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Contents

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IMPLEMENTATION OF LOW-COST PRODUCTION OF A SERVICE ROBOT MODEL

Jozef SVETLÍK – Štefan ONDOČKO – Juraj KOVÁČ

Abstract: The main motivation of the contribution was to verify the possibilities of low-cost production with the required parameters on a service robot. The service robot is designed to demonstrate the robotic soccer system using a multiagent controlled system. This was addressed at SjF TUKE with great success. The idea was born to restore a robosoccer team with low costs. Since the actual production of a service robot intended for robot football of the MIROSOT category under the FIRA association is relatively difficult to produce, it is also reasonably expensive. The requirement to modify the structure using the latest knowledge in construction and production technologies leads to interesting results. The progressive production technology of the CCF (Continuous Carbon Fiber) type from the Markforged company was used in the production. With this relatively cheap technology, it is possible to produce Continuous Fiber Composite.
Keywords: Continuous Carbon Fiber, Continuous Fiber Composite, robosoccer

Introduction

Current trends in manufacturing technologies are characterized by an increasing demand for efficiency, sustainability, and advanced materials. One such material that has garnered significant attention in recent decades is continuous carbon fiber (CCF). Due to its exceptional mechanical properties, such as high strength, low weight, and excellent corrosion resistance, this fiber has found widespread application in various industries – from aerospace and automotive to sports equipment and renewable energy [1].

Progressive manufacturing, often referred to as advanced manufacturing technologies, encompasses a range of innovative processes and methods that improve efficiency, productivity, and environmental sustainability. One such method is the integration of continuous carbon fiber into manufacturing processes, which enables the reduction of material and energy consumption, extends the lifespan of products, and enhances their performance. While traditional manufacturing methods for composite materials, such as hot forming or laminating, offer reliable results, advancements in additive manufacturing and automation are opening new possibilities for processing carbon fibers. The aim of this article is to provide an overview of the current state of progressive manufacturing with a focus on the use of continuous carbon fiber, identifying the main technological challenges and benefits of this integration, as well as presenting new approaches to improving mechanical properties and optimizing processes. The discussion will also focus on future development prospects, particularly in the context of sustainable and intelligent manufacturing, enabling even broader and more cost-effective use of carbon composites.

Initial parameters

In the MiroSot category, robots have limited dimensions, up to max. 7.5x7.5x7.5 cm and weigh max. 600 grams. This category is divided into two leagues, each with a different number of robots and the size of the football field. Each match is played by two teams consisting of either 5 robots (Middle League) or 11 robots (Major League). The process of improving robot designs using 3D printing can help solve many of the problems developers face in the field, such as the complexity of manufacturing parts, limited materials, and limited resources. It is expected that the results of this research will be useful for the further development of robofootball and contribute to the emergence of more efficient, comfortable and productive robots in this interesting field of sports and technology. The task is to develop and optimally design a robotic soccer robot using 3D printing. This includes analyzing existing solutions, identifying their advantages and disadvantages, and designing and manufacturing new parts that meet the requirements we will consider, such as stiffness, strength, and weight [2-4].

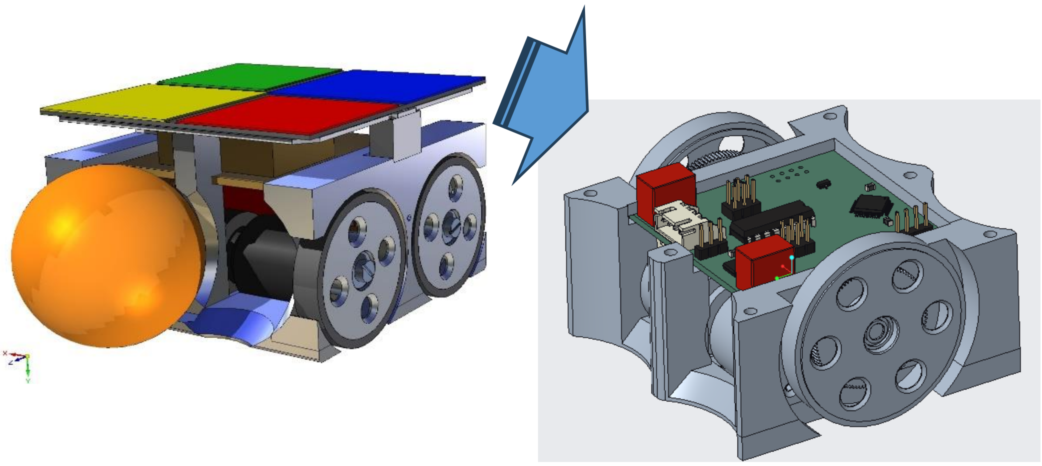

Fig. 1 3D model of a service robot with a 4x4 drive made to order by CNC machining (on the left) and a 3D model of an optimized - simplified robot, intended for 3D printing.

Optimized object of production – service robot

The robotic soccer player whose construction we will reconstruct and optimize is basically a service robot, with specific requirements, namely: size, weight, structural ability to keep the ball moving - these are the main requirements from Mirosot, and we can also separate the requirements that meet our needs , namely:

- Maximum possible speed in the forward direction (optimal transmission and grip).
- Maximum possible speed in a turn (the robot's center of gravity as low as possible, max. grip wheels to the mat).
- Maximum possible acceleration (powerful motors and batteries, suitable design arrangement).
- Ability to "carry" the ball without loss during direct movement (suitable blade shape).
- The ability to "carry" the ball without losing it when changing direction.
- Reduce the effect of the change in shear friction to a minimum (suitable structural arrangement).
- Impact resistance (mechanical robustness of all parts).
- Respect international FIRA rules (e.g. max. dimensions 75x75x75mm,
- Weight max. 600g, team color rule, use of radio frequencies, etc. ...).
- Ambidextrous (reduction of reaction time when turning in place).
- Reliability (custom design of the entire mechatronic system).
- Battery life for at least one final half (minimum 7 min + possibility of fast charging or replacing batteries).
- Safe operation (no sharp edges, dangerous LiPol "motor" batteries).

• Simple assembly and disassembly (routine repairs before and during matches).
• Simple maintenance (absence of special equipment).
• Low acquisition and operating costs.
• Easy manufacturability (technology).
• Prevention of overheating of motors and batteries (motors are overloaded).
• The same dynamic properties in both directions of movement (center of gravity in the center of the robot).

The design corresponding to the mentioned requirements is shown in Fig. 2.

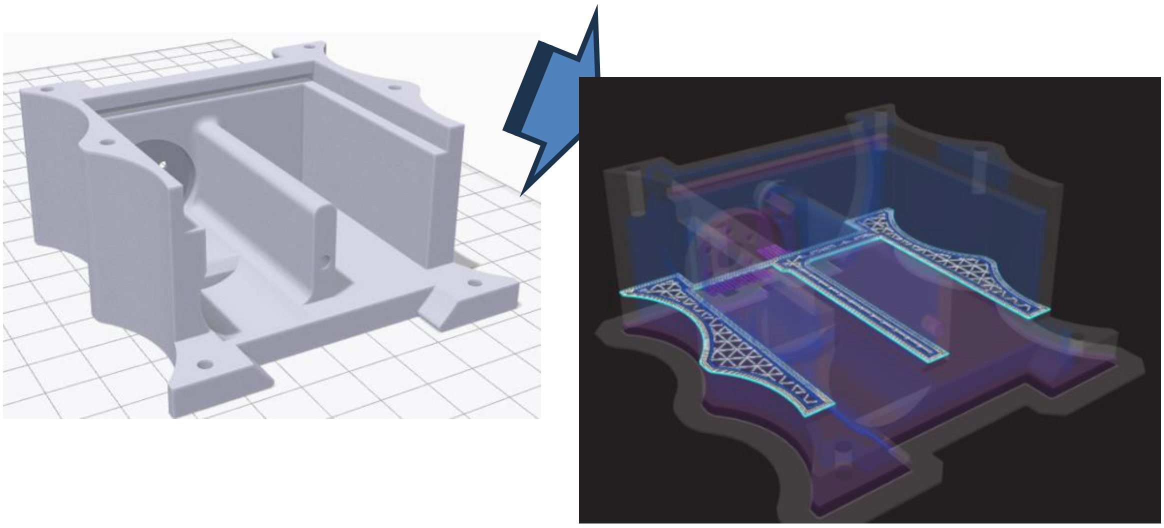

Fig. 2 3D model intended for slicing (on the left) and slicing process - preparation for 3D printing in Eigher software [1].

In Fig. 2 is an illustrated 3D model of a service robot intended for printing. The actual preparation process for the Markforged Mark Two 3D printer is done in the Eigher software.

