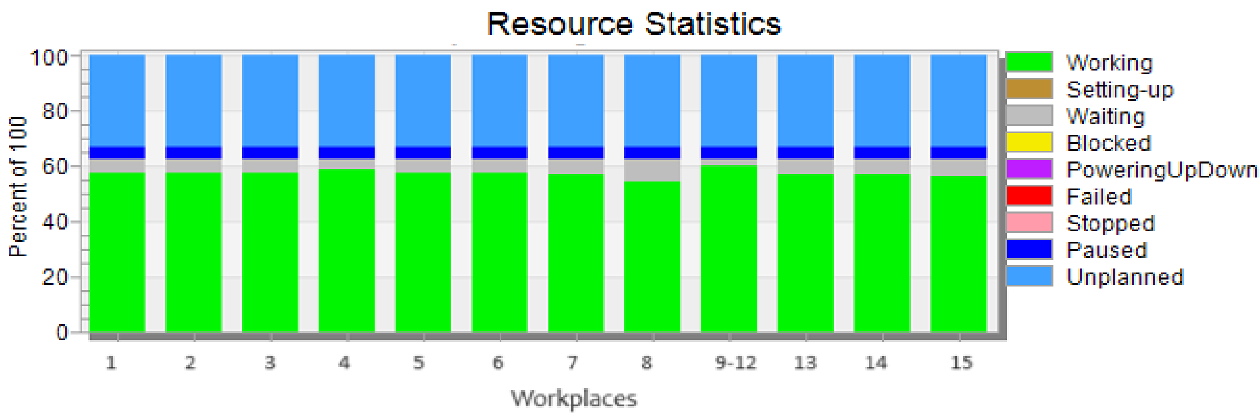

Figure 5 The utilisation of workplaces

Based on experiment F, it was found that on a given line, by reducing the work cycle of selected workplaces, it is possible to remove the blocking of workplaces and increase production by 25%.

3.6 Proposals and recommendations

However, the question arises: How to reduce the time of working cycles in operation?

One of the solutions would be to eliminate the deficiencies identified by the analysis, which are related to the work items and materials used in the workplaces (the workplaces contained objects that were not necessary for the operation, material and work tools used by workers during production, were not marked and did not have a precisely defined place or arrangement, the operator sometimes has to search for these aids and material and thus the work cycle is extended).

Eliminating these deficiencies is possible by applying the 5S method in workplaces and removing unnecessary items. Most of the material is in crates and pallets of various sizes without marking. Therefore, it would be advisable to place labels with information about the given material (material code, photo of the component, etc.). Precisely designated places for all work aids, tools, and materials used at work would be marked on the worktables, applying a plan for cleaning workplaces and work aids at workplaces at regular intervals, which would impact safety and work productivity.

What increase in production can be achieved in possible demand from this line?

Based on the results of the last experiment, it is possible to increase production by 25%, i.e., 24 pcs per shift, which is 48 products during a two-shift operation. The future decision is whether this increase in production after its efficiency in two-shift operation is sufficient or necessary, e.g., it is within the company's competence to introduce a third direction following its business goals. As for downstream processes, such as the storage distribution of products when production is increased on this line, their assessment was not the subject of the solution in this contribution.

The newly added production volume determines the increase in the degree of employing the production capacity and vice versa [25].

4 Conclusions

It is essential for a manufacturing company that production activities are efficient. So that the production process runs without unnecessary complications, the work cycle should be continuous with as little idle time as possible. This contribution presents a simulation model of a production line where several workplaces were blocked due to the accumulation of material that could not be continuously moved to the following workplace, whose work cycle was not following the previous workplaces. After verifying the model, experiments were carried out on the simulation model, the aim of which was to eliminate the blocking of workplaces, to equalise the workload of workplaces and to find out whether it is possible to increase the production of finished products. Based on the experiments, it was found that in the case of shortening the work cycle at critical workplaces No.5 and No.15 (Experiment F), the accumulation of material at the workplaces that precede the critical workplaces will be removed, the material will continuously move along the production line, the workload of the workplaces will be equalised (Figure 5), downtimes at workplaces will be shortened and partially equalised, thereby increasing the speed of the material flow on the production line. It can be concluded that by shortening the work cycle at workplaces No.5 and No.15, it is possible to make the process more efficient - to equalise the workload of individual workplaces and increase production by 25%, increasing the number of products by 24 pcs/shift.

However, how can we reduce work cycles at critical workplaces? The article presents one of the options, namely the application of the 5S method, which focuses on organising and maintaining a safe, organised, and efficient workplace. Applying this method, whether at selected workplaces or the production line itself, will be beneficial in several areas - reduction of downtime, increase in worker productivity and thus production of the line, and finally, benefits in the field of occupational safety and accident prevention.

Applying the 5S method at workplaces No.5 and No.15 is the first time-saving solution for eliminating the problem related to material flow. Suppose the problem with the material flow persists even after the 5S methods have been applied. In that case, the presented simulation model can be used to verify and evaluate future solutions to the problem.

It is more than likely that in the coming years, there will be an increase in demand for the creation of simulation models of production systems in manufacturing companies that will try to implement the Industry 4.0 strategy and thus increase their competitiveness.

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