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LOGISTICS PLANNING AS AN IMPORTANT ELEMENT OF STRATEGIC DECISIONS IN PRODUCTION MANAGEMENT IN THE COMPANY – CASE STUDY

Summary. The authors have developed algorithms and a simulation model of the production process in the selected enterprise, and proposed variants of emergency conduct. An aggregated simulation model as well as simulation results will allow for the implementation of appropriate procedures for dealing with emergencies. Through employing these measures, audits conducted in the company

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will reveal how the company is prepared for various failures and what their impact is on the efficiency indicators of the process.

Keywords: production logistics, management, process quality, technological transport

1. INTRODUCTION

Proper organization of production and logistics processes is based on the use of decision support systems, which are intended to support the work of logistics managers. Simulation programs enable testing of different process variants without incurring the excessive costs of physical model building. Industry 4.0 requires precise decisions that are made in the shortest possible time. This can, in turn, determine competitive advantage. Since the time required for running multiple simulations is relatively short, simulation models fit perfectly into the trend of Industry 4.0. The proper conduct of simulation must be preceded by appropriate preparation, i.e., process mapping. The scope of implementation must also be defined to map the real process as closely as possible. Moving through successive procedures included in data collection, as well as process mapping and simulation of possible solutions, translates into a permanent improvement in the quality of the processes in place. Production is based on a number of major decisions that must be made in a short time to avoid bottlenecks. Quality management standards applied in production companies provide for the introduction of appropriate contingency plans, which serve to prevent lengthy downtimes as well as undesirable emergencies. These situations translate into a decrease in the level of customer service and competitive advantage in the market.

2. LITERATURE REVIEW

In order to ensure the quality and safety of each link involved in the production and delivery of products, enterprises must implement quality standards. The concept of service quality in the aspect of logistics has been defined by the logistics management council. According to Megoze Pongha, quality in logistics means that the company meets the requirements and expectations agreed upon with the customer [1]. In terms of service characteristics, include [2]:

- ease of getting the information you need and placing and obtaining orders,
- timeliness and reliability of delivery of ordered goods and communication,
- processing of orders accurately, completely and without damage to goods and error-free documentation,
- timely and responsive after-sales service,
- the accurate and timely acquisition and transfer of information between partners to support the planning, management, and execution of the activities mentioned earlier.

In practice, a detailed assessment of the quality of services can be problematic because some factors that affect it may be subjective, such as customer satisfaction [3]. According to Anneri van Zyl, increasing competitive advantage and acquiring customers requires companies to introduce appropriate management modules oriented toward pro-quality actions in their management systems [4].

Manufacturing industries, which have a high degree of responsibility for tasks, have developed industry-specific standards. Examples of these standards include the IATF (International Automotive Task Force) for the automotive industry or the HACCP (Hazard Analysis and Critical Control Points) for the food industry.

The IATF 16949:2016 standards are a set of pro-quality considerations aimed at developing a quality management system for continuous improvement. In particular, it focuses on the prevention of errors and the reduction of variability and losses in the supply chain [5]. When applied, these standards allow for the elimination of undesirable behavior and conduct in manufacturing and supply processes [6]. The implementation of quality standards is classified as a strategic decision. Such an extensive and specified interference in the management system should be preceded by a thorough analysis, and its introduction should proceed in stages and in accordance with the rules of conduct [7]. The approach adopted in the standard, which takes account of risk, is called PDCA (Plan, Do, Check, Act) [8]. The abbreviation PDCA originates from the Deming cycle presented in (Fig. 1.).

Fig. 1. Deming cycle [5]

The indicated approach allows for the identification of factors that may have a destructive impact on the process and deviate from the planned results. What is more, the Deming cycle enables a simpler introduction of preventive supervision measures and gives the possibility of minimizing negative effects while maximizing the use of emerging opportunities. Quality management requires consideration of the external and internal determinants that are relevant to the process [9].

Leadership represents an important aspect that is mentioned in the IATF standards. Top managers and executives should demonstrate commitment to the whole management system [10].

The tasks of the management include responsibility for the effectiveness of the management system, compliance with the quality policy and its objectives, as well as accessing the indicated objectives. Further duties include ensuring an integrated quality management system and promoting the process approach. The system must be audited regularly, and its effectiveness evaluated to ensure continuous improvement [11]. The company policy must be customer-oriented, and the leadership should ensure that customer demands and applicable legal and regulatory requirements are understood and followed consistently [12-13]. Trends of increasing customer satisfaction should be maintained, and communication between units should be efficient. It is also necessary that the standards introduced are presented in a documented form that is accessible to stakeholders.

It is also important to define precise quality objectives, which must be consistent with the quality policy, and measurable [14]. These objectives should take into account all requirements, ensure the conformity of products and services, and thus increase customer satisfaction. Furthermore, it is essential that they are monitored, properly communicated, and continuously updated.

An equally crucial element in the implementation of quality standards is support, which is understood as the scope of activities aimed at maintaining continuity of the functioning pro-quality systems as well as the implemented quality standards [15]. The main task of the company in this respect is to guarantee the resources necessary to establish the implementation, as well as the maintenance and continuous improvement of quality management systems. Analysis of the measurement system requires systematic statistical studies to perform an analysis of the variability of the results obtained for each type of inspection, measurement and test equipment system, defined in the control plan [5]. The results of such tests should be consistent with those adopted in the regulations. According to the IATF quality standards, knowledge necessary for the operation of the processes should be established [16]. It is also key to identify the current know-how and actions needed to achieve a higher level of expertise [17]. Further, in the context of knowledge, the key competencies of the units involved in the process must be indicated [18]. Appropriate training should therefore be provided to enrich staff competencies. Importantly, the individuals involved in the process should be aware of the quality policy, the relevant goals, and their contribution and consequences.

Operational activities comprise actions related to the direct production of products or the provision of services [19]. Each operational measure should be properly planned and supervised. The organization of operational activities includes the definition of requirements for products and services, the establishment of criteria for processes, and the acceptance of products and services. Further elements involve the indication of resources, the implementation of supervision of activities, and the establishment of guidelines for record-keeping. All operational activities should be characterized by a high degree of confidentiality. Planning in this respect requires taking into account:

- customer requirements in the context of product-specific and technical requirements,
- logistical scheduling requirements.

ISO 9001 quality standards indicate product design and development as well as manufacturing processes with a view to preventing defects in the final products. Prevention is a more important aspect than detection. During product manufacturing planning and process design, it is necessary to identify the input data required to indicate the purpose of the process and the desired outcomes. As per the guidelines for the evaluation of performance, it is essential to determine which effects should be monitored and measured. This includes the type of monitoring and measurement methods, as well as methods of analysis and evaluation of the time appropriate for measuring and monitoring. Whenever it becomes impossible to use the process capability factor to indicate compliance, we must reach for an alternative method based on the evaluation of the compliance of the batch with the specification [20].

The last key aspect addressed in the IATF standards is improvement. In terms of manufacturing logistics, by improvement we mean continuous improvement, enhancement, as well as gaining competence in manufacturing processes [21].

2. PRODUCTION LOGISTICS

The era of Industry 4.0 sees more pressure being put on logistics. This aims to increase process efficiency in a broad sense. Most processes are designed according to the customer's requirements in order to meet their expectations. Production logistics is located between two groups of entities that have interacting properties. The former includes factors that can influence and exert pressure on production, i.e., a one-way action. Production must be adapted to the standards imposed at the time. The second group consists of cooperating actors who are oriented towards achieving a common set of goals. The positioning of production logistics between the two absorbing groups of cooperation, as well as the influencing factors and the continuous growth rate of production and consumption of the offered goods, enforces the use of modern concepts in production (Fig. 2.).

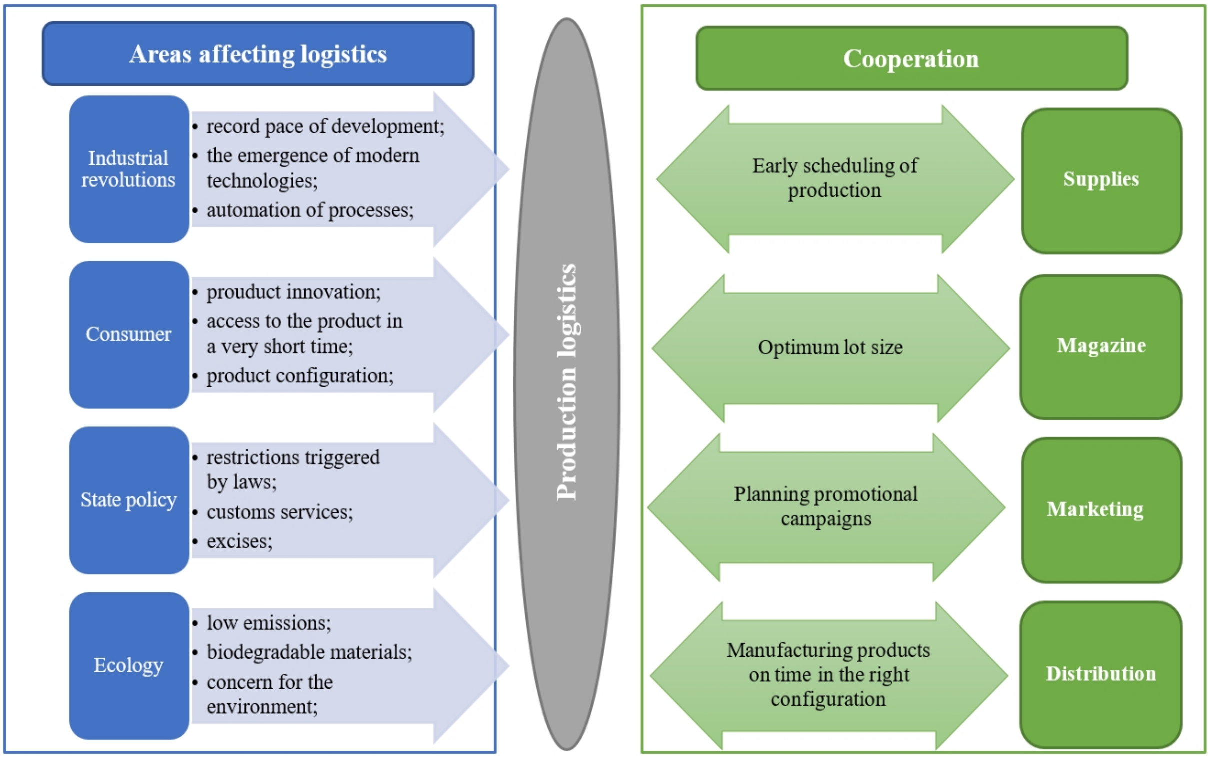


Fig. 2. Factors influencing production logistics

Production logistics, in addition to modern technologies and management concepts, is mainly based on planning and production control. The former consists of forcing such actions in the process that will bring the desired results. We can exert control over processes by the methods shown in (Fig. 3.) [23].