Continuous Fiber	Test (ASTM)	Carbon	Carbon FR	Kevlar®	Fiberglass	HSHT FG
Tensile Strength (MPa)	D3039	800	760	610	590	600
Tensile Modulus (GPa)	D3039	60	57	27	21	21
Tensile Strain at Break (%)	D3039	1.5	1.6	2.7	3.8	3.9
Flexural Strength (MPa)	D790[1]	540	540	240	200	420
Flexural Modulus (GPa)	D790[1]	51	50	26	22	21
Flexural Strain at Break (%)	D790[1]	1.2	1.6	2.1	1.1	2.2
Compressive Strength (MPa)	D6641	420	300	130	180	216
Compressive Modulus (GPa)	D6641	62	59	25	24	21
Compressive Strain at Break (%)	D6641	0.7	0.5	1.5	—	0.8
Heat Deflection Temp (°C)	D648 B	105	105	105	105	150
Izod Impact - notched (J/m)	D256-10 A	960	810	2000	2600	3100
Density (g/cm³)	—	1.4	1.4	1.2	1.5	1.5

Fig. 3 Parameters of materials used on Markforged printers [5].

The process of preparing the laying of continuous fibers, which are used for reinforcement, can be seen in dark blue. The orientation, density and number of fibers can be changed.
Also, the materials of the fibers and base material can be changed, according to the specifications of the material manufacturer and the printer. The parameters of the used continuous fibers are shown in Fig. 3.

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Conclusion
Following this development, the production of robotic football players is possible without the use of expensive processes such as milling and can also be carried out on a regular 3D printer. This greatly simplifies the task not only for robot soccer constructors, but also for ordinary amateurs. Furthermore, our work paves the way for further research in the development of multi-agent systems, which can be useful in many applications. Of course, future research opportunities include further optimizing the design, integrating advanced control technologies, and improving mechanisms to achieve better robotic soccer performances.
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STREAMLINING PRODUCTION AND ASSEMBLY PROCESS: CASE STUDY

Ján ZUZIK – Ľuboslav DULINA – Marián MATYS – Mariana MÁCHOVÁ

Abstract: This case study focuses on the analysis and proposal of guidelines for improving efficiency and management in work environments through the improvement of production and assembly processes. Identified issues include uncontrolled material storage and chaotic working conditions in production settings. The primary outcome of the study is the development of proposed guidelines aimed at addressing these challenges. Additionally, the article discusses future research directions emphasizing the detailed formulation and subsequent validation of proposed measures. This approach aims to refine manufacturing practices and expedite project timelines. By systematically addressing identified inefficiencies through structured guidelines and empirical testing, the study aims to propose effective solutions for enhancing operational efficacy and overall project management within manufacturing contexts.
Keywords: industrial engineering, assembly process, production process, case study

Introduction

In today's dynamic industrial environment, continual improvement of manufacturing and assembly processes is critical for the success and competitiveness of companies [1]. Effectively managing these operations is not only about cost reduction and enhancing performance, but also about achieving higher standards of quality and adapting flexibly to dynamic market conditions [2]. Enhancing manufacturing and assembly flows enables companies to achieve better outcomes and strengthen their capacity for innovation and growth [3].

Therefore, systematic improvement in these areas is crucial for managers and professionals in the industrial sector committed to achieving excellent results in their operations [4]. This approach not only supports the maintenance and enhancement of competitiveness in today's globalized market environment but also contributes significantly to reducing project lead times, optimizing finances, and increasing resource efficiency [5].

Reducing project lead times enables faster product delivery to market and better responsiveness to customer demands, crucial in today's fast-paced business environment [6]. Similarly, reducing costs through improved manufacturing and assembly processes provides companies with more financial resources for further research and development investments, thereby enhancing their innovative potential [7]. This holistic approach to manufacturing and assembly management is thus foundational for long-term sustainable competitiveness and business growth in the global market [8].

Case study

The case study aimed to enhance the manufacturing and assembly process. The case study was conducted at Company 1, a consulting firm specializing in digitalization, automation, and robotization.

A specific project was examined, in which Company 1 worked for an unnamed Company 2 to improve the production and assembly process. As part of this project, relevant procedures were reviewed and improved. Company 2 manufactures an interior element for cars. Company 1 was responsible for overseeing the construction of an assembly line used to assemble this automotive interior element. The assembly of this line took place at Company 1's location in Slovakia.

In the Fig. 1, a image of a sample part of the ceiling panel assembly line is presented. This image illustrates the detailed design and layout of the assembly process, highlighting the key components and machinery involved in the efficient production of the automotive interior element. The visual representation provides a comprehensive overview of the assembly line's configuration and functionality.

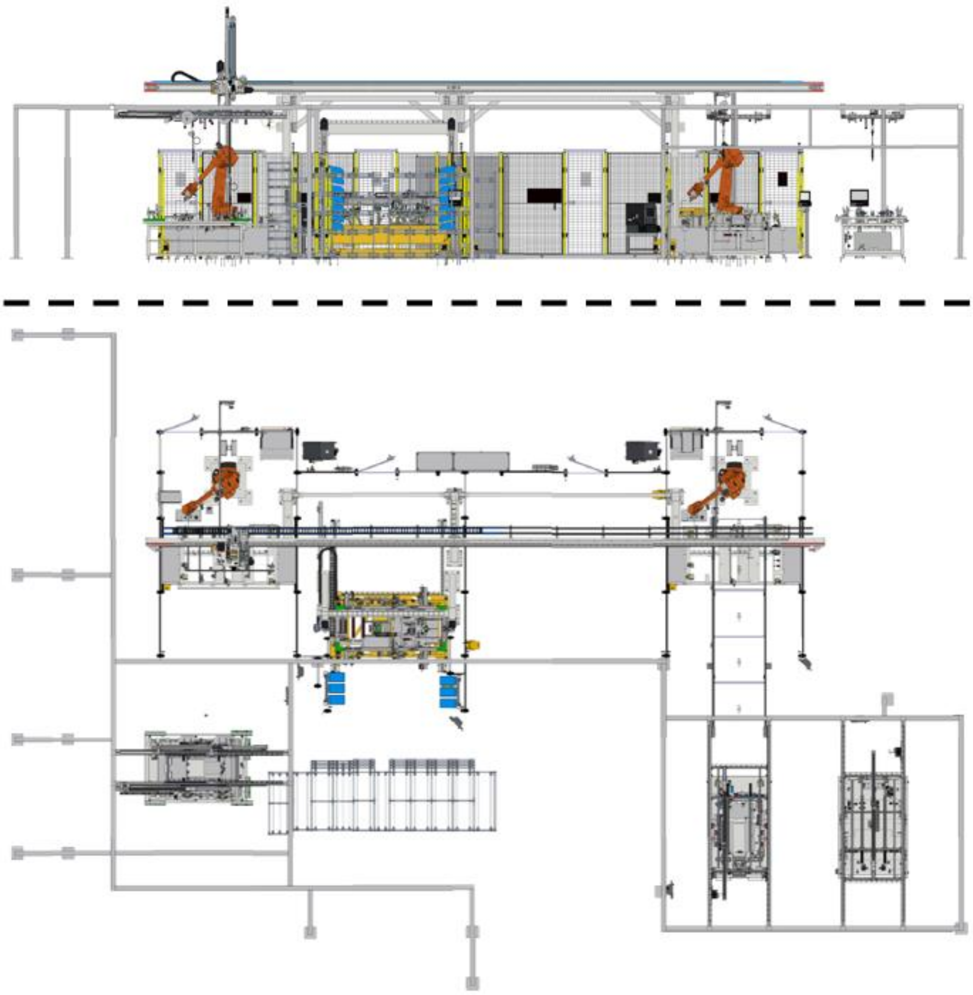

Fig. 1 An assembly line for ceiling panels [Source: Authors]

Company 1 follows standard project management processes, which encompass various stages such as:

- Handling customer inquiries.
- Creating offers.
- Accepting project orders or providing services.

- Generating computer-aided Design (CAD) models and documentation.
- Material procurement process.
- Production and assembly process of the product.
- Installation and startup at Company 1.
- Programming and activation of the product at the customer (Company 2).
- Complete handover and creation of the handover protocol.

This article specifically focuses on one of these project activities, namely the production and assembly processes, addressing their improving.

Description of the current state of the production and assembly process

The current state of the production and assembly process is characterized by a lack of regulation and the absence of comprehensive guidelines for employees to follow. This deficiency in clear and valid procedures leads to various issues such as inefficient use of time and resources, delays in the process, and disorganization in material handling. Additionally, the inability to track material usage in real-time and insufficient coordination in managing multiple projects simultaneously significantly extend project durations and decrease productivity. These problems are elaborated further below.

