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IMPROVING MATERIAL FLOW IN A MODIFIED PRODUCTION SYSTEM

Abstract

The aim of the article is to present a model of material flow organisation in a changing production system operating under small batch production conditions. Material flow is an element of the value stream that transforms production inventory into a finished product, creating value for the purchaser. Material flow management aims to ensure the consistency of supply and reliability of the production processes being carried out. Carrying out simulations for various production scenarios will be the basis for developing an effective method of material flow management in small batch production of cutting tools. Material flow simulation makes it possible to uncover selectively disruptive factors in existing production systems in order to systematically improve systems. Implementing material flow simulation in a timely manner allows the right trajectory to be established before manufacturing reality knowledge is available.

1. INTRODUCTION

One way of verifying the correctness and completeness of the modified production system is to carry out tests using tools for modelling and simulating production processes. Process simulation capabilities have a significant impact not only on the effective implementation of the production process, but also on the effective improvement of these processes. This includes the refinement of material flow, inventory management or their evaluation according to production time and cost criteria.

Production preparation refers to the work that precedes the start of production of a product or the implementation of a manufacturing process in a company (Szatkowski, 2018). The high variability of customer expectations creates complexity in product development and manufacturing processes, which occurs in all types of production systems (Allet, 2016). Organisational production preparation includes work aimed at enabling the best possible use of the technologies used in both the basic and auxiliary processes of the production system. The basic element of the production system is the workstation, which carries out the tasks of the processes performed in the production system. In order to fulfil its function, the workstation must be equipped with appropriate resources (Pająk, 2021; Szatkowski, 2014) – Figure 1. The main objective of planning and organising production processes is to produce high-quality products on time (Litwin et al., 2019).

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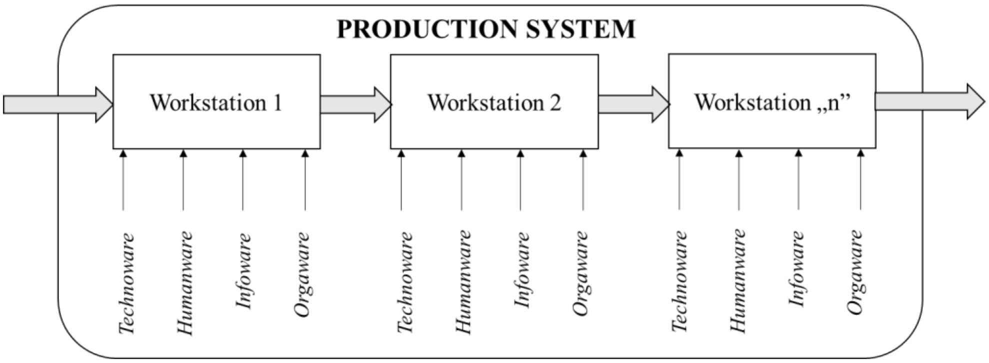

Fig. 1. Workstation resources (Pająk, 2021)

The form of production organisation determines the way in which material flows between the various workstations, while the type of production organisation is related to the volume of production and the degree of specialisation of the workstations. For the most part, the tasks performed in auxiliary processes allow the efficiency of the production system to be improved. (Pająk, 2021) Selection of the right production structure is a key element in any production system, because it has consequences in the productivity, efficiency and costs of the operated production system (Gola, 2019).

Resource flow analysis boils down to lead time analysis and is most often based on the structure of unit times for individual operations in the manufacturing processes of the parts that make up the product. The calculated production cycle from this perspective is the basis for scheduling work in the production department.

The production cycle, i.e. the time from order receipt to order closure, can be calculated from the following function:

$$C = f(C_p, C_s, C_i, C_m, C_f, C_n)$$

where: C – production cycle,
C_p – labour cycle of employees,
C_s – work cycle of the means of production,
C_i – information flow cycle,
C_m – material flow cycle,
C_f – cash flow cycle,
C_n – execution cycle of the order to make *n* finished products.