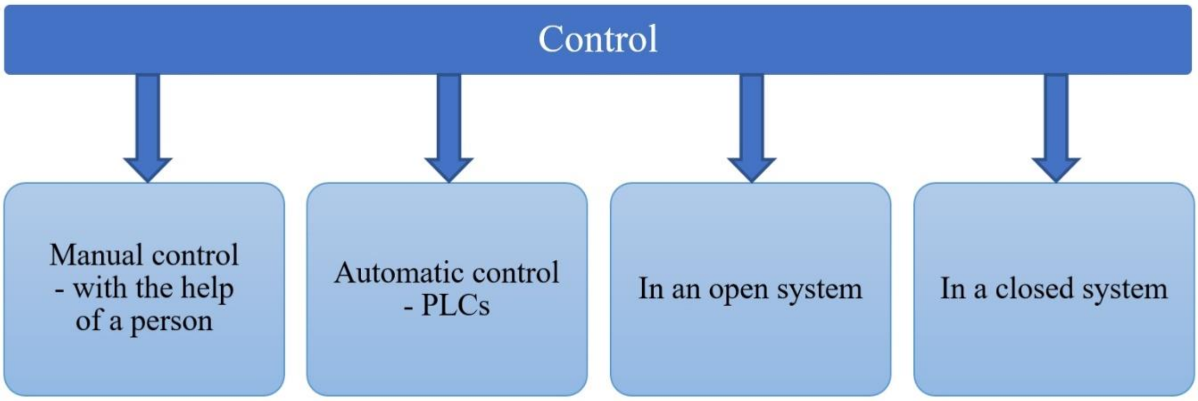


Fig. 3. Types of control systems [23]

Control of material flows depends on the choice of manufacturing system and the level of activity of the implemented technology. The implication of adequate control aims to reduce lead time, guarantee a relative level of customer service, minimize inventory, shorten production cycles, and effectively utilize production capacity.

The standard control approach predicts the following quantities:
- tide,
- drain,
- flow (period of stay),
- supply.

This is reflected in the selection of two formulas for controlling the flow of materials [22]. The first group is the so-called quantitative formula (Z - resource, X - inflow scale, Y - flow and outflow). Group two, on the other hand, is the temporal formula (A - entry time, start, B - exit, C - residence time).

Group one

1. Drainage volume and stock control (the supplier's plan must be accepted by the recipient and should take into account deviations). (Fig. 4) (1).

$$Z, Y = f(X) \tag{1}$$

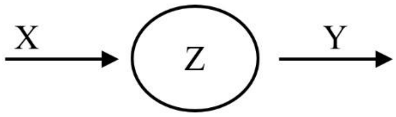


Fig. 4. Controlling outflow volume and stock [23]

2. Controlling the size of the outflow (the supplier's plan is identical to the customer's plan) (Fig. 5) (2).

$$Y = f(X); Z\text{- fixed quantity} \tag{2}$$

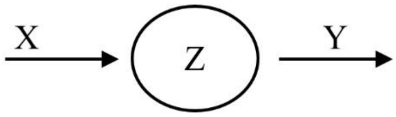


Fig. 5. Controlling the size of the outflow [23]

3. Controlling the size of the stockpile (Fig. 6) (3).

$$Z = f(X, Y) \tag{3}$$

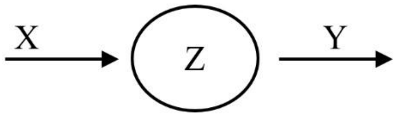


Fig. 6. Controlling the size of the stock [23]

Group two

1. Controlling the timing of the outflow and the residence period (Fig. 7) (4).

$$C, B = f(A);\ A = B - C \tag{4}$$

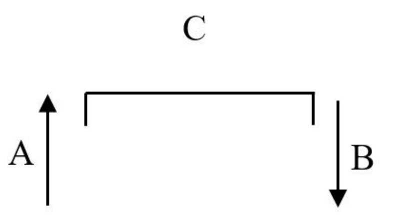
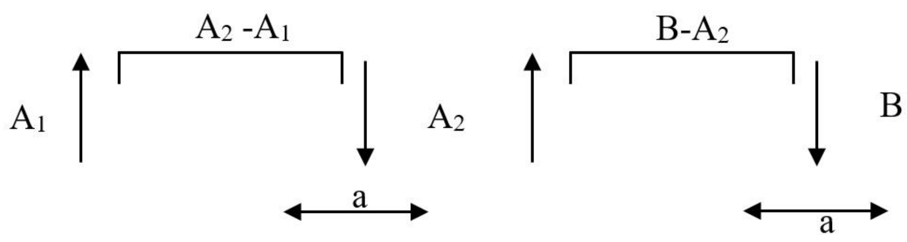


Fig. 7. Controlling the timing of outflow and residence time [23]

The implementation of an advance compensation period will allow the manipulation of disturbances during production cycles. The start and finish in the interdepartmental approach are derived from the cyclogram.

2. Controlling the drain term (Fig. 8) (5).

$$B = f(A, C);\ A_1 = B - 2a;\ A_2 = B - a \tag{5}$$



$$a = A_2 - A_1\ i\ a = B - A_2$$

Fig. 8. Controlling the drain term [23]

The planning period can be divided into fixed contractual stay units "a". The urgency number of the processes can be determined by running the next number of the production startup. The process marked with a lower number has a higher urgency. Designation a is used to denote a fixed average cycle size for particular organizational units in interdepartmental planning.

3. Residence period control (Fig. 9) (6). Controlling the residence period, where p - beginning, k - end, and $A \geq p$ (preparatory advance in the cyclogram), $B \leq k$ (early termination of the stay period).

$$C = f(A, B);\ A \wedge B \in < p; k > \wedge A < B \tag{6}$$

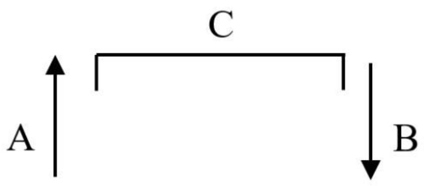


Fig. 9. Controlling the residence period [23]

The increasing pace of industrial development requires flexible and functional methods of production management. Control methods must be resistant to sudden crises and provide complex solutions for production processes.

3. TOOLS FOR DETERMINING THE EFFICIENCY OF MACHINES ON PRODUCTION LINES

Organizations and manufacturing companies strive to ensure failure-free production processes, taking into account the elimination of unnecessary activities. This is done in accordance with the Lean Manufacturing model, with simultaneous minimization of expenses [24]. It is an extremely difficult and responsible task to prevent possible failures in manufacturing enterprises. Breakdowns are an undesirable state that has a destructive effect on the production process.

Logistics managers are required to ensure continuity of the entire supply chain, with particular emphasis on production processes.

Production processes should be monitored by checking product quality, controlling the operating parameters of the machine, performing audits, introducing improvements, standardizing processes and servicing equipment. Production capacity must be adjusted in such a way that each subsequent machine has a higher production capacity to ensure the elimination of bottlenecks in production lines.

Production managers and planners seek savings in every aspect of manufacturing. Proper operation of machinery parks is often associated with the use of the OEE (Overall Equipment Effectiveness) indicator. Calculations performed utilizing the OEE indicator reflect the effectiveness of production machines and are performed with the use of data such as downtime, machine changeover time, failure time, and other factors that may influence the machine's effectiveness. The OEE must first and foremost answer the question of whether the selected machine, process or system is used effectively in a specific time interval.

The equipment utilization efficiency ratio is determined by equation (7):

$$OEE = A * E * Q \tag{7}$$

where:
A – Availability
E – Effectiveness,
Q – Quality.

We calculate the availability ratio by using the planned working time in the expected period, in relation to the real operating time of the machine in an equivalent period (8):

$$A = \frac{APT}{PBT} \tag{8}$$

where:
APT – Actual Production Time,
PBT – Planned Busy Time.

The productivity index represents a normative unit of time in relation to the actual time required to make 1 unit of the product (9):

$$E = \frac{PRI}{\frac{APT}{PQ}} = PRI * \frac{PQ}{APT} \qquad (9)$$

where:
PRI – Planned Run time per Item,
PQ – Produced number of products,
APT – Actual Production Time.

By quality index, we mean the number of good products in the context of the total number of products produced in the indicated time period (10):

$$QR = \frac{GQ}{PQ} \qquad (10)$$

where:
GQ – number of products that comply with quality guidelines,
PQ – number of all products manufactured.