The current production process suffers from a lack of segmentation, with material being issued from the warehouse in bulk for entire projects, resulting in several inefficiencies. The process is unregulated, as material is supplied without records of its usage in the project. There are no standard procedures in place, leading to sporadic material issuance, often in large quantities, such as on a single pallet, without any systematic management. This lack of organization in the issued materials causes wasted time during searches and extends the project duration.

Materials intended for production and assembly are typically placed on a single pallet or shelf without any systematic arrangement, causing workers to lose track of specific components and unnecessarily prolonging the project through time-consuming sorting.

In the production hall, multiple projects often run concurrently, but storage and organizational systems are inadequate to support this. This results in a lack of space, inefficient storage, and occupied areas by issued materials that are needed for subsequent projects.

The space within the production and assembly areas is not utilized efficiently. This inefficiency stems from poorly managed material issuance processes that lack predefined rules. Consequently, space utilization is suboptimal, leading to complications in managing multiple projects, extended project timelines, disorganization, wasted time, and an increase in non-productive activities.

Overall, the current state of the production and assembly process is characterized by inefficiencies in material issuance, space utilization, and the concurrent execution of multiple projects. These issues contribute to extended project timelines, increased non-productive activities, and overall inefficiency in the production and assembly processes.

Fig. 2 Production and assembly area of Company 1 [Source: Authors]

In the Figure 2, production and assembly areas are depicted. These are situated adjacent to warehouses within Company 1. From Figure 2, it can be observed that the production hall of Company 1, utilized for production and assembly, is spacious. However, it accommodates a large amount of material stored for projects, leading to chaos, disorder, and confusion. With multiple projects concurrently underway, this space is challenging to effectively utilize. Consequently, this results in an uncontrollable and nearly dysfunctional production and assembly process, thereby extending the overall project completion time.

Proposal of recommended solutions

The chapter proposes recommended solutions focusing on the establishment of a comprehensive guideline for production and assembly processes. Emphasizing the guideline's pivotal role, it aims to provide clarity on operational procedures, ensuring structured and efficient workflows. Fig. 3 illustrates the proposed guidelines for the production and assembly processes. The first step involves verifying the availability of all components required for product assembly. A decision is made regarding the need to order materials, following standard procedures of the material and stock procurement department if necessary. If no further materials are needed, the process proceeds to the second step. The outcome of the first step is the issuance of an order. In the second step, product assembly and completion occur according to production documentation and scheduled production order dates, resulting in the finished product. The third step involves material ordering, managed through purchasing department standards, resulting in the procurement of necessary materials or services. The fourth step involves device configuration and setup, while in the fifth step, basic device functionalities are tested, generating a test protocol as output. In the sixth step, a decision on device functionality is made based on the test protocol. If satisfactory, the process moves to step 7; if not, it returns to step 4. The confirmed test protocol is the output of this step. The seventh step focuses on developing project-related documentation for client handover and informing stakeholders. The output is the accompanying project documentation. Finally, project completion and handover to the customer are confirmed as per project specifications.

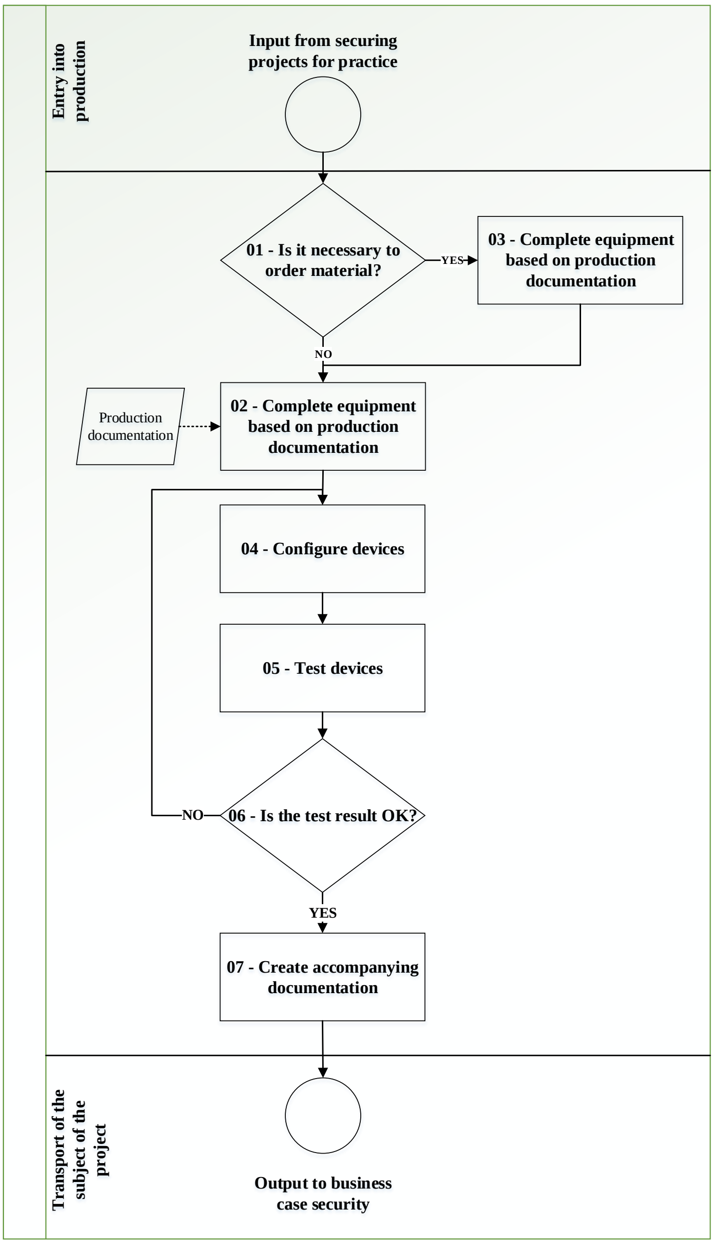

Fig. 3 Proposal for the creation of a guideline for the production and assembly process [Source: Authors]

Conclusion

In the concluding section, a guideline was proposed for the production and assembly process, aimed at addressing identified issues such as uncontrolled material storage and chaotic working environments. Implementation of this guideline could mitigate these problems and improve process efficiency. Further attention should be directed towards resolving specific issues identified in the current state analysis, and proposing specific solutions that could be tested and verified for their efficacy. Future studies could evaluate the effectiveness of these solutions in practice, aiming to optimize production and assembly operations and reduce overall project completion times.

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ANALYSIS OF THE USE OF INNOVATIVE TECHNOLOGIES IN MANUFACTURING IN SLOVAKIA

Erik VARJÚ - Juraj KOVÁČ - Peter MALEGA - Ján KOPEC

Abstract: Thesis contains theoretical knowledge of innovative technologies, innovative technologies for production, implementation risks and a detailed description of innovative technologies like automation and robotics. The aim of this thesis was to analyze the use of industrial robots in Slovak manufacturing companies. In order to develop this thesis we used method of analysis and comparison, using a graphical representation. Data originating from the 2018 survey, how Slovak companies implement innovative technologies, namely automation and robotics, for their own production.

Keywords: Industrial robots, innovation, company, manufacturing, automation

Introduction

In today's highly competitive and volatile market, innovation and good management are essential the basis of the company's success. They help him maintain a competitive advantage and orient himself in the changing operating environment of the company. So, we can confidently say that innovate is the driving force behind the development of every society today. The aim of this thesis was to analyze the use of industrial robots in Slovak factories. The method of analysis and comparison was used to develop this work, while using graphic representation. The data comes from a 2018 survey of Slovak businesses implement innovative technologies, namely automation and robotics, in their production. The survey includes questions such as number of employees, complexity of the manufactured product, year of establishment, annual turnover, series production, etc.