A comprehensive production system model should take into account the resource flows mentioned above. Building such a model is very labour-intensive. Gathering all the necessary information requires a lot of additional analysis, e.g. cost analysis, staffing analysis, organizational structure analysis, links between organizational units, information flow analysis, etc. Various simulations can be carried out on such a comprehensive model, the purpose of which can be, for example, to check the feasibility of various production orders, develop a production schedule, etc. We can then be sure that the decisions taken will be correct and that the likelihood of failure will be reduced. These programs can be used to increase productivity, production flexibility and optimize production systems through the use of visualization. A simulation process model is created to test new ideas and propose options in various scenarios before actual implementation. (Butrat & Supsomboon, 2022)

This is the main reason for creating the simulation model project at the presented manufacturing company, where there was a need to analyse the flow of materials in order to increase the efficiency of the current production system, which currently has to operate under conditions of fluctuating demand.

2. CONTROLLING THE FLOW OF MATERIALS IN THE PRODUCTION SYSTEM

Materials include raw materials, components and subassemblies from purchases that are transformed into finished goods in production processes (Pająk et al., 2014). The design of production systems must provide effective solutions to satisfy demand. The main difficulty in including flexibility in the decision-making process is the challenge of measuring and comparing it due to future production scenarios that are not definitively definable (Gola, 2014). The control of material resources, especially the flows of material and information streams of a controlling and controlling nature, is the basis of logistics processes in a company. In reality, the variability of demand and lead times must be reckoned with, resulting in the need for safety stock (Pająk, 2021). Material handling encompasses all the phenomena and processes related to materials management, which determine their rational consumption and the rhythmicity and fluidity of material flows, and thus the correctness and efficiency of the production process. The organisation of material handling is fundamental to the timely completion of production tasks, as it ensures that the production process is supplied with raw materials and materials. The efficiency of material handling should be assessed both through the prism of material utilisation and the time and cost of obtaining and delivering materials to individual consumption sites (Szatkowski, 2014). The development of the processes carried out in the production system, their division into operations and tasks, and the apt selection of technological equipment, is an important part of production preparation activities. Equally important is the development of links between individual operations and tasks, i.e. the design of an appropriate form of production organisation. The form of production organisation determines the way in which the stream of materials, i.e. parts of product assemblies, flows between workstations (Pająk et al., 2014).

In any company, a sudden complete reorganisation of the organisational form may result in the collapse of its management system and business principles. Nowadays, however, many enterprises wishing to stay in business have to redesign their processes using modern methods and tools in order to use their production resources more efficiently. Modern management, being a means to an end, is oriented towards results, which are a measure of management effectiveness, above all putting the customer and his requirements in the foreground (Knosala, 2017). When processes are properly controlled and improved, much better results are achieved, which are mainly manifested in financial savings, increased efficiency or a reduced workload for employees (Lehocká et al., 2016; Plinta & Kłaptocz, 2021).

3. THE ROLE OF SIMULATION MODELLING IN IMPROVING MATERIAL FLOW

Simulation is the technique of using representative or fictitious data to reflect in model form the various conditions that are likely to occur during the operation of the system in its current state (Blackstone, 2016; Kolny et al., 2019). It is a technique that supports the continuous improvement of production processes, with particular emphasis on material flows (Fig. 2), (Maciąg et al., 2013). There are a few stages that include the activities that are generally performed during modelling. The first stage is the examination of the data, followed by the development of a model based on the data, and finally the verification and validation of the model, which allows one to determine whether the model and data are correct or detailed enough to reflect the actual production process (Figure 2). The next stage involves improvement analysis and is based on experiments, which can be carried out as simulations. These show whether the changes that planned for the production process will lead to its improvement or not. The final stage is the carrying out of pilot studies, which make it possible to verify the improvement method in only part of the actual process (Burduk et al., 2021).