In practice, this indicator is influenced by many factors, which include, above all, time. It is necessary to determine the time interval for the calculations. Here, it is important whether this concerns a single shift, which is usually assumed to be 8 hours of work, or if the calculations are made on a weekly basis. We must also take note of the number of changeovers and the duration of a single changeover. Another key component is the number of goods with losses that do not comply with the requirements of the recipients. The last criterion includes losses caused by failures. Each failure necessitates the cessation or limitation of production. Figure 10 presents a diagram of possible losses in the course of production, as well as their influence on the OEE index.

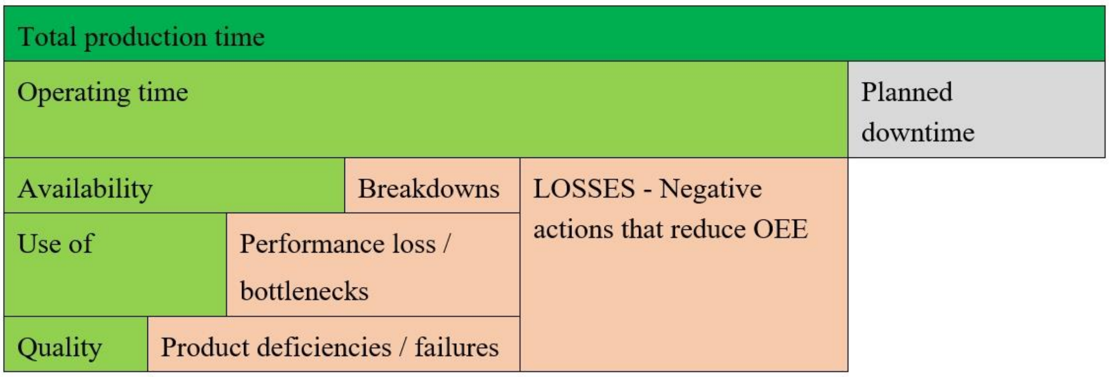


Fig. 10. The OEE indicator [23]

It is also possible to indicate which area reduces the whole process efficiency.

A group of indicators that relate directly to machine maintenance and performance.

MTTR - mean time to repair failure (11):

$$MTTR = \frac{t_A}{n_p} \text{ [min]} \quad (11)$$

where:
t_A– failure time [min],
n_p – number of corrective incidents.

The *MTTR* (Mean Time To Repair) indicator determines the average time from the moment of failure to the time of its removal, i.e., the rate of removing machine failures. The average time from failure to repair is an important marker, especially for UR services in manufacturing plants. It improves the monitoring and analysis of productivity and efficiency, as well as the execution of corrective actions that affect machine availability rate.
MTTF - mean time to failure (12):

$$MTTF = \frac{t_D - t_A}{n_p} \text{ [min]} \quad (12)$$

where:
t_D – time available [min].

The *MTTF* indicator is used to determine the average time to failure. It is very important for processes with lengthy unit operations. The MTTF is directly connected with the *MTBF*, where it is one of the components. The indicator is used by production companies in planning and organizing maintenance processes. The *MTTF* represents the difference of the availability time of a machine and the failure time, divided by the number of failures in a certain time unit.
MTBF - mean time between failures (13):

$$MTFB = MTTR + MTTF \quad (13)$$

MTBF - the performance of a machine park in terms of maintenance. The indicator informs about the average time between one failure and another. With it, companies can verify the time of failure as well as the availability of equipment and machines in use.

In the context of machine availability, in addition to the basic formula, we can distinguish between three states. Availability represents the ability of a machine to remain in a state that allows it to perform the desired functions, under the designated operating conditions and for a set period of time, assuming that all the required external resources are provided. The efficiency of the entire production process is determined by availability, i.e., the degree of use of the planned time, as well as the losses caused by production problems or possible deletions. The first component of availability is related to maintenance and depends on the reliability and maintainability of the technical system as well as the support capacity of the maintenance organization, while the latter depends on the time required for adjustment and tuning.
Ai (Inherent availability), which covers only the technical system (14):

$$Ai = \frac{MMTF}{MMTF + MTTR} \quad (14)$$

Achieved availability *Aa* also considers the organization of UR (15):

$$Aa = \frac{MMTF}{MMTF + MTTR + MTW} \quad (15)$$

Ao (16) (Operational availability) includes both the time for repairs and for preventive work. Only the time during which the equipment has to be stopped is taken into account.

$$AAo = \frac{MTTM}{MTTM+MMT+MLD} \tag{16}$$

where:
MMT (Mean Maintenance Time) is the sum of repair and preventive maintenance times,
MTTM (Mean Time To Maintenance) is the average time between them,
MLD (Mean Logistic Delay) is a measure of the support's capability; it represents the average waiting time for a repair.

The operational capability of a piece of equipment consists of availability, maintenance, operation and operational context.

4. MODELLING PROCEDURES USING FLEXSIM

Process improvement should be preceded by process mapping and modelling. Proper mapping is treated as a starting point for further improvement and modeling. It is impossible to achieve maximum potential without well-mapped processes. When a company is launched, a new department is created in the organization, or an innovative project is introduced, it requires mapping the most important processes.

Queuing is a very common occurrence on production lines, particularly when processes are not properly planned or adapted to the existing conditions. In particular, queues are formed when there are more products to be processed than the available capacity. Queues usually occur when machine utilization is above 70% with a simultaneously high variability of the input flow.

In order to calculate the size of queues, we usually apply the formula used to calculate the average waiting time in a queue (17).

$$\overline{w}_t = 0{,}5(1 + C_v)\left(\frac{\rho}{1-\rho}\right)(\overline{P}_t) \tag{17}$$

where:
ρ – utilization rate,
C_v – coefficient of variation,
$\overline{P}_t$ – average handling time.

Queuing is caused by the high utilization of the service station, as well as the variability of the interval between input requests and the service time. An equally important factor is batch processing, which results in increased handling time since the batch must be completed before it is passed to the service station. Batch processing reduces the number of steps between changeovers and processing. The variability of processing can be reduced through methods that serve to cut down on the setup time required to change the produced parts. Queues are very common and can be simulated through discrete simulations. The importance of the queuing issue and its impact on the performance index is shown in Figure 11.

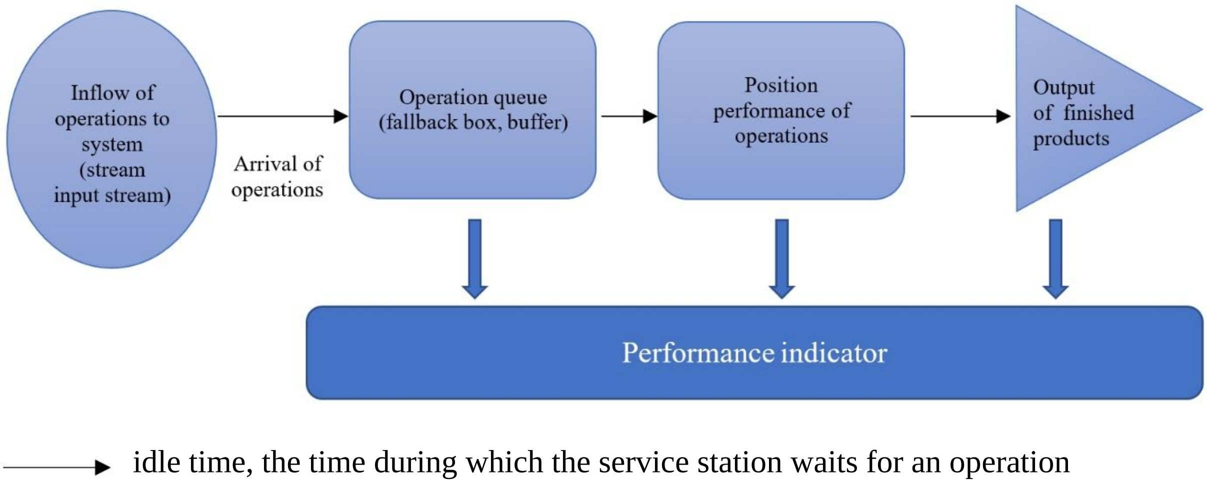


Fig. 11. Queuing issues in processes [24]

Each case of idle time and waiting time translates directly into a performance indicator. When the waiting time is high, the indicator is at a low level. This is reflected in the underutilization of the maximum production potential, the occurrence of costs associated with lost production, low competitive advantage, and the lack of customer confidence.

4.1. Processes for preparing and aggregating enterprise data

The research was preceded by an analysis. From a wide range of production or service companies, we selected a group of enterprises focused on the automotive industry. Next, one company located in the Podkarpackie voivodeship was chosen. The company belongs to an international manufacturing concern, and the main scope of its service portfolio includes the production of metal construction elements for bodies of popular cars, with a specialization in the production of such construction elements as vehicle frames, bumpers, transverse beams, B-pillars, chassis, vehicle floors, and other car body parts.

The production of the company is performed on a large scale, with the parts produced in the Podkarpackie branch being sent to numerous car factories throughout Poland. The real essence of this research lies in the application of the principles of sustainable development and Corporate Social Responsibility (CSR). The activities planned for the next few years of the company's operation consist mainly of continuous improvement and the development of an innovative management system. Figure 12 presents the factors that determine the choice of the company and refers to highly specialized manufacturing enterprises. They allocate a large part of the revenues obtained revenues to permanent development of the provided services and reliability of processes.

The analysis revealed that the company complies with ISO and IATF quality standards, as well as automotive quality guidelines. Production process planning managers have indicated the need for analysis and possible emergencies in the process, as well as the construction of emergency maintenance plans. The activities included in process analysis, together with the design of the contingency plan, are presented in the form of an algorithm (Fig. 13).