Introduction to the theory of innovation

American scientist Joseph Shumpeter, of Austrian origin, is considered the founder of the theory innovations. In 1911 he compiled the so-called "combinations of developmental changes", which we understand as going beyond the recovery of systems and certain processes in a closed circle. He identified five characteristic changes:

- Use of new production techniques, processes and production assurance
- Introduction of new products or change the properties of the original products
- Use of new raw materials and materials
- Changes in production, distribution and sales
- Changes in market structure, opening of other markets

This field received a new term in 1935, "innovation" understood as "change with the aim of trying to use new types of goods, means of production and transport, newly opened markets and ways of organizing production and services". [1]

Introduction to robotics

Robotic technology has changed the manufacturing industry ever since the first industrial robot was introduced used in the early 60s. Development of flexible solutions where production lines are possible quickly to re-plan, adapt and structure for new or slightly changed products is still a big one a problem. Today, industrial robots are largely pre-programmed for their tasks, unable to detect errors in its own performance or robustly interact with complex environment and human workers. This development is even more important when it comes to different species collaborative robots. Full robot autonomy, including natural interaction, learning from person and with person, safe and flexible performance of work under demanding conditions v unstructured environments will remain out of reach in the near future. According to the current the direction in which today's factories are innovating their production, we can assume whether it will already be the case in domestic ones or office environments, humans and robots will share the same workspace and perform various object manipulation tasks in a collaborative manner. [2]

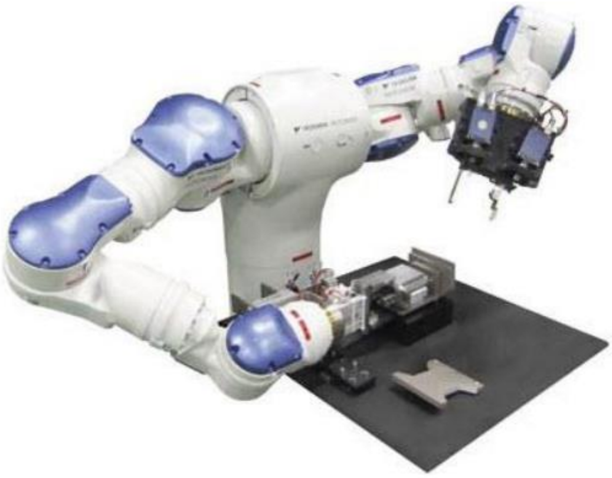

Fig. 1 Autonomous industrial robot [2]

Mobile industrial robots

With advances in control and robotics, it can perform tasks such as delivering products mobile industrial robot. This additional flexibility in production can save the company time and money during the production process, resulting in a cheaper final product. [10] Mobile robot technology has the potential to revolutionize many industries industry, but it carries with it certain disadvantages. Production logistics will be made more efficient by robots will enable you to navigate autonomously to different areas of your work. [3]

Fig. 2 Mobile industrial robots [4]

Analysis of the use of automation and robotization in Slovak companies

In thesis, we use the results of research taking place in Slovakia within the framework pan-research European Manufacturing Survey. A total of 114 companies answered in the survey.

Based on the classification question at the beginning, which divided the companies according to the used technology, it can be said that 5% of plants (6) can be classified as High Technology, 15% of plants (18) Medium-High Technology, 27% of plants (32) Medium-Low Technology and 53% of plants (61) Low Technology. [5]

The graph (fig. 3) was created according to the designation of the NACE code, which divides companies according to the technology used and at the same time it tells us what industry the given factory is dedicated to, whether it is the production of pharmaceuticals products, electronics, chemical products, engineering industry, etc.

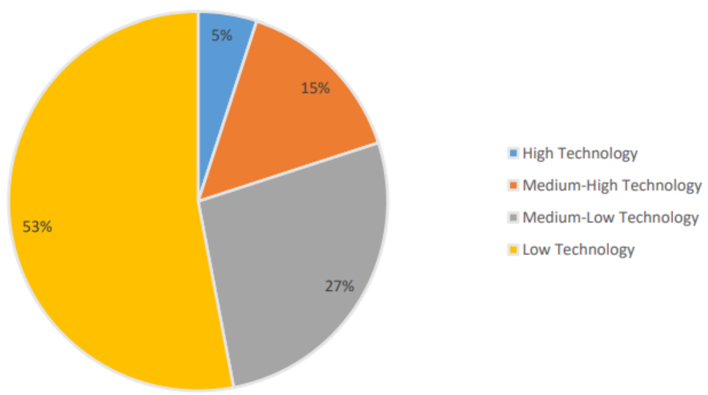

Fig. 3 Divided companies according to their technological maturity

In the next point (fig. 4), we have already specifically focused on the use of industrial robots in plants with different levels of technology. The graphic representation shows that the best is High Technology where 50% of factories use automation in production. They are followed by Medium-Low Technology and Low Technology, where the percentage of plants is very similar, 40% and 38%. The worst on that is Medium-High Technology, where it is only 28% of plants. It follows from this graph that there is no clear connection between technological the maturity of the industry and the use of industrial robots.

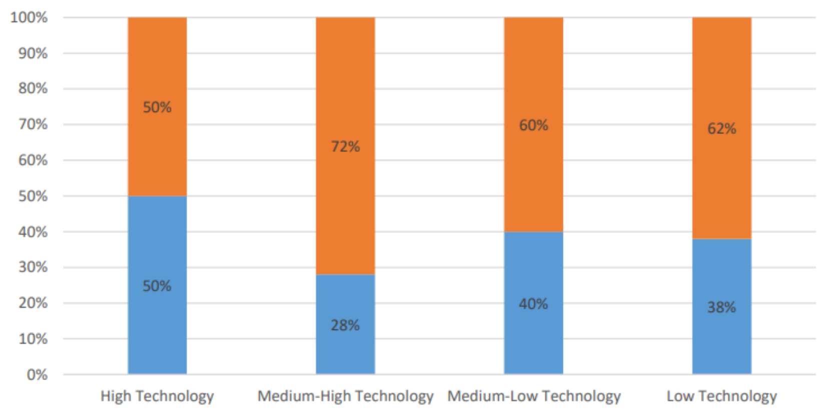

Fig. 4 Comparison of the use of robots according to the technological maturity of the industry

We can compare the resulting data with a survey carried out in plants all over the Europe in 28 countries (Fig. 5). The graph shows us that the automotive industry together with the metal industry uses robotization the most. At the same time, we see a comparison from 2017 versus 1995, where the automotive industry has the highest growth. Robots are classified by International standard industrial classification of all economic activities.

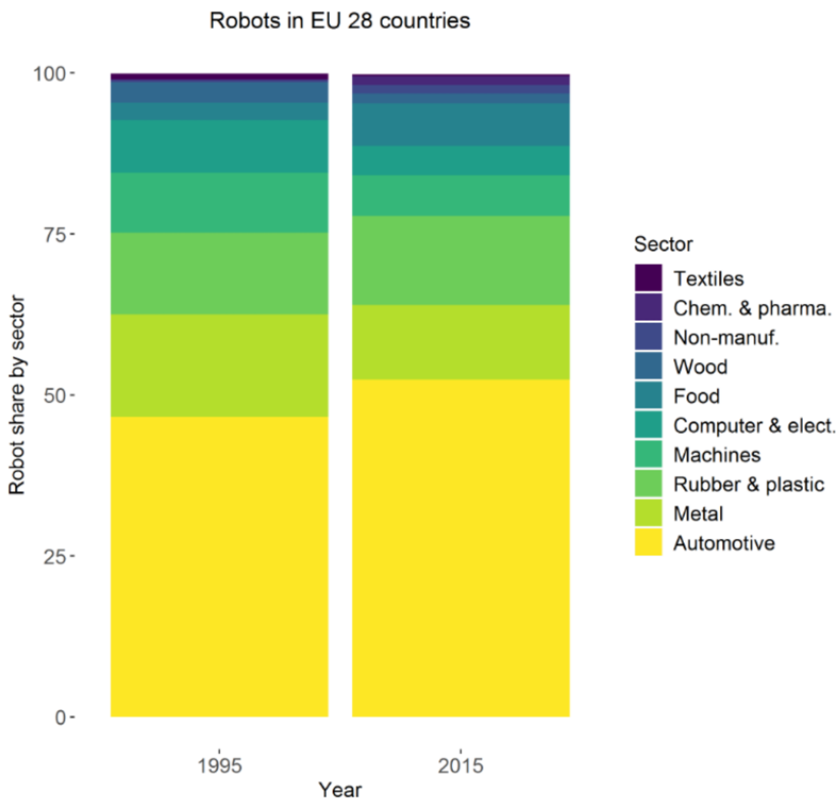

Fig. 5 Robotization in 28 countries by sector [6]

From fig. 5 it is obvious that almost all industrial robots in Europe are deployed in production, mainly in four sub-sectors – automotive industry, metal processing, rubber and plastic products and manufacturing machines. These industries use more than 80% of all industrial robots. In order to we obtained relative data on the rate of adoption of the robot in production, independently according to the size of the economic one sector, we define robot density according to the number of robots per 1000 employees. This metric is also sometimes called "robot intensity" and is widely used in the robot literature. [6]

Conclusion

In the analysis, we found that the use of robotization in production is related to the number of employees in enterprises and annual turnover. A larger percentage of plants with more than 250 employees are using robots versus factories with 50 to 250 employees and the smallest percentage of small plants uses them. It is also used by a higher percentage of plants with an above-average annual turnover are using industrial robots compared to companies with low turnover. Also batch/batch size in plants is related to the use of robotics. A higher percentage of mass production enterprises use industrial robots as a percentage of enterprises with small series or piece production. We have similarly compared the complexity of the product and we found that a high percentage of plants with complex products use robotics in production, compared to factories with the production of moderately complex or simple products.