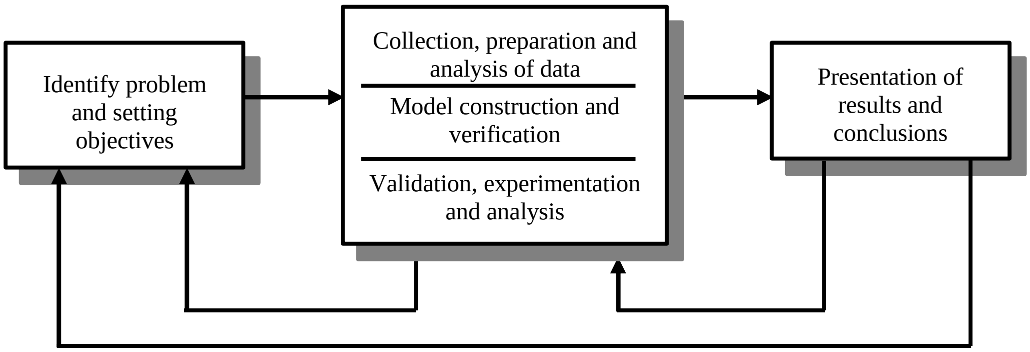

Fig. 2. Stages of simulation analysis

Various simulation models are used to develop and improve production processes and systems. An appropriate model formulation describes the function and interaction with the various related elements and is based on data analysis and research (Alquraish, 2022). The use of simulation to analyse material flows helps in the evaluation and planning of these flows (Silva et al., 2021). Simulation models allow new processes, or changes to processes, to be evaluated outside of the production environment – allowing experimentation with processes and operating procedures without exposing real world systems to perturbation (Kelton, 2014; Małopolski, 2012). The second benefit is related to time compensation, since activities that would normally take much longer can be simulated in a short period of time. Another advantage of simulation modeling is to analyse different variants of situation development. With simulation, it is possible to know the consequences of such events without waiting for them to actually occur (Bozarth & Handfield, 2018). Computer simulation methods are widely applied in increasing the efficiency of production systems, identifying bottlenecks or testing the design assumptions of production processes (Kłos & Patalas-Maliszewska, 2020).

4. USING SIMULATION MODELLING TO IMPROVE MATERIAL FLOW IN A MODIFIED PRODUCTION SYSTEM

The production system modification project presented below emerged from the need to reorganise the production department in connection with the increasing dynamics of changes in the range of products offered. As a result of the observed changes, there was a need to develop a new way of planning material flows. It was proposed to create a system using simulation modelling based on the activities shown in Figure 3.

In the proposed solution, there are two steps related to the modelling and simulation of the system and production processes, which are the most time-consuming activities especially when implementing simulation tools in production. On the other hand, in the analysis of subsequent improvements, we use the same previously developed model, introducing the current production plan.

In order to improve the material flow in the modified production system, an analysis of the production plan for the band knives was carried out. It was decided to carry out research on this product group, as the company in question is experiencing continuous growth in sales of these products. The production of band knives currently requires constant organisational and technological changes to ensure the highest quality of the products offered.

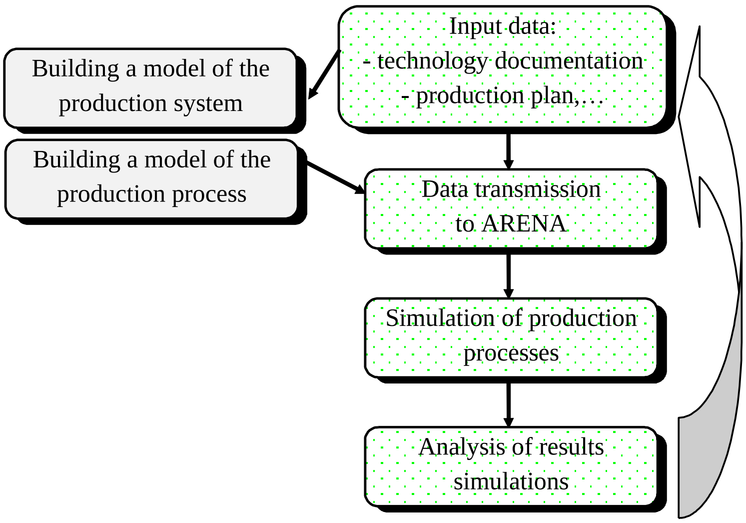

Fig. 3. The proposed modelling and simulation process flow

4.1. Characteristics of the company

The company, on the example of which the simulation model is made, is an existing and well-known manufacturer of construction, abrasive and cutting tools on the Polish and world markets. The company devotes considerable financial outlays to development research and improvement of its manufacturing technology, year by year strengthening its position on the market and systematically increasing the sales of its products.

The main difficulty identified in the defined research area, which gave rise to this project, is the problem of organising the flow of materials for the production of band knives under conditions of fluctuating demand for cutting tools. The company's mission is to provide the best quality tools to help customers complete their projects and increase their efficiency. The company is committed to continuous development and improvement of its products to ensure not only reliability, but also convenience and safety during use.