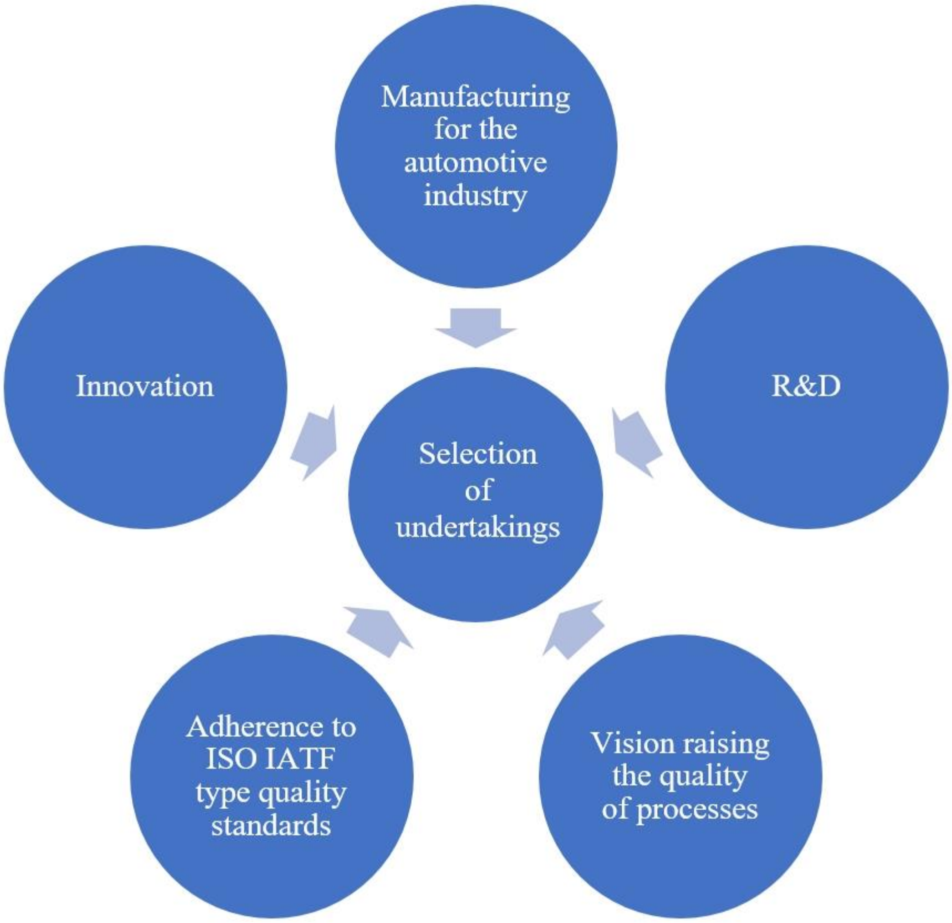


Fig. 12. Factors for choosing a company

The algorithm includes individual steps that affect the correct representation of the production process (Fig. 13). It is correct to indicate all factors which are reflected in the realized services, but it is also crucial to check if the data entered is correct and to analyze the simulation results accordingly. The implementation of a faulty design can cause errors. As a consequence, during an emergency situation, the production will be stopped or will not proceed according to the assumptions of the emergency plan. The manufacturing process consists of the following steps (Tab. 1), (Tab. 2), (Tab. 3), (Tab. 4).

The date and the number of picked coils on the sheet (Tab. 5) were used as the basis to calculate the number of manufactured semifinished products. The table below presents the number of withdrawals of material for the production of the semifinished product ZX01.

The data collected as part of the research was used to identify the level of *OEE* and to calculate *MTTF MTTR*, and *MTBBF*.

The machine park is characterized by the utilization of production machines at a safe level (Fig. 14.). The highest utilization of machine capacity occurs with the welding robot R_24 with a result of 89%. An equally good result was achieved by the progressive press, which is used at a level of 80%. The lowest values were found in welding machines Z_5 and Z_26. The trend line is at 78%. In the case of the *MTBF* indicator (Fig. 15.), defined as the average time between repairs, the highest level is reached by Z_26 with a result of 4,320 [min]. The shortest time between repairs was established for R_28 and P_15 with the result of 864 [min].

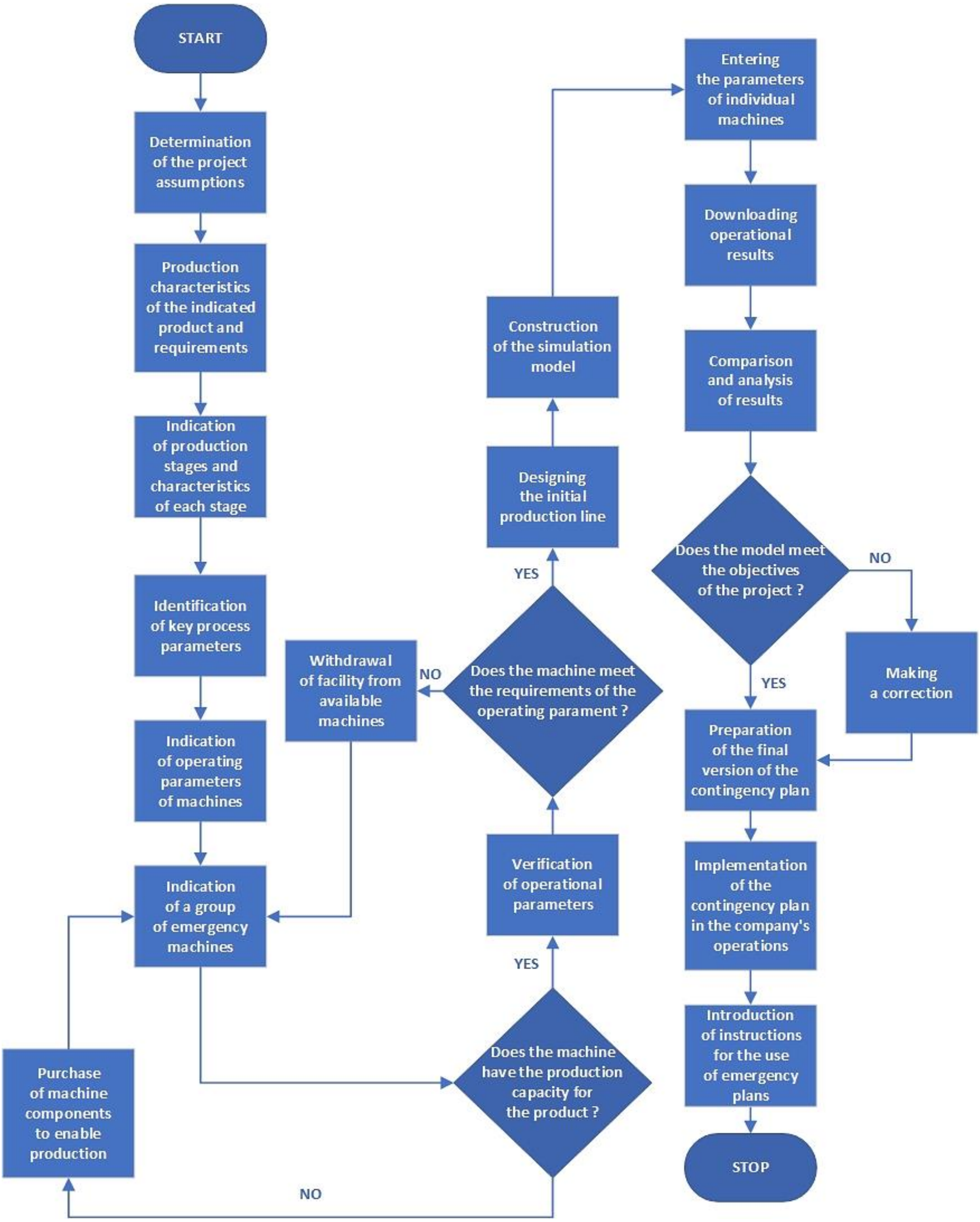


Fig. 13. Algorithm of conduct in the design of emergency plans

Tab. 1

Characteristics of production operation No. 1

No. of operations	**Name of the operation**	**Description of task**	
Operation No. 001	Sheet metal pressing ZX01.00	The sheet comes in appropriate lengths of coil and is then cut into the appropriate size sheet.	
Name of device/machine	**Technical notes**		
P-19 press 250 [t].	Process preparation and warmup 36 min.		**Progressive press**

Tab. 2

Characteristics of production operation No. 2

No. of operations	**Name of the operation**	**Description of task**	
Operation No. 002	Pressing of parts ZX01.01	The finished sheet is fed to the next press, which performs the pressing of ZX01.01 subassemblies.	
Name of device/machine	**Technical notes**		
Hydraulic press P-15 63 [t]	Preparation for the process and warming up of the press 30 min.		**Hydraulic press**

Tab. 3

Characteristics of production operation No. 3

No. of operations	**Name of the operation**	**Description of task**	
Operation No. 003	Spot welding of parts ZX01.02	The nut should be welded to the stamped pieces ZX01.01 on a movable retainer that allows the nut to be held with sufficient handling clearance.	
Name of device/machine	**Technical notes**		

Welding machine Z-26	Process preparation and warmup 36 min.	 **Intermediate product ZX01**	 **Welder**

Tab. 4

Characteristics of production operation No. 4

No. of operations	**Name of the operation**	**Description of task**	 **Sealing robot**
Operation No. 004	End welding ZX01.03	Prepared part ZX01.02 is welded to master part ZC05.	
Name of device/machine	**Technical notes**		
Welding robot R-24	Welding time 36 [s] Preparation of the welding robot 30 min.		