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OPTIMIZATION OF PROCESSES USING SIMULATION

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Abstract: Over the past decade, simulation software has emerged as a crucial tool for managing and controlling business operations. The latest software advancements enable businesses to achieve superior outcomes through optimization techniques such as genetic algorithms. This paper explores the application of modeling and simulation in enhancing shipment and sorting processes via genetic algorithms. The developed algorithm and simulation model aim to optimize the processing times for shipments and the number of workers required. Utilizing the commercially available Tecnomatix Plant Simulation software combined with genetic algorithms, the study focuses on reducing processing times and identifying the most efficient solutions for given inputs. This approach has yielded superior results compared to traditional heuristic methods and is notably less time-consuming. The core of this paper details the algorithm used to ascertain the optimal number of workers in sorting warehouses, along with the outcomes of its implementation. The concluding section evaluates this new approach against conventional methods and underscores the benefits of these improvements. The primary objective of this research is to determine the workforce needed to expedite shipment departures and optimize worker workload.

Keywords: Simulation software, Business process management, Optimization, Genetic algorithms, Shipment processing, Sorting processes

Introduction

The shipping industry is still figuring out how to manage its processes in a cost-effective and efficient manner. As a result, several delivery companies seek out cutting-edge solutions to improve customer experience and revenues. Whether it is a company with a large or small volume of shipments, it is always necessary to adhere to specific transport standards of, and solutions to, the sorting process. In a delivery company, every process is closely linked; it must therefore respond flexibly to every change and error in the process. This means that the delay of one element of a shipment and sorting processes will be reflected in the next process [1,2]. Today, modelling and simulations are commonly used for all production or logistics companies. Due to the sensitivity of delivery processes, finding the optimal solution with the highest possible quality is necessary. Simulation can be especially useful in cases involving a complex system with dynamic inputs and conditions. It can be used not only for the determination of a future object’s state but also to determine the optimal path to achieve this state. Genetic algorithms (GA) are commonly used to generate high-quality solutions, as well as to optimise and search for problems by relying on biologically inspired operators such as mutations, crossover, and selection [3,4]. The advantages of such algorithms include, for example, the ability to implement GAs as a “universal optimiser” that can be used to optimise any type of problem belonging to different areas. Genetic algorithms in the field of logistics are an area of interest for many researchers. As will be demonstrated further, this technique can solve practical problems that occur in logistics companies. There are many areas where genetic algorithms find application in optimisation, such as artificial intelligence, robotics, services, automatic control, manufacturing, and warehouses [5, 6]. The article’s main purpose is to highlight the advantages that optimisation in the form of simulation using genetic algorithms can offer to the stated case study of applied research in a sorting depot. The fundamental goal of optimisation is to obtain the most feasible time structure for sorting processes while maximising the utilisation of labour resources. The result is a process for determining the number of workers for the sorting depot for a certain number of shipments at various time intervals, using genetic algorithms to construct simulation experiments.

Materials and Methods

Genetic Algorithms

A genetic algorithm (GA) was utilized to identify the optimal solutions for various processes within the simulation model, as detailed previously. The genetic algorithm is a fundamental stochastic optimization technique with significant evolutionary features. It intelligently uses random selection from a specified search space to address problems. By handling multiple tasks simultaneously, a GA enables a comprehensive search for the best solution. It is currently the most widely adopted evolutionary optimization algorithm, with numerous theoretical and practical applications.

Tecnomatix Plant Simulation and Genetic Algorithms

Tecnomatix Plant Simulation, a Siemens PLM Software tool, is employed for modeling, simulation, analysis, visualization, and optimization of manufacturing systems and processes, including material flow and logistics operations. This tool allows for the integration of virtual device models with real-world plant management to simulate actual production environments. Using this integrated simulation approach, various aspects such as control, automation, material transport, and technical operations can be tested and optimized. The principles of genetic algorithms in Tecnomatix software mirror those in biology. The best solutions are selected from a pool of potential solutions and used to generate new ones, leading to better solutions in subsequent generations. The simulation model provides a fitness value to determine if the proposed solution is advantageous and should be used to create a new solution. The model indicates the processing time for each proposed sequence [7]. Genetic algorithms are advantageous due to their versatility and ability to produce satisfactory results. Consequently, they are well-suited for supporting numerous simulation-based optimization tasks. Genetic algorithms can address a wide range of problems without requiring extensive time to develop and adjust simulation models. By employing an iterative approach, genetic algorithms solve optimization challenges. The simulation model assesses the viability of proposed solutions based on specified fitness parameters. The optimal solution is identified after completing optimization cycles and can be used for future modeling.

Results

As mentioned earlier, Tecnomatix Plant Simulation 15.2 software was employed to develop the simulation model. This software allows for the insertion and modeling of items, ensuring that the modeled objects closely resemble the real ones in terms of size and shape, thus providing highly accurate distance and time estimates. It also includes a worker function, which enables researchers to simulate workers' behaviors and actions, such as sorting, carrying, unloading, and loading. The primary component of the simulation model is the conveyor system, which distributes consignments to sorters and then to conveyors and transport trailers Fig. 1.

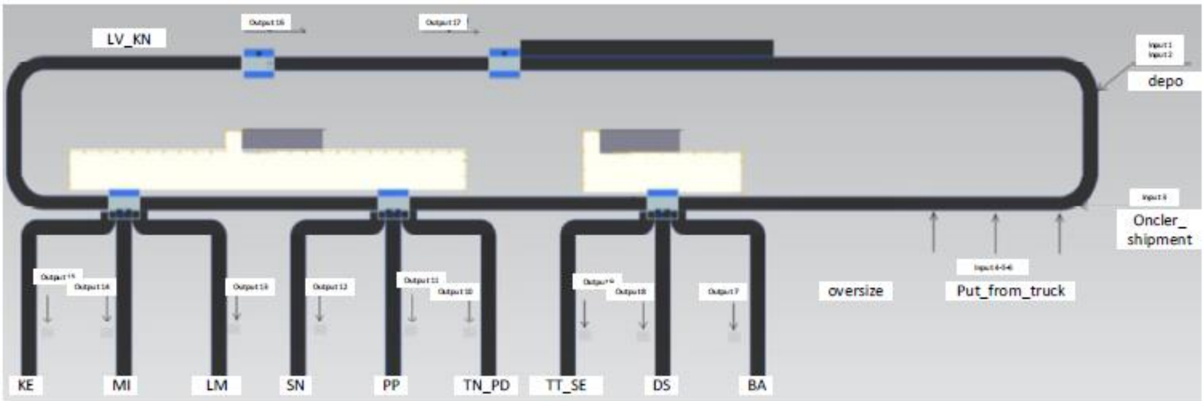

Fig 1. Conveyor system of sorting in the warehouse and workplaces

The model includes three key input locations for shipments. Input 1 represents shipments brought in by couriers. Input 2 is designated for letter items, and Input 3 is for large quantity shipments from a single shipper. Consignments brought in by trucks from various locations are represented by Inputs 4, 5, and 6. Without simulation, decisions are made about which worker performs specific activities, with an estimated 21 workers currently, but their utilization is low due to poor coordination of activities. The model assumes that no more than three trucks can unload simultaneously at Inputs 4, 5, and 6, as shown in Figure 7. Outputs 7 to 16 represent workers assigned to remove consignments from the conveyor belt, inspect them, and place them in trucks for loading.

Following validation and verification, a simulation model was created based on the current state, including all necessary objects and demonstrating appropriate accuracy. The model is shown in 3D in Fig. 2.