The goal is to continuously improve production processes to ensure the high quality of our products.

4.2. Object of the research

The products analysed from the cutting tool group are band knives These are manufactured from premium high-carbon steel in the 6 to 50mm width range.

This group of products was subjected to the study because the company has noted a continuous increase in sales of this product group. However, production is not simple. It requires continuous improvement of the technological process and production organization.

There are several main groups of band knives offered by the discussed company. These are raw band knives (unsharpened and untoothed), band knives sharpened on one side, band knives sharpened on both sides, single toothed band knives, double toothed band knives. The production process, depending on the type of band knife, includes various processes, among which are: measuring and cutting to size, welding, toothing, sharpening and setting. The production process for band knives is shown in table 1. Not all products require all operations to be carried out.

Band knives of all types with a band width of 20 mm and a thickness of 0.7 mm and a length of 1500 mm were analysed for each knife type. The process starts with the receipt of an order by a member of the sales department. On the basis of the order, the production department prepares an order sheet, appoints people to carry out the order and sets a planned completion date. The final step is packing and taking the saws into storage. The unit times of the operations are summarised in the table 2.

The main problems and difficulties identified in the defined research area is the organization of the flow of the material for the production of cutting tools, and consequently the management of material flow.

Tab. 1. Production process for band knives

OPERATION NUMBER	OPERATION DESCRIPTION
10	Measuring and cutting to size
20	Welding
30	Toothing
40	Sharpening
50	Setting

Tab. 2. Production process for individual types of band knives, including lead times

BAND KNIFE 20 x 0,7mm								
Types of band knives	**Quantity [pcs]**	**Dimensions [mm]**	**Tooth pitch TPI**	**Cutting to size [s]**	**Welding [s]**	**Toothing [s]**	**Sharpening [s]**	**Setting [s]**
TYP-15X – type of blade X (raw band knives)	20	20 x 0,7		60	90			
TYP_16Y – type of blade Y (one edge sharpened - angle 20°)	15	20 x 0,7	2	60	90	170	180	
	5		2,5	60	90	150	180	
TYP_16Z – type of blade Z (two edges sharpened - angle 20°)	25	20 x 0,7	2	60	90	170	320	
	10		2,5	60	90	150	320	
TYP_17Y – type of blade Y (one edge sharpened - angle 20°)	10	20 x 0,7	6	60	90	65	180	
	5		10	60	90	40	180	
	5		12	60	90	35	180	
TYP_19Y – type of blade Y (one edge sharpened - angle 20°)	15	20 x 0,7		60	90		180	
TYP_19Z – type of blade Z (two edges sharpened - angle 20°)	45	20 x 0,7		60	90		320	
TYP_20Y – type of blade Y (one edge sharpened - angle 40°)	10	20 x 0,7	12,5	60	90	35	255	
TYP_21X – type of blade X (double-sided toothed)	30	20 x 0,7	2	60	90	170		
	20		4	60	90	100		
	15		6	60	90	65		
TYP_21R - type of blade R (double-sided toothed and setted)	5	20 x 0,7	2	60	90	170		140
	5		4	60	90	100		100
	5		6	60	90	65		55
TYP_22Y - type of blade Y (one edge sharpened - angle 20°)	10	20 x 0,7	12,5	60	90	35	255	
TYP_23Z - type of blade Z (two edges sharpened - angle 20°)	5	20 x 0,7	12,5	60	90	35	320	
	10		16	60	90	35	320	
	5		20	60	90	35	320	
TYP_24X - type of blade X (unilaterally toothed)	5	20 x 0,7	4	60	90	100		
	10		6	60	90	65		
	20		8	60	90	50		
	10		10	60	90	40		
TYP_24R - type of blade R (unilaterally toothed and setted)	15	20 x 0,7	4	60	90	100		80
	10		6	60	90	65		65
	5		8	60	90	50		55
	15		10	60	90	40		50

4.3. Course of the research

This paper presents a proposal for the modification of a production and material flow improvement run in the Arena simulation programme. Two runs were developed to simulate the operation of two ways of material flow. To build models in the Arena program, ready modules with specific functionality were used, which are grouped in appropriate templates. Three models were created – an excerpt from the model is shown in the Figure 4.