Tab. 5

Specifics of material intake for production

Task No.	Name of task	Date of task	Quantity	Unit	State of material in production
101	Acceptance of material	11.01.2022	2 555	KG	2 555
101	Acceptance of material	11.01.2022	2 555	KG	5 110
261	Consumption of production material	11.01.2022	-1 236	KG	3 874
261	Consumption of production material	11.01.2022	-1 354	KG	2 520
261	Consumption of production material	11.01.2022	-1 353	KG	1 167
262	Return of material from production	11.01.2022	34	KG	1 201
262	Return of material from production	11.01.2022	1 354	KG	2 555

261	Consumption of production material	11.01.2022	-2 421	KG	134
261	Consumption of production material	11.01.2022	-156	KG	-22
101	Acceptance of material	11.01.2022	3 089	KG	3 067
101	Acceptance of material	12.01.2022	2 555	KG	5 622
262	Return of material from production	12.01.2022	19	KG	5 641
262	Return of material from production	12.01.2022	3	KG	5 644
261	Consumption of production material	12.01.2022	-719	KG	4 925
261	Consumption of production material	12.01.2022	-1 869	KG	3 055
261	Consumption of production material	12.01.2022	-48	KG	3 007
262	Return of material from production	12.01.2022	82	KG	3 089
261	Consumption of production material	12.01.2022	-1 571	KG	1 518
101	Acceptance of material	13.01.2022	2 555	KG	4 073
101	Acceptance of material	13.01.2022	2 155	KG	6 228
261	Consumption of production material	13.01.2022	-30	KG	6 198
261	Consumption of production material	13.01.2022	-1 014	KG	5 184
262	Return of material from production	13.01.2022	33	KG	5 217
261	Consumption of production material	13.01.2022	-733	KG	4 484
261	Consumption of production material	13.01.2022	-1 875	KG	2 609
261	Consumption of production material	13.01.2022	-1 873	KG	735
262	Return of material from production	13.01.2022	31	KG	767
262	Return of material from production	14.01.2022	1 875	KG	2 642
101	Acceptance of material	14.01.2022	2 525	KG	5 167
261	Consumption of production material	14.01.2022	-1 237	KG	3 930
261	Consumption of production material	14.01.2022	-1 372	KG	2 558
261	Consumption of production material	14.01.2022	-30	KG	2 528
261	Consumption of production material	14.01.2022	-1 375	KG	1 153

262	Return of material from production	15.01.2022	1 375	KG	2 528
262	Return of material from production	15.01.2022	37	KG	2 565
101	Acceptance of material	15.01.2022	2 540	KG	5 105
101	Acceptance of material	15.01.2022	2 540	KG	7 645
261	Consumption of production material	15.01.2022	-2 546	KG	5 100
262	Return of material from production	16.01.2022	21	KG	5 120
261	Consumption of production material	16.01.2022	-2 560	KG	2 560

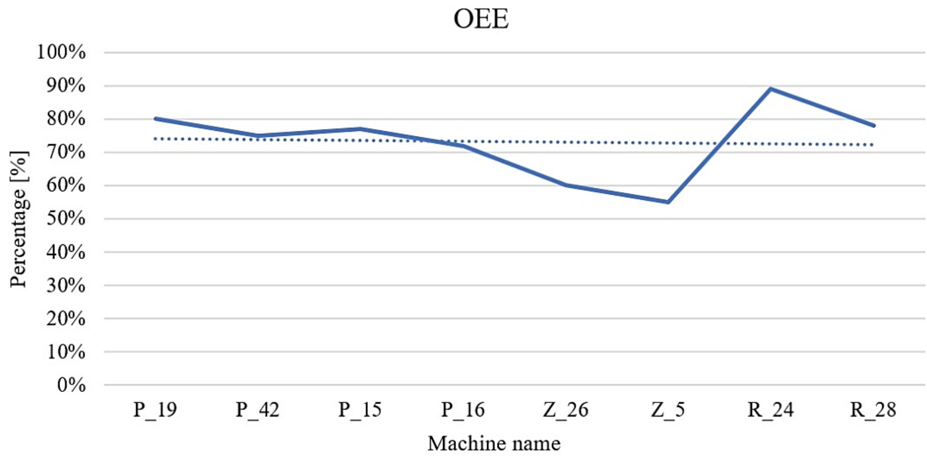


Fig. 14. OEE consumption rate

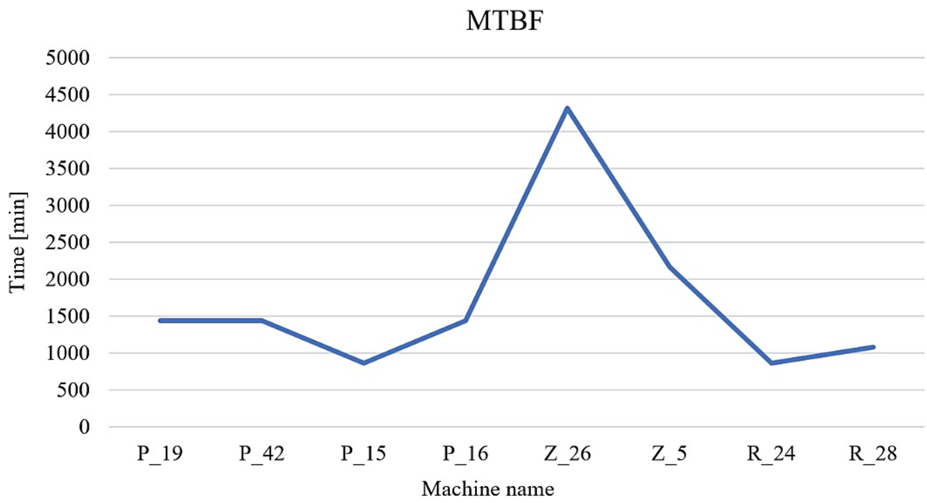


Fig. 15. MTBF indicator

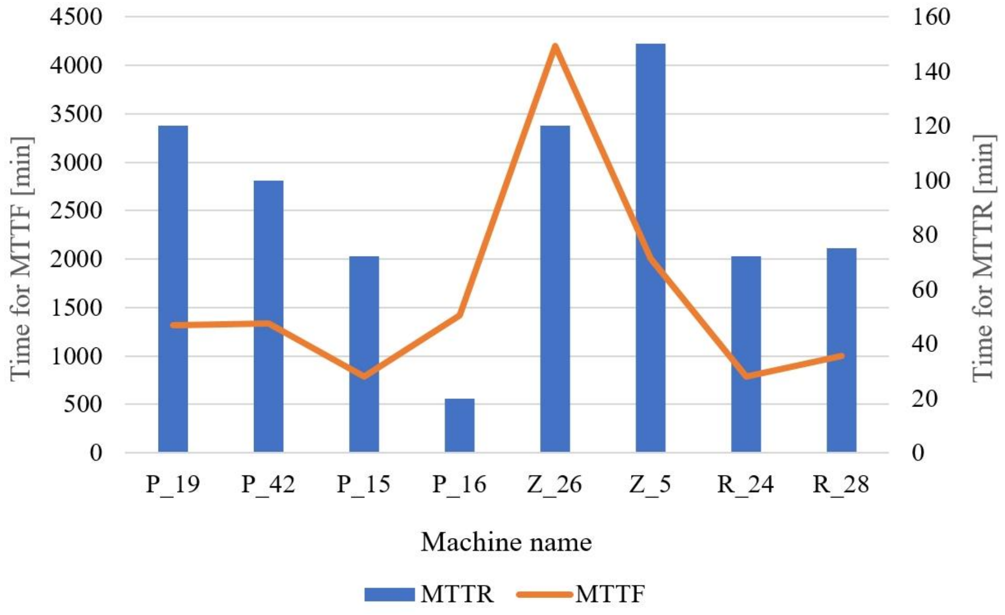


Fig. 16. Breakdown of production machinery

Comparative characteristics revealed the following values in the context of the average MTTR repair time (Fig. 16.). The longest repair time was recorded on machines Z_26 and Z_6, with a result of 150 [min]. The longer repair time is due to the technical specification of the machine; the presented welding machines are very precise and difficult to repair. In terms of MTTF, the longest time between failures was found for machine Z_26. Presses P_19 and P_40 are characterized by a similar MTTF of 1320 [min].

4.2. Flow of the production line testing process on the simulation plane

The analyzed manufacturing process was represented by a simulation model by means of the FlexSim tool. The process takes place in two production halls. In (Fig. 17.), production hall No. 1 has been visualized with a blue color, and the first production operation No. 0001 is performed in the indicated area. Production hall No. 2 has been marked with a yellow color, and it is where operations No. 002, 003 and 004 are performed.

Alternative machines were proposed for the production machines indicated in the model. The following factors were taken into account in the selection of the machines: production capacity higher or similar to the original model, distance from the existing production line, technical parameters, appropriate compression force in the press, welding time of the elements, compatibility of the robots, use of the machines on the shop floor, functionality of the machine allowing mutual substitution, and performance of the indicated operations. The list of alternative production machines is presented in the table (Tab. 6.).

Production hall 1, shown in (Fig. 18), has been updated by plotting on the simulation plane alternative machines proposed from the list of available production machines.

The machinery shown in (Fig. 18) consists of equipment that can replace each other. Each machine in relation to the serial process can be assigned an alternative production machine, or a completely new production line that performs analogous operations can be started up. If production is transferred to an alternative machine, the necessary operating time associated with running the task on the indicated machine must be added.