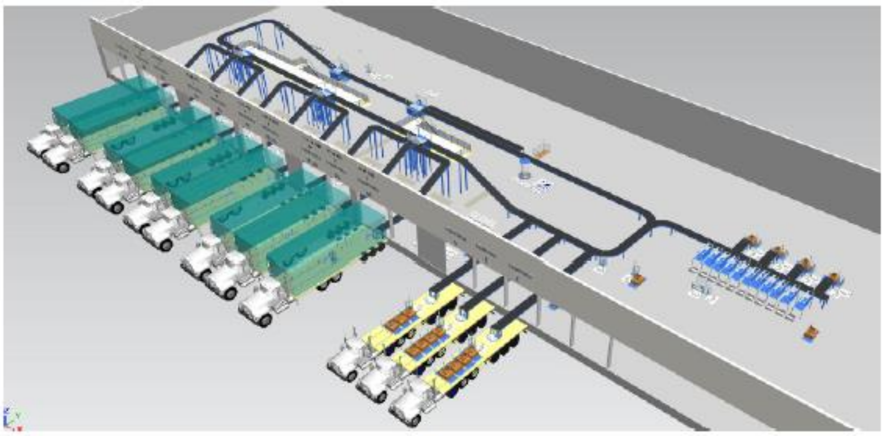

Fig 2. Actual simulation model in 3D view

One of the model’s main constraints is the simulation runtime. The quantity of bales for each direction and the estimated arrival time of sorting trucks are known 4 hours before sorting begins. Up until this point, past data can be used, but they do not yield reliable results.

For the simulation, 8330 consignments were used to compare the current situation regarding the number of workers and truck departure times. The daily cost for one permanent employee is EUR 9, and for part-time employees, it is EUR 6. The cost of failing to arrive at the next processing location on time is EUR 6 per minute. The departure of the last sorted vehicle must not exceed 5 hours 40 minutes to avoid these fees. Without the simulation model, the number of employees was estimated based on a conventional table, which indicated seven employees per 1500 shipments. Consequently, 42 staff members are ready for the simulation. The simulation results show that with this number, the end time is 5 hours 28 minutes 53.42 seconds, with an occupancy rate of 20%. The GAWizard function in the software allows for defining the target function, which includes the value to be optimized and weighted. The loading time of the last truck and the number of personnel were the two functions. Each simulation run aimed to minimize personnel and expedite the departure of the last truck. A fitness function was established, with worker number optimization weighted at 1 and truck departure time at 0.5.
To optimize employee numbers, integer variables representing employees were created, corresponding to zones where they perform specific tasks. The zones and activities optimized are listed in Fig. 3.

ZoneA	ZoneB	ZoneC	ZoneD
Carry_SN	Carry_BA	carry_dep_I	Sorting_oversize
Carry_TN_PDCarry_PP	Carry_DS	carry_depo_II	Carry_input_from_track_A
Carry_LM	Carry_TT_SE	carry_depo_III	Carry_input_from_track_C
Carry_MI	Delivery_oversize	carry_depo_IV	Carry_input_from_track_B
Carry_KE	Carry_TN_PD	carry_oncler_shipment	
Carry_LV_KN	Carry_PP	Carry_input_from_track_A	
		Carry_BA	
		Carry_DS	

Fig 3. Range of activities in different zones

The genetic algorithm identifies the best fitness function by combining various factors. The models contain both variable and constant elements.
These variables are defined in the GAWizard under “problem definition,” specifying the lower (1) and upper (10) limits for the number of workers and the increment step (1) for each zone. The increment step determines the number of experiment simulations. The number of observations (3) and generations (20) is also specified.
Using genetic algorithms, optimization began based on input data. After each simulation, the value is checked, and another experiment is constructed, reducing the number of experiments needed. With 960 simulation runs completed for 320 experiments with three observations, each generation showed improvement. Without genetic algorithms, 10,000 experiments with three observations would be necessary. Fig. 4 shows the development of fitness values for the best, average, and worst solutions in each generation. For a 16-core CPU, the simulation and test planning using genetic algorithms took a total of 21 minutes and 20 seconds. Conducting all 10,000 experiments would take 11 hours 6 minutes and 40 seconds, which is impractical for timely temporary staff allocation. In terms of costs, the company employs four regular employees and several day-to-day recruits. The resulting costs include staff, temporary workers, and penalties for delayed truck departures. These costs are used as benchmarks.

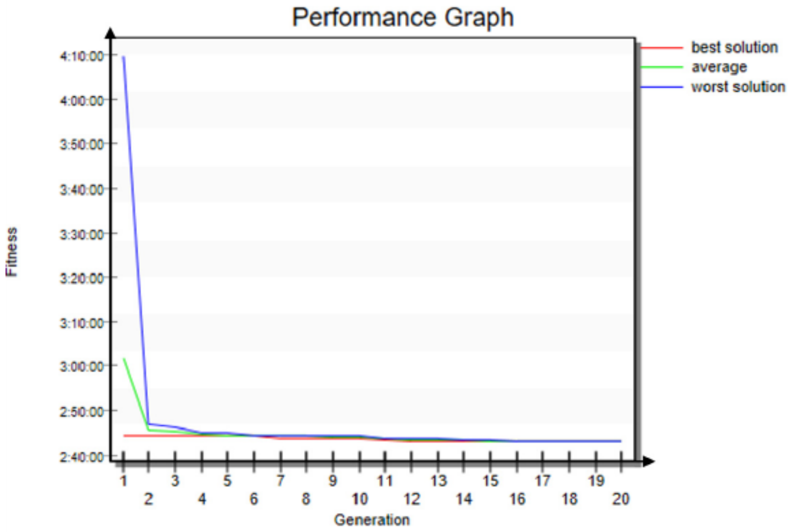

Fig 4. Graph showing the development of fitness values for the best, average, and worst solution in each generation.

After running the experiments, the best solutions were recorded, with the corresponding fitness values shown in Fig. 5. The number of workers specified for each zone is indicating a 25% reduction in workload. Utilization cannot be used as a performance metric, as higher values can only be achieved by reducing personnel or changing truck arrival times, which are not feasible.

Fitness	End of the Simulation	Number of Employees	Costs (EUR)
2:43:23.5794	5:26:07.1587	20	451.11
2:42:49.5336	5:24:59.0671	20	451.00
2:43:01.1835	5:25:22.3670	20	451.03

Fig 5. Best results in optimisation using genetic algorithms for three observations

Conclusion

Rough estimates often lead to resource wastage due to inaccuracies. Modern computing technologies and simulation software enable precise outcome predictions without disrupting real systems. In dynamic settings like logistics warehouses, accurately determining the number of personnel needed to maximize efficiency is challenging. The goal is to minimize workers while ensuring sorting trucks depart promptly. This article presents an algorithm to optimize the number of workers in a sorting warehouse and demonstrates its effectiveness. Tecnomatix Plant Simulation software and genetic algorithms were used to predict staffing needs. The algorithm helped reduce the workforce by 52.38% while maintaining truck departure times, cutting costs from EUR 727.70 to EUR 451.00. Simulation helped prevent labor resource wastage and significantly shortened the time required to find the optimal solution, needing only 320 experiments instead of 10,000. This study confirms the effectiveness of genetic algorithms in logistics, showcasing their practical application beyond theoretical discussions. The advancement of computing technology and simulation tools paves the way for more businesses to implement genetic algorithms, solving real-world industrial challenges.

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OPTIMIZATION DESIGN FOR FINALIZED MODIFICATIONS OF PRODUCTS

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Abstract: The presented article deals with the analysis of the current state of the production line of final modifications of engineering products and its optimization with the help of technological innovations in the field of automation. In the first step, a detailed analysis of the current state of polishing of engineering products was carried out, and then a simulation in the simulation software Tecnomatix Plant Simulation was used to propose an optimal solution for the mentioned process. The article also provides an evaluation of the proposal from a time and financial point of view.
Keywords: automation, optimization, lean manufacturing, production line, ball stud**.**

Introduction

At this time, industrial enterprises already have relatively more advanced technology in the field of production processes, but it is not only this sphere. Logistic or transport processes are also sufficiently modernized. However, there are still some gaps in certain production processes that are capable of additional optimization. Thanks to current technological innovations, there is the possibility of any improvement in the production process and thus bringing it closer to full-fledged Industry 4.0.

Description of the finalization of engineering products

Within the presented article, the issue of the polishing line itself will be addressed, where the current state of the production process and its parameters, its layout will be described, and then the main problems of the process will be highlighted. The current state of the station for polishing ball studs allows final treatment for a maximum of 3,800 pieces in one eight-hour shift with a half-hour break, but it also includes several shortcomings that reduce the overall efficiency of the line in its work. The overall line and its respective parts such as suction or the tank with polishing paste can be seen in Fig.1. The entire layout of the polishing station also includes places for storing unpolished and finished modified pieces, a stand for polishing wheels, which are used depending on the reference of the ball pin, and also a table for the operator, or control station.

Fig. 1 A preview of the polishing line

The following Tab. 1 contains an overview of the individual necessary activities of the complete polishing cycle of 232 pieces of ball studs and the respective times of the individual activities. The polisher itself performs its work for only 1375 seconds out of a total of 1683 seconds for one complete cycle, which is 81.7%. The other almost 19%, or approximately 312 seconds, is carried out by the worker by loading, transposing and other relatively useless activities. The current cycle time of the total work of the polisher is in the range of approximately 7.25 to 7.37 seconds. The cycle time per production worker is approximately 1.55 seconds, which is 21.38% of the total cycle time. This area will be the subject of the presented optimization proposal with the considered automation of the polishing center. Considering the entire 7.5-hour shift, 18.4 cycles are performed, which would result in a cycle time of 6.31 seconds.