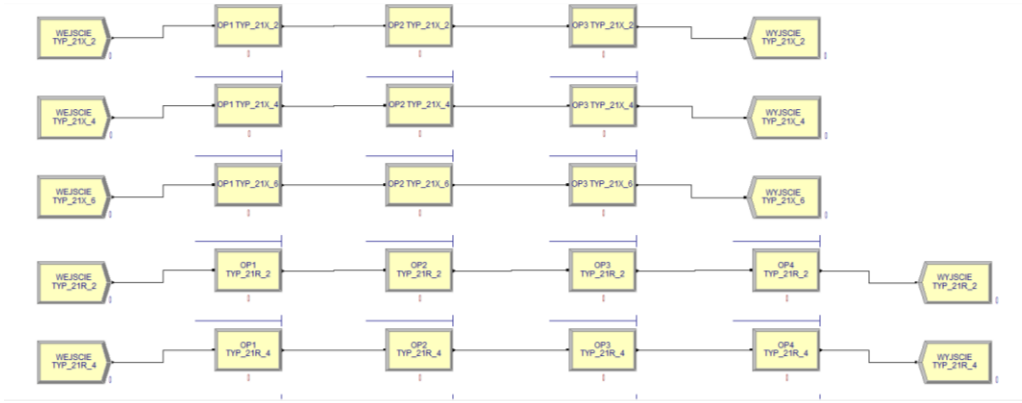

Fig. 4. Extract from the simulation model of the band knives

The first model was a test of the feasibility of the daily production plan. It turned out that the production plan would be fully realised during two production shifts. The most loaded station would be the sharpening machine (81%) and the least loaded would be the saw setting machine (2.5%) – Figure 5. The sharpening workstation is worth observing, because it is not excluded that with inappropriate organization of production it could become the bottleneck of this system. If the workstation load is below 45% then it would be possible to schedule such workstations to work only one shift. Another option is to introduce multi-station working, which is reasonable in this case. It will eliminate the need to hold the workpieces until the next shift, when a low-load station will be working. Data received in this way are the basis for monitoring this system.

Scheduled Utilization	Value
Guillotine saw	0.3743
Saw set	0.02563431
Band knife sharpener	0.8159
Toothing machine	0.4606
Welding machine	0.5705

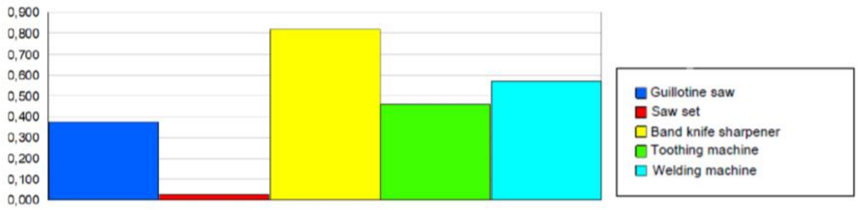

Fig. 5. Workload presented in Arena simulation report

In subsequent models, different groupings of products were tested by changing the start times of production orders for different types of knives. As a result, a split was made between products whose production is ordered on the first and on the second shift. Testing such variants in Arena involved changing the values in the 'create' table in the 'first creation' column – Figure 6.

Create - Basic Process

	Name	Entity Type	Type	Value	Units	Entities per Arrival	Max Arrivals	First Creation
10	WEJSCIE TYP_19Z	TYP_19Z	Random (Expo)	1	Hours	45	1	0.0
11	WEJSCIE TYP_20Y_12.5	TYP_20Y_12.5	Random (Expo)	1	Hours	10	1	0.0
12	WEJSCIE TYP_21X_2	TYP_21X_2	Random (Expo)	1	Hours	30	1	0.0
13	WEJSCIE TYP_21X_4	TYP_21X_4	Random (Expo)	1	Hours	20	1	0.0
14	WEJSCIE TYP_21X_6	TYP_21X_6	Random (Expo)	1	Hours	15	1	0.0
15	WEJSCIE TYP_21R_2	TYP_21R_2	Random (Expo)	1	Hours	5	1	8
16	WEJSCIE TYP_21R_4	TYP_21R_4	Random (Expo)	1	Hours	5	1	8
17	WEJSCIE TYP_21R_6	TYP_21R_6	Random (Expo)	1	Hours	5	1	8

Fig. 6. Extract from the report of the second version of the simulation

The base variant, before the implementation of the changes, represents the current situation. Production so far proceeds according to this variant, but it was noted that process efficiency could be increased. Later variants presented two types of improvements. It was decided to rearrange the production plans for the first and second working shifts. In variant one, simulation time was reduced. Variant two involved organizing the production plans for both working shifts. In this way of arranging for shorter planning periods separately for each shift, the simulation allows ongoing observation.