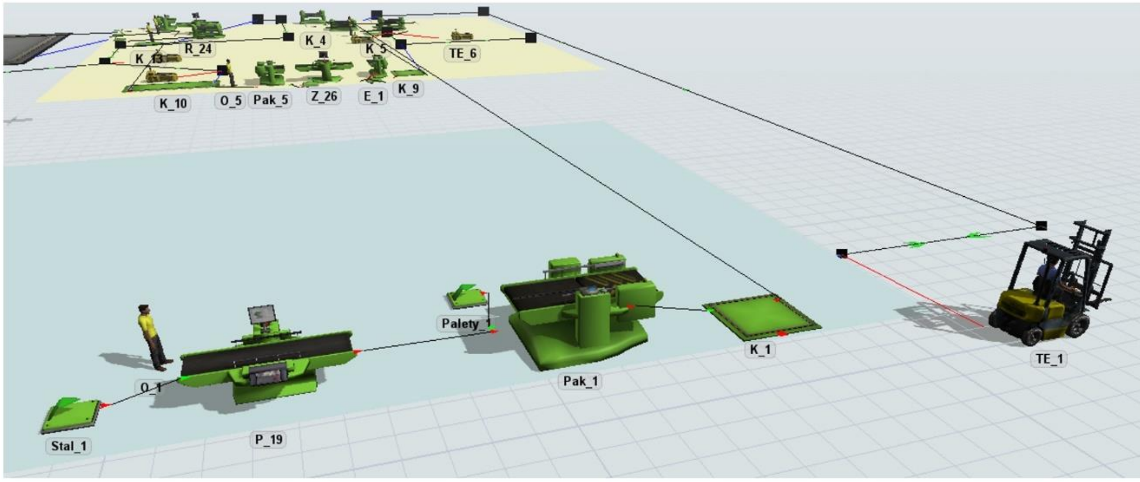


Fig. 17. Diagram of the base production line in hall no. 1

Tab. 6

Alternative machinery

No.	Series process machine	Alternative machine	Reprogramming time
1	P-19 press 250 [t].	Press P-42 400 [t].	Piston change 45 min
2	Hydraulic press P-15 63 [t]	Hydraulic press P-16 63 [t]	Piston change 36 min
3	Welding machine Z-26	Welding machine Z-5	Reprogramming 20 min
4	Welding robot R-24	Welding Robot R-28	Reprogramming 45 min

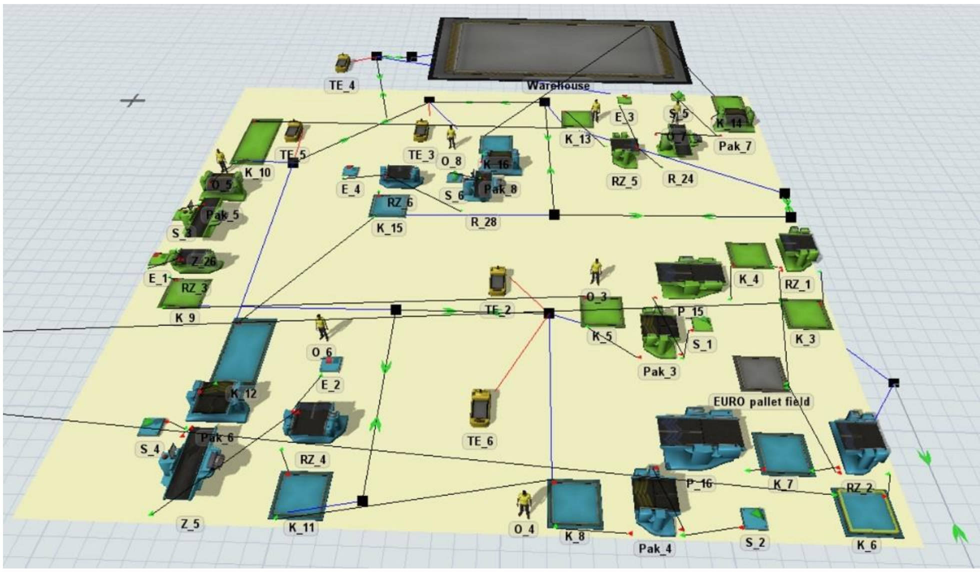


Fig. 18. Scheme of the simulation model hall no. 2

All devices were programmed in the simulation model according to the actual technical parameters of the production machines in the studied enterprise. Repeated reproduction of the simulated production process demonstrated the correct representation of the real process in the FlexSim program. The simulation plane contains the objects included in the table (Tab. 7) with the number assigned according to the order. The time and number of realized processes were comparable by 95%. With such accuracy, the results of the simulations offer a very precise examination of the validity of introducing alternative solutions.

Tab. 7

Objects available on the simulation plane

No.	Name of object in the simulation plane	Description of functionalities
1	Steel_[No.]	Source supplying the steel required to cut the sheet
2	P_[No.]	Progressive and hydraulic presses
3	Pallets_[No.]	Pallet feeder
4	Pak_[No.]	Space for the packaging of components
5	K_[No.]	Storage area
6	O_[No.]	Activity operator
7	TE_[No.]	Transport trolleys
8	Pallet field EUR_[No.]	Storage area for pallets
9	RZ_[No.]	Unpacking area
10	S_[No.]	Source of transport containers
11	Z_[No.]	Welding machines
12	R_[No.]	Sealing robots
13	E_[No.]	The area of removal of redundant elements on the simulation plane that does not affect the time and manner of implemented processes

4.3. Findings on variants of production operations

The initial phase of the research project refers to analyzing and extracting the results from a simulation model where all processes run smoothly and no machine failures occur. In subsequent phases, the downloaded outcomes will enable a comparison of how the indicated process affects the overall services performed.

The planned production schedule is to manufacture 20,280 units of ZX01 parts on the base production line, shown in green in the simulation plane, and, in addition, 11,016 units of ZXM01 parts on the alternative production line, shown in blue in the simulation model.

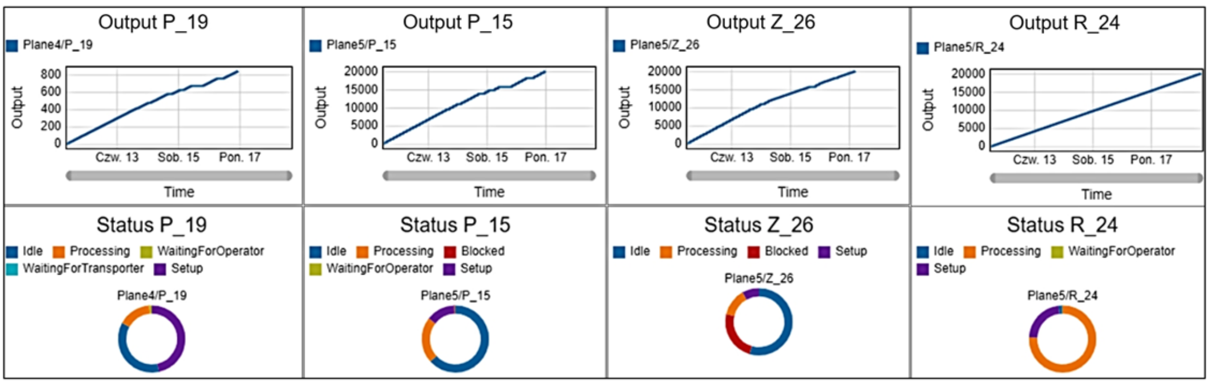


Fig. 19. Utilization of production machines on the baseline

The presented results of operating parameters, taken directly from the objects on the simulation plane, indicate the presence of idle times on progressive and hydraulic presses, which can be optimized by appropriate scheduling of deliveries (Fig. 19). At the same time, the machine's operating status must be controlled so that changes do not cause blocking of the machines in the process. The welding machines are characterized by a high degree of blocking. On the other hand, welding robots are utilized at 75%, which means a good machine utilization rate. The start time of the simulation adopted in the project was set to 11.01.2022 at 8:00:00 a.m. and each subsequently executed simulation variant refers to the indicated hour. The end time of the entire process, under proper conditions and without the emergence of a failure, is 16:43:35 on 18.01.2022. This is a continuous operation without breaks and shifts, all to ensure the readability of results. The total time to complete the task is 176 h and 43 min.

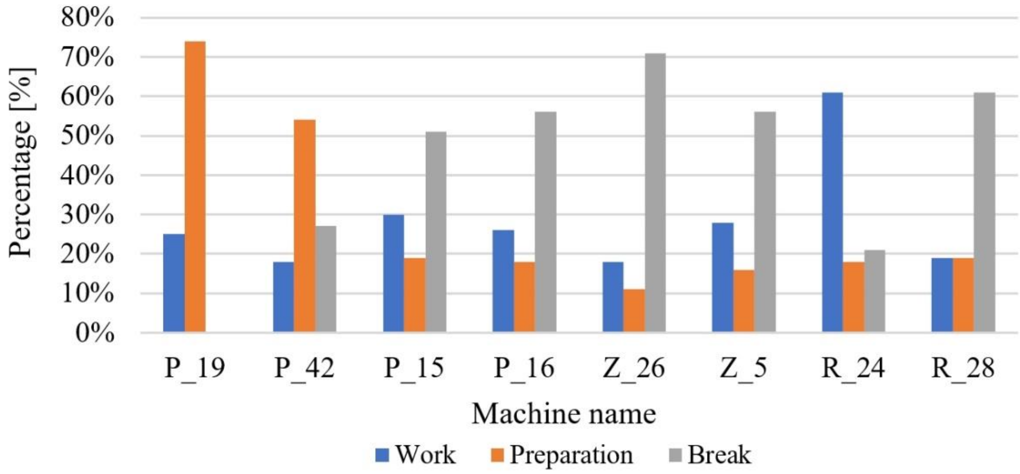


Fig. 20. Efficiency of production machines on the simulation plane

The highest utilization rate in terms of preparation was found for P_19 with 74% (Fig. 20). The scope of the preparation work includes proper sheet metal positioning, securing the part, and similar activities. The highest rate of completed processes was recorded for robot R_24 with a score of 61%, process preparation 18%, and break 21%.