Tab. 1 Time overview of individual operations

Activity designation	Total time [s]
Loading pieces into a KLT crate (according to the reference)	26
Loading 232 pieces into "nests"	230
Loading "nests" and KLT crates into the polisher	17
Activating the cycle on the control panel and on the robots	13
Inserting the movable pallets of the polisher inwards	8
Polishing process (polishing time in active state)	1375
Extending the movable pallets of the polisher outwards	8
Moving KLT crates onto a pallet	29
Removing empty "nests"	3
Current cycle time of polishing pieces	5,7
Total cycle time for one 7.5 h shift	6,31
The time of the polisher in the inactive state during the first cycle	308 – 334
The time of the polisher in the inactive state during the second and subsequent cycles	78
The total time of a person at work	292 – 318

Layout of the line

The position of the polishing center and its necessary components is given by the layout, where all the parts and spaces used in the complete process of finalization of engineering products by polishing are marked. This layout is shown in Fig. 2.

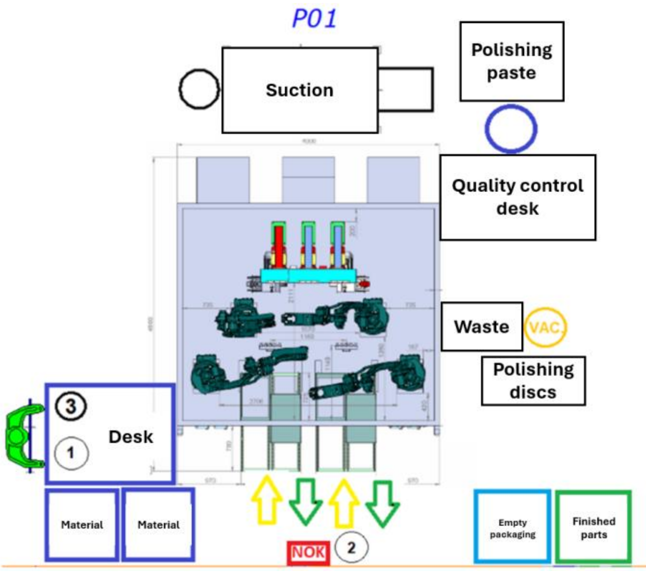

Fig. 2 Layout of the polishing line

As part of the optimization proposal, attention will be paid to the process of loading 232 pieces of ball studs into the prepared "nests" and their transfer. Said process will be automated using magnetic arm automatic feeders with gravity guidance to the grasping robot, increasing efficiency and eliminating unnecessary and repetitive manual work. Thanks to this, the production worker would not have to perform this activity, and thus there would be no need for constant maintenance of this line. The already mentioned time for this activity would be saved, i.e. 115 seconds for one "nest", taking into account the total cycle time. The proposed automation expressed in Fig. 3 contains several new implemented elements. It is a step conveyor with a container for several pieces, linear vibrating lines with a distributor, a two-story transport system for the entry and exit of KLT crates, an elevator for these crates, a flowmeter for monitoring the flow and dosage of the polishing paste and the necessary electronic cabinets with protective barriers for moving parts . These technological systems will be applied to eliminate unnecessary manual activities, increase output and potentially reduce cycle time for polishing a single ball stud.

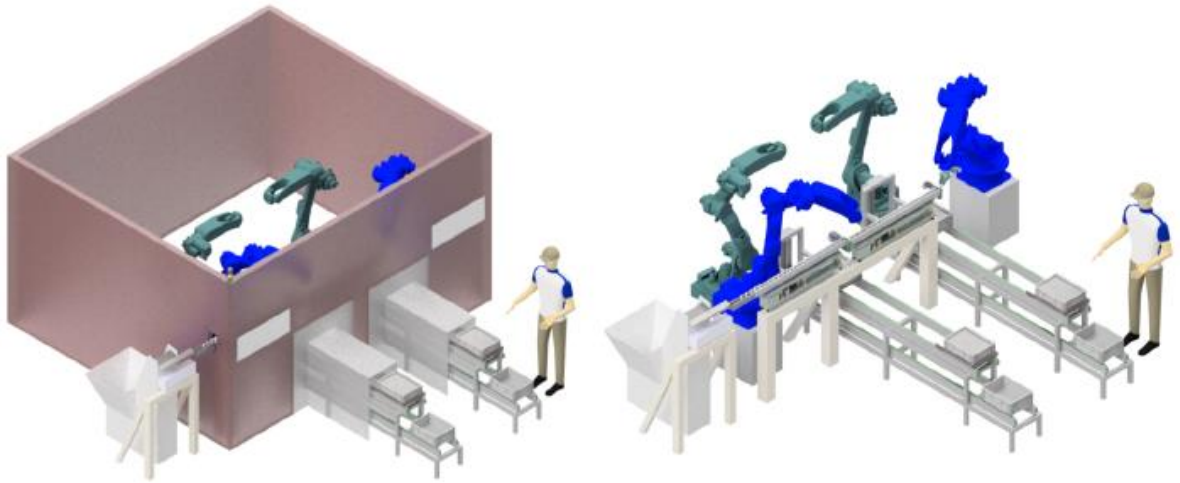

Fig. 3 Visualization of the optimization design

Before actually starting the polishing center, a production worker is required to fill the hopper for unpolished ball studs so that the stair conveyor can take and vertically feed the ball studs. The second activity of the worker before turning on the line is filling the transport systems with empty KLT crates. After these activities, the line can be activated. A stepped vertical feeder, located on the side of the polishing center, moves the pieces from the hopper onto a linear vibrating guide that moves the ball studs to the first pair of robots. Thanks to the distributor, the ball studs are also moved to the rear robot. If the ball pins reach the designated place, the first pair of robots will grab them by the ball part. Both robots have two grippers. These then feed the second pair of robots the ball studs, which are further attached to the thread of the stud, so that the ball part will be ready for polishing with polishing discs and final cleaning with air. After this process, the robot places the final pieces into the prepared KLT crate, which is already located on the second level of the transport system thanks to a small elevator. After reaching a certain number of polished pieces in the KLT crate, this crate is further moved to the outlet for final storage, the so-called palletization. This process is repeated until the polishing process for that reference is complete. The overall layout of the line after optimization is shown in Fig.4.