The analysis of the reports obtained showed that this production could be carried out in one working day (two working shifts) and by 3 operators. A comparison of the reports from the subsequent simulations noted a reduction in the production time for the different types of knives (Figure 7), which resulted from the reduction in waiting times after the product grouping (Figure 8).

The simulations resulted in a 35% reduction in average manufacturing time. The average waiting time was reduced by 36%. The biggest difference in average production time was found in type WP_24X_8. The difference is more than 3 hours, which compared to the base production time dor WP_24X_8 represents almost 56% reduced average production time. The situation looks very similar with the average waiting time. In the case of two types of knives, the production time, as well as the waiting time, was slightly increased compared to the base variant.

Based on the performed material flow simulation, it can be indicated that a properly executed simulation process makes it possible to maximise productivity and capacity exploitation. Maximising productivity is the result of discovering areas for improvement and catching bottlenecks in the production process. As a result of the simulation, the cycle time was reduced. The effect of performing the simulation is to increase the reliability of planning and increase compliance with cutting tool production schedules, which also helps to minimise stocks. Simulation allows the avoidance of erroneous investments in the future, due to the conclusions that can be reached during the simulation exercise.

Average production time [hrs]	Variant I	Variant II
TYP_15X	4,84	2,68
TYP_16Y_2	5,88	4,13
TYP_16Y_2.5	2,27	1,58
TYP_16Z_2	7,93	5,86
TYP_16Z_2.5	4,63	3,25
TYP_17Y_10	4,74	3,36
TYP_17Y_12	2,71	2,02
TYP_17Y_6	2,56	1,86
TYP_19Y	6,03	4,27
TYP_19Z	9,94	7,66
TYP_20Y_12.5	4,85	3,48
TYP_21R_2	2,26	0,60
TYP_21R_4	2,29	0,92
TYP_21R_6	2,30	0,94
TYP_21X_2	6,51	3,86
TYP_21X_4	5,50	3,18
TYP_21X_6	0,45	0,45
WP_22Y_12.5	4,93	4,18
WP_23Z_12.5	2,98	3,60
WP_23Z_16	5,06	4,31
WP_23Z_20	3,15	3,78
WP_24R_10	4,89	2,27
WP_24R_4	4,86	2,24
WP_24R_6	3,86	1,81
WP_24R_8	2,49	1,15
WP_24X_10	3,80	1,75
WP_24X_4	2,36	1,01
WP_24X_6	3,75	1,71
WP_24X_8	5,57	2,47
Average time	**4,26**	**2,77**
Difference	**35%**	