The next stage of the project consisted of simulating an emergency, whereby progressive press P_19 had to be stopped, and all operations transferred to machine P_42.

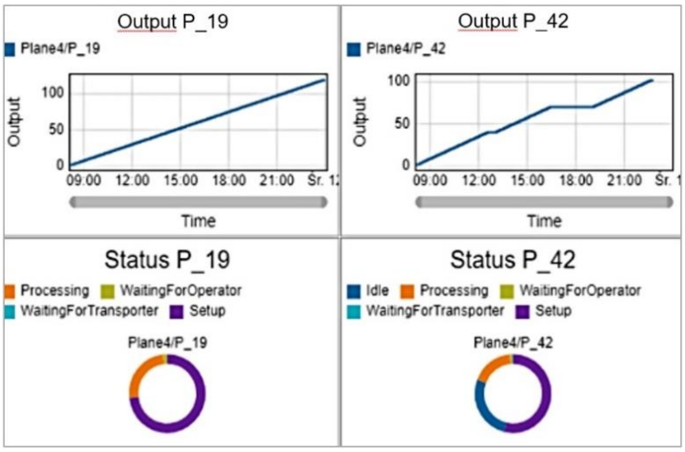


Fig. 21. Comparison of results for P_19 and P_42

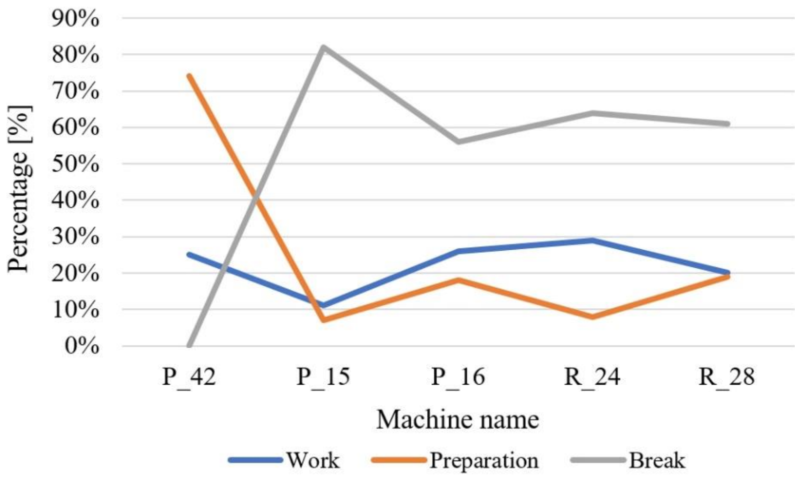


Fig. 22. Activity of machines with variant I

In the first variant of the planned failure simulation, there is a large increase in the break, which is necessary for component change and reprogramming (Fig. 22). Press P_15 recorded an interruption of 82 %, also, robots R_24 and R_28 are characterized by a large number of interruptions at 60 %. Production in the first press P_42 runs without interruption due to the operations assigned from press P_19 (Fig. 22).

The presented results refer to a comparison of the work efficiency of both machines throughout 16 working hours (Fig. 21). It should be noted that press P_42 has an adequate reserve of time in which no activity is performed. The indicated parameters, e.g., the idle time of the machine and its location, should be considered in the context of the relocation of production in case of failure.

The simulation revealed the possibility of using the indicated alternative machine without significantly extending the process. Fig. 23 shows the results for increasing throughput up to the maximum performance of the indicated machine. The total task execution time for the selected alternative machine is 190 h and 34 min.

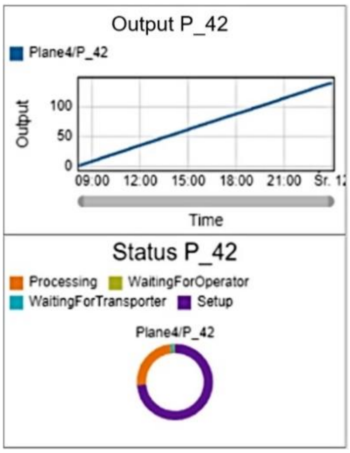


Fig. 23. Press utilization for P_42

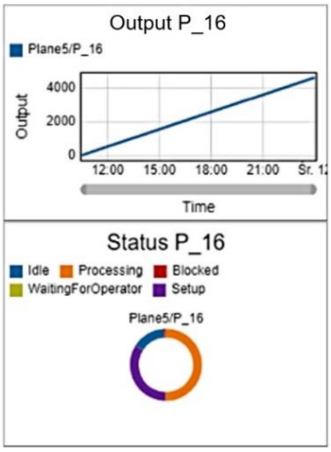


Fig. 24. Press utilization for P_16

In the event of a failure on hydraulic press P_15, an alternative press P_16 with comparable parameters was selected. The behavior during the failure of the pressing process indicates that all the parts that arrive from production hall 1 are redirected from press P_15 to press P_16. The aggregate data shown in Fig. 25 indicate that the redirection of operations to press P_ 16 has not blocked its production capacity, for which there is a safety reserve. The time necessary for completing the job in an emergency situation was 177 h and 38 min, with a machine workload of 55% operation and 30% preparation.

The last variant of the tested simulations involved a complete suspension of production on the "green" line and the assignment of all tasks to the "blue" line. To ensure that the simulation was conducted correctly, a new production plan was arranged, and a division was made into orders resulting from the previously planned operations on the "blue" line as well as orders that had been rewritten from the "green" line. It was also necessary to consider appropriate breaks for reprogramming the production machines.

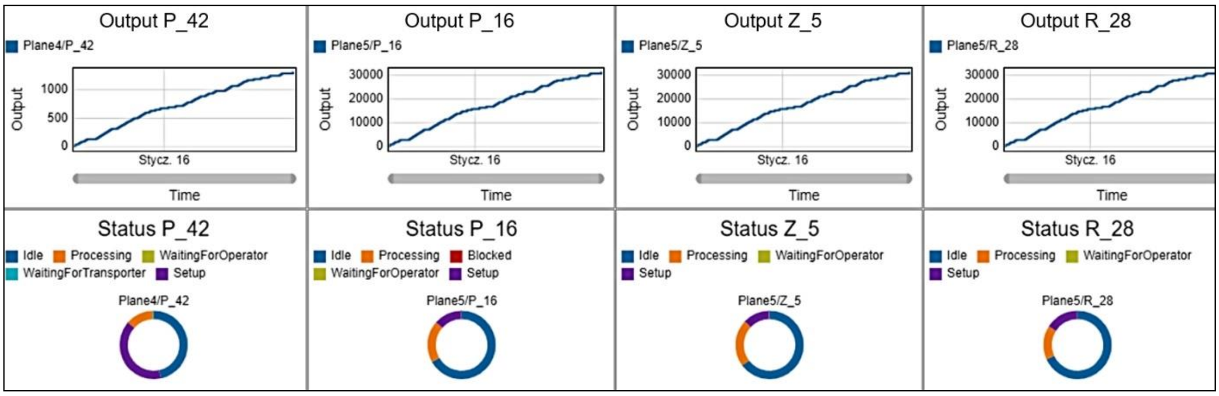


Fig. 25. Results of the use of alternative machines

Changes introduced in the production series decreased the utilization of production capacity in the whole machine park and caused an idle state (Fig. 25). Welding machine Z_5 has an idleness level of 60%; there is also a high idle state in robot R_28 with a result of 68%. Blockage of the whole production line significantly increased the time necessary to perform individual tasks. In the case of starting production on one "blue" line, the total time was 272 h and 59 min.

For visualization purposes, emergency machines are shown in red (Fig. 26). These machines do not perform operational activities. All tasks have been performed by the "blue" line.

The presented raw material delivery plans demonstrate the number of delivered loads for standard production (Fig. 27). On the other hand, Fig. 28 presents a situation where operations must be combined on the blue production line due to the third variant of the failure. Production was extended from 123 h to 269 h. It was also necessary to include technical interruptions in the new production plan, which are essential to reprogram machines.

Emergency situations must be handled according to accepted standards. In order to standardize processes and improve quality, an algorithm has been developed (Fig. 29).

Not every emergency situation is associated with the use of an alternative machine. If repairs occur within 72 hours, production can be stopped and the breakdown reported to the maintenance team for rectification. The decision to introduce an alternative machine, and thus to change the production process, must be approved by the production manager, whose job requires, among others, the selection of the machine envisaged in the list of alternative machinery and introducing appropriate adjustments to the existing production plans.

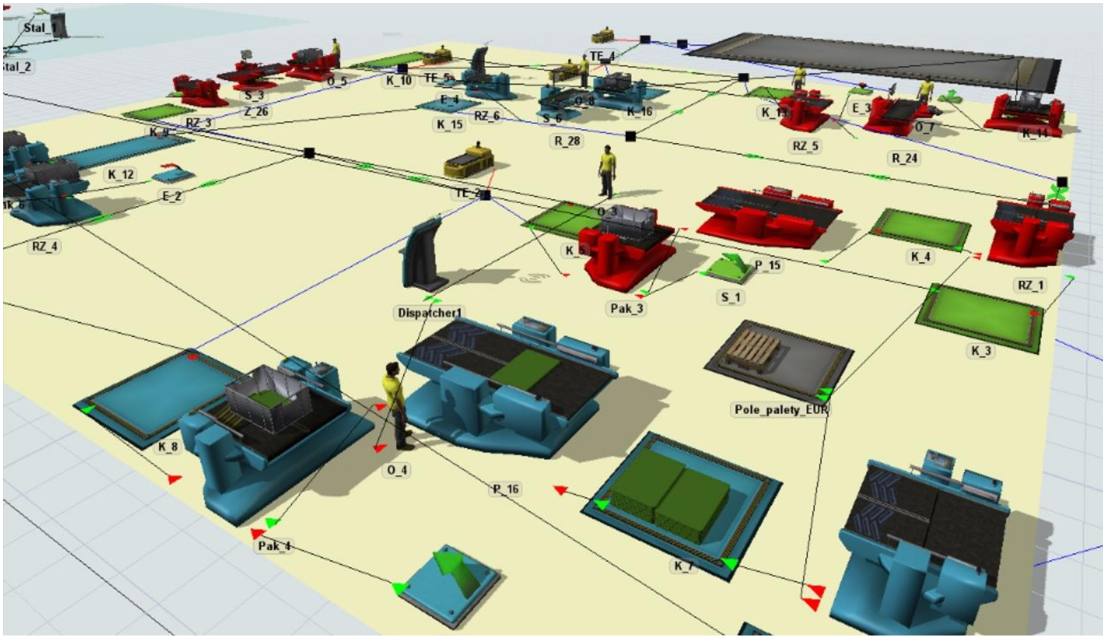


Fig. 26. Simulation model during the execution of operations

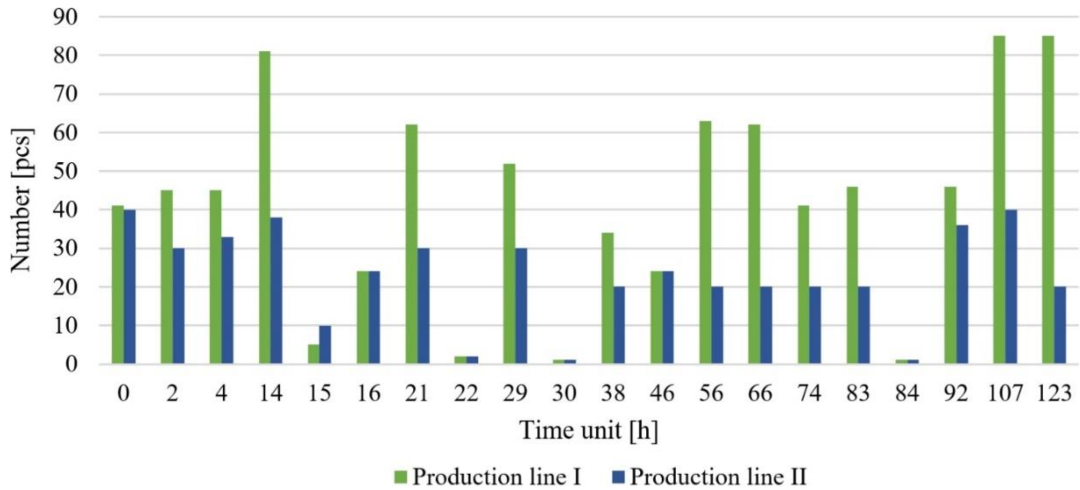


Fig. 27. Number of raw materials delivered

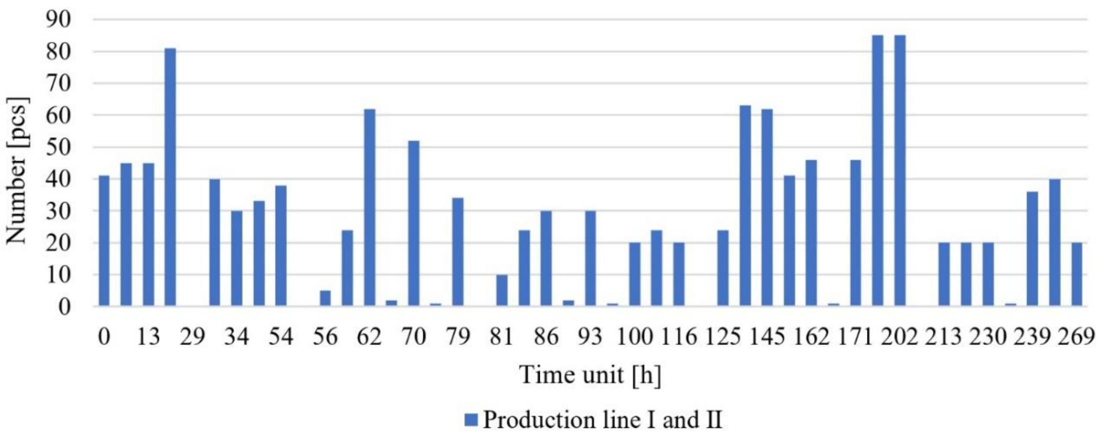


Fig. 28. Plan of raw materials delivered II

Fig. 29. Algorithm of proceeding in emergency situations

5. CONCLUSION

Considering a holistic view of production logistics, the end customer plays a significant role. A particularly important factor in on-time delivery is the company's assurance of a continuous production process. Emergency situations require the management of many variants of production operations, which have an important function. With the sudden appearance of technical problems, decision-making must be quick, especially in the automotive industry. However, it is still important that management decisions are analyzed thoroughly.

The research and analysis performed on a real object indicate the validity of the use of the compiled indicators, algorithms and simulation models in the context of determining the accuracy of emergency plans. Therefore, the posed hypotheses have been confirmed. A simulation model offers the possibility of experimentation without losses for the company, as well as helps to develop an optimal solution. Furthermore, simulations allow us to instantly visualize emergencies, as shown by the authors. On the other hand, modeling production processes brings benefits such as a quick response to emerging threats. The scope of the research included the selection of alternative machines, taking into account their technical and operational parameters. The collected data were used as the basis to program three variants of emergencies, which are characterized by the highest probability of occurrence in the studied enterprise. Appropriate machines were plotted on the simulation plane, including technical parameters and emergency situations. Multiple simulations without stopping production and incurring additional losses allowed to find the optimal solution, i.e., transferring tasks to other objects, which takes place in cases of repairs lasting longer than 72 hours. An analysis of the exploitation parameters allowed us to compare the use of the machine during continuous operation and upon failure.

An important element related to machine failure rate is rate analysis. *MTTR* has made it possible to determine the average time from failure to recovery. Furthermore, it has a fundamental impact on the measurement and analysis of trends in the context of efficiency and the rate of removal of machine failures. The lowest *MTTR* value was characteristic for press P_16, with a result of 20 min, which informs us that the repair of a given machine usually proceeds very quickly. The highest *MTTR* value, and at the same time the longest repair time, is registered on machine Z_5 with a value of 150 min. In this case, it is necessary to improve the repair process or to diagnose the failure faster.

Another indicator considered in the selection of the machines was the *MTTF* index, which represents the average time to failure. Welding machine Z_26 achieved the highest score of 4,200 min, and the lowest value was found for press P_15 and robot R_24 with a result of 792 min. *MTTF* is especially significant for processes with lengthy unit operations. With the help of the results aggregated and analyzed in the company, we also diagnosed areas where failures or process disturbances could occur. The simulation model was used to test variants of operations in order to obtain the optimal solution.

A detailed analysis of the entire production process performed by calculating common indicators of *OEE* is essential for simulation. *OEE* makes it possible to indicate the effectiveness of machines. The use of the indicator in the study provides the answer to the question whether the chosen machine, process or system is used effectively in a certain time interval. In the case of *OEE*, efficiency should be increased for machine Z_5 with a score of 55% and for Z_26 with a score of 60%. In further processes, improvement opportunities can be sought for machines that have a high score but also room for further improvement. Additional enhancements can be realized on press P_19 with a score of 80%, welding robot R_24 with an *OEE of* 89%, and robot R_28 with a value of 78%. The time differences resulting from the tested variants are as follows: in the case of the failure of press P_19, the production was extended by 13 h and 34 min. Variant 2 during the failure of press P_15 resulted in a production extension of only 55 min. The last simulation of variant 3 showed an extension of the realized tasks by 96 h and 16 min. The third variant is characterized by a significant difference in the time necessary for performing services. The longer time results from the complete stoppage of operations on one production line and redirecting the performed tasks to the neighboring line.

The utilization of the capacity of alternative machines is at an acceptable level. No additional bottlenecks are created as a result of task redirection. Furthermore, individual machines are not blocked. An appropriate selection of machines made it possible to perform tasks interchangeably. A changeover of operations on different components requires a proper changeover time, which was taken into account during the design of the new production plan.

The proper operation and use of alternative machines requires the construction of an algorithm for emergency situations. The use of an alternative machine is the last resort, as it requires appropriate procedures for shifting task priorities and creating a new schedule. Due to the specificity of the tasks, a limit of 72 hours was set for the company as the maximum time for repairing the machine. If the company cannot carry out the repair in the set time, it is necessary to implement a contingency plan, which is decided by the production manager or other management staff.

The results indicate an increase in the use of the production potential to its maximum capacity. During the changes in operations, there were also technical interruptions, which meant that the machine was idle at a given moment, but the modifications were necessary to reprogram or replace technical components. Such actions also served to compile instructions for the procedure and standardize processes. The simulations conducted made it possible to introduce an appropriate algorithm to handle failures. In such a case, the management will dispose of the necessary means, such as the tested contingency plans, and thus react quickly to the emerging threat. The use of an analytical approach to aggregate data and parameters from individual machines, as well as to record individual indicators, together with mapping the simulation process, makes it possible to test emergencies and is essential to the overall view of the implemented processes.

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