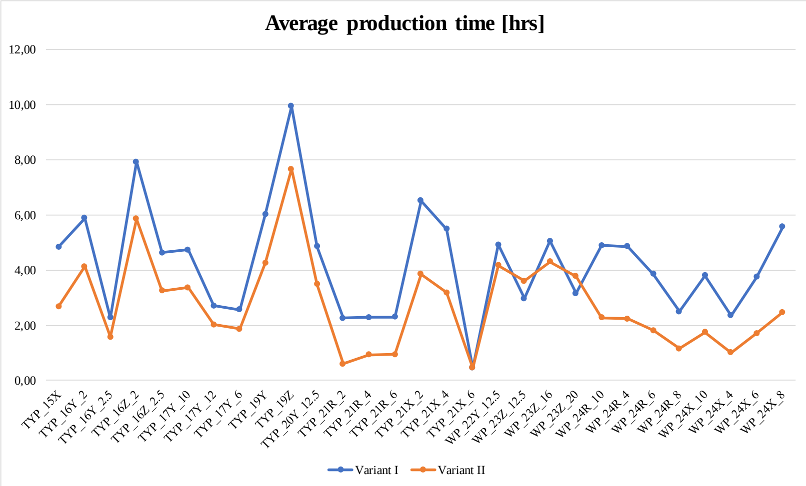

Fig. 7. Comparison of manufacturing times

Average waiting time [hrs]	Variant I	Variant II
TYP_15X	4,80	2,65
TYP_16Y_2	5,74	3,99
TYP_16Y_2.5	2,14	1,44
TYP_16Z_2	7,75	5,69
TYP_16Z_2.5	4,46	3,08
TYP_17Y_10	4,64	3,26
TYP_17Y_12	2,61	1,92
TYP_17Y_6	2,45	1,76
TYP_19Y	5,93	4,18
TYP_19Z	9,81	7,53
TYP_20Y_12.5	4,73	3,36
TYP_21R_2	2,13	0,47
TYP_21R_4	2,19	0,83
TYP_21R_6	2,23	0,86
TYP_21X_2	6,42	3,77
TYP_21X_4	5,43	3,11
TYP_21X_6	0,39	0,39
WP_22Y_12.5	4,80	4,05
WP_23Z_12.5	2,84	3,46
WP_23Z_16	4,92	4,17
WP_23Z_20	3,02	3,64
WP_24R_10	4,84	2,22
WP_24R_4	4,79	2,17
WP_24R_6	3,80	1,75
WP_24R_8	2,44	1,10
WP_24X_10	3,74	1,70
WP_24X_4	2,29	0,95
WP_24X_6	3,69	1,65
WP_24X_8	5,52	2,42
Average time	**4,16**	**2,67**
Difference	**36%**	

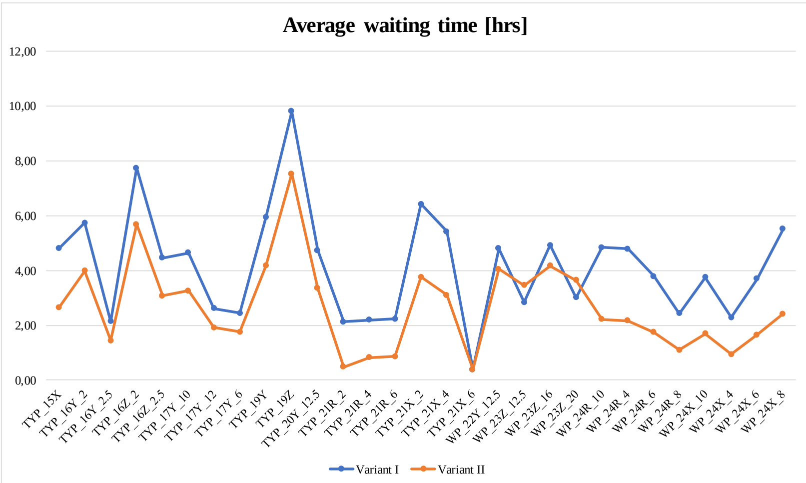

Fig. 8. Comparison of waiting times

The goal of improving the method of material flow and the capacity of the production process has been achieved. The production process has been comprehensively optimized. The simulation modelling provided an opportunity to decide how to achieve the improvement without interfering with the actual process.

Received results are the basis for further analysis. Future research should be enriched by performing simulation modelling that considers the risks of manufacturing processes.

5. CONCLUSIONS

The simulation verification made it possible to identify the interrelationships between the individual perspectives of production changes and to assess operational efficiency. From the point of view of material flow and resource utilisation, it is particularly beneficial to apply a model with grouped production orders and multi-workshop working to the production process. Improvement requires good recognition of the current situation. In doing so, it becomes necessary to analyse the flow of operations in detail in order to identify the wastage that is occurring. Once a production system has been designed and is functioning, it is subject to further improvement. Similarly, once a simulation model has been developed, it can be used again and again in the testing of subsequent production plans.

Material flow simulations allow important test phases in which the technical solution can be verified. It enables early identification of problems and optimisation potential. The timely use of material flow simulations helps to set the right course before the knowledge from production reality is available. The benefits of material flow optimisation allow full visibility of the entire material flow. This is an opportunity for cost savings, higher operational efficiency and increased productivity.

This approach can be applied in the area of manufacturing systems development and improvement, where simulations are used to effectively predict processes. Simulation modelling is a useful method that supports key decisions to improve the manufacturing process.

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