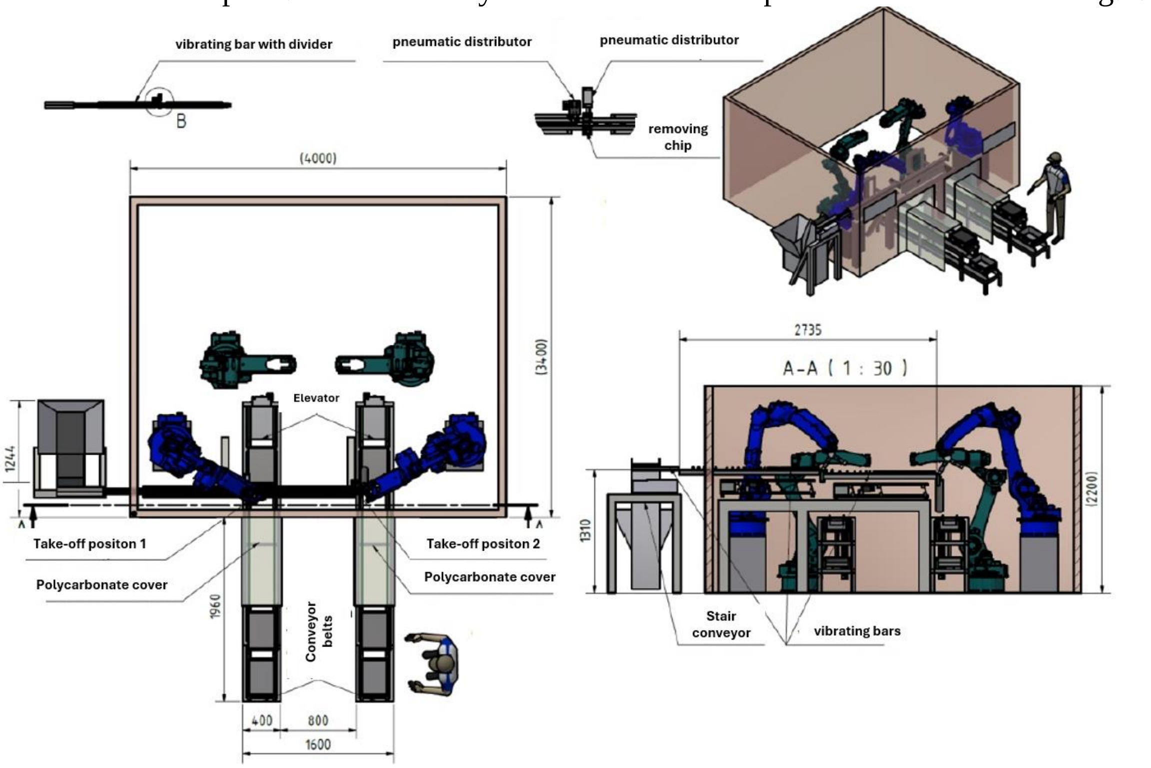

Fig. 4 Layout after optimization

Simulation of optimization design in Plant Simulation 2201 software

The Tecnomatix Plant Simulation software from Siemens is a relatively simple software that is mainly used in logistics for the given operations, for monitoring and optimizing the material flow, but also for monitoring various processes, their analysis and modeling and many other activities. Thanks to this software, it is possible to model perfectly precise technological operations and compare their advantages and disadvantages, on the basis of which the optimal variant is selected. Thanks to a wide range of different functions and utilities, its operation is very easy. Since an approximate visual form of the design is available in addition to the design itself, it is possible to build an identical model, taking into account all aspects that are constant for this line, such as the actual polishing and blowing time at individual stations.

As an input, a reservoir in the form of the Buffer function will be used, which will be filled by a worker to the value of 5,000 pieces, or created Parts from the Source function. From this magazine, the step magazine and two vibrating linear rails continue, with the actual speed set to 0.1 m/s. Conveyor functions were used for these parts. When the position of the ball pin is detected by the sensor on the bar, one, and subsequently also the second robot, from the first pair of robots is activated, which appropriately hands the two ball pins to the robot for polishing and blowing. The feed operation was provided by the PickAndPlace functions and the ParallelStation polishing process. After these processes, the polished pieces are thrown into a KLT crate with a capacity of 250 pieces, in the form of a Moveable Container unit. These KLT crates arrive after the conveyor, onto which they are loaded by workers. The maximum number of KLT crates on all conveyors is 5 pieces. After reaching the number of 250 pieces in one KLT, a small elevator is activated, which raises the crate to a higher conveyor, which is directed to the total output. This one is not specially designed, the conveyors are simply modeled this way. From this output, it is necessary to transfer full crates to a pallet with finished pieces for logistics, which is shown in the Drain form. Figure 25 shows a visualization of the proposed solution. On the basis of real data, an identical model of the line was created with consideration of all essentials. Loading conveyor belts with 5 pieces of KLT crates will take a total of 50 seconds, and loading a magazine with 5,000 pieces will take almost 14 minutes. After loading the KLT crates and pouring the first number of ball studs into the container, automated processes begin, which are already assigned parameters, such as the speed of classic and linear conveyors and the polishing cycle time. At the same time, the output of KLT crates was set, which will be carried out by a worker, as well as the simultaneous loading of empty KLT crates. Polishing takes 7.5 hours.

Fig. 5 Design in Tecnomatix Plant Simulation software

Thanks to the output report, more information about the process was detected. Most important, however, is the total output, which is 18 crates, which actually means 4,500 polished pieces. There are still two KLT crates on the conveyor belt, which are already partially filled. Their sum is 262 pieces, so 4,762 pieces of ball studs are polished for the entire 7.5-hour shift. The evaluation of the efficiency of the production equipment is shown in Tab.2.

Tab. 2 Comparison of the current and future state of the polishing line star_border

Relevant data	Current status	Status after optimization
Production [pieces]	3 800	4 762
Increase by 962 pieces / 25%		

Annual final capacity [pieces]	1 824 000	2 270 905
Increase of 446,905 units / 24.5%		
Cycle time [s]	6,31	5,91
0.4 seconds reduction / 6.3%		
Polisher inactivity [s]	1 679,37	33
1646.37 seconds / 98% reduction		
Worker activity [s]	5 616,18	1 396,78
4219.4 seconds / 75% reduction		
Annual costs per employee [€]	15 607,48	4 653,27
Reduction by €10,954.21 / 70%		

Thanks to the created simulation, which has real dimensions and parameters, it was possible to extract several output data to optimize the polishing production line. After applying all the technological devices and running a complete simulation, a total of 4,762 pieces were produced during one 7.5-hour shift, which was also proven by calculations based on the cycle time of polishing and the duration of other processes. This is an increase in the number of pieces per shift by 25%. As for the total annual capacity of the polishing line, based on the input data such as the number of weeks, the number of working days per week and the work shifts during the day, the production capacity will increase by almost 25%, which means 446,905 more pieces produced annually. The applied optimization also affects the cycle time, which is reduced by almost half a second. Even this minor change has a huge impact on the overall output, the difference of which is mentioned above. Polisher idle time during which the production line could continue to produce was reduced by 98%, as the polishing center will only be inactive at the beginning of the shift, when replenishing KLT crates and ball studs. This is a total of 33 seconds. The main problem was the total time spent by the worker performing unnecessary manual work, which was currently more than 5,500 seconds. This has been reduced to 1,396 seconds, which will be needed especially at the beginning of the shift. Since the production worker will be less needed during one shift, he will be able to perform other production activities during other processes, and therefore, based on this fact, the costs per worker for operating the polisher will be saved in the amount of around €10,000 per year. In conclusion, it can be concluded that the initially proposed solution for optimizing the process of polishing engineering products will be very effective from various points of view after the introduction of automation.

Conclusion

Automation of production processes is very necessary in the current industrial world, as it is still possible to achieve greater outputs of production lines at lower costs. In this case too, optimization of the polishing production process was necessary. Thanks to technological innovations and various modeling software, nowadays it is possible to know in advance the benefits of a given change and at the same time to eliminate possible shortcomings. An example is the proposal to optimize the polishing process using automation, which was described in the presented article.

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WLKATA EDUCATIONAL ROBOTS IN THE SPECIALISED LABORATORY

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Abstract: The presented article focuses on the analysis and development of a robotic simulation system created using Wlkata Mirobot in a specialized laboratory at the Department of Industrial and Digital Engineering (KPaDI). The goal of this work is to deepen the understanding of simulation techniques, analyze the possibilities and limitations of Wlkata Mirobot, and propose effective solutions for use in industrial applications. The work is mainly focused on theoretical research, experimental testing and practical implementations, which will have a benefit in the field of industrial and digital engineering by implementing educational robots in real laboratory models with the use of software support in simulations.

Keywords: Educational, robots, laboratory, simulation.

Introduction

Wlkata Mirobot is a robotic arm designed mainly for educational purposes and for beginners, students and researchers in the field of programming and robotics. It is a tool that allows users to learn about different aspects of robotics such as programming, kinematics, sensors and control. Mirobot has 7 axes and can be controlled using a computer, tablet or smartphone connected to Wi-Fi. It can be programmed using a graphical interface or classic Python code. Mirobot comes with several accessories, including a micro-servo gripper, a suction cup, a camera, a light sensor, a laser sensor, and a touch sensor. This allows users to experiment with different applications and tasks. Mirobot can be a useful tool for students and researchers who want to learn the basics of programming and robotics, but also for educational institutions that want to give students hands-on experience with the technologies of the future.

Fig. 1 Wlkata Mirobot with accessories and control view in software

In today's dynamic world of engineering and automation, robotics plays a key role in the efficiency, accuracy and automation of various industrial and production processes. In recent years, the rapid development of robotics and automation technologies has become a fundamental pillar for innovation in industry, medicine, logistics and many other industries. In this context, it is important to have advanced simulation systems that allow the design, testing and optimization of robotic applications before their physical implementation.

Procedure for creating a simulation system using robots:

1. Set the goals we want to achieve - create an automated simulation system using a robotic arm and a camera from Wlkata Mirobot.
2. Find the necessary data to achieve the goals - find out the procedure for connecting the robot and the camera to the computer and then install the necessary applications, in which the robot with the camera is set up and learns to perform certain operations and movements.
3. Determine how the production and automated process will proceed - from the information obtained, it will be determined how to appropriately place the robotic arms and the camera, and the process of moving materials will proceed accordingly.
4. Build a simulation system using robots according to the scheme of the production and automated process - design and set up a complex simulation system that will work autonomously, that means the robot moves the material on time, the camera sends information to the robot about what color the material is and that the robot moves it correctly collected and sorted by color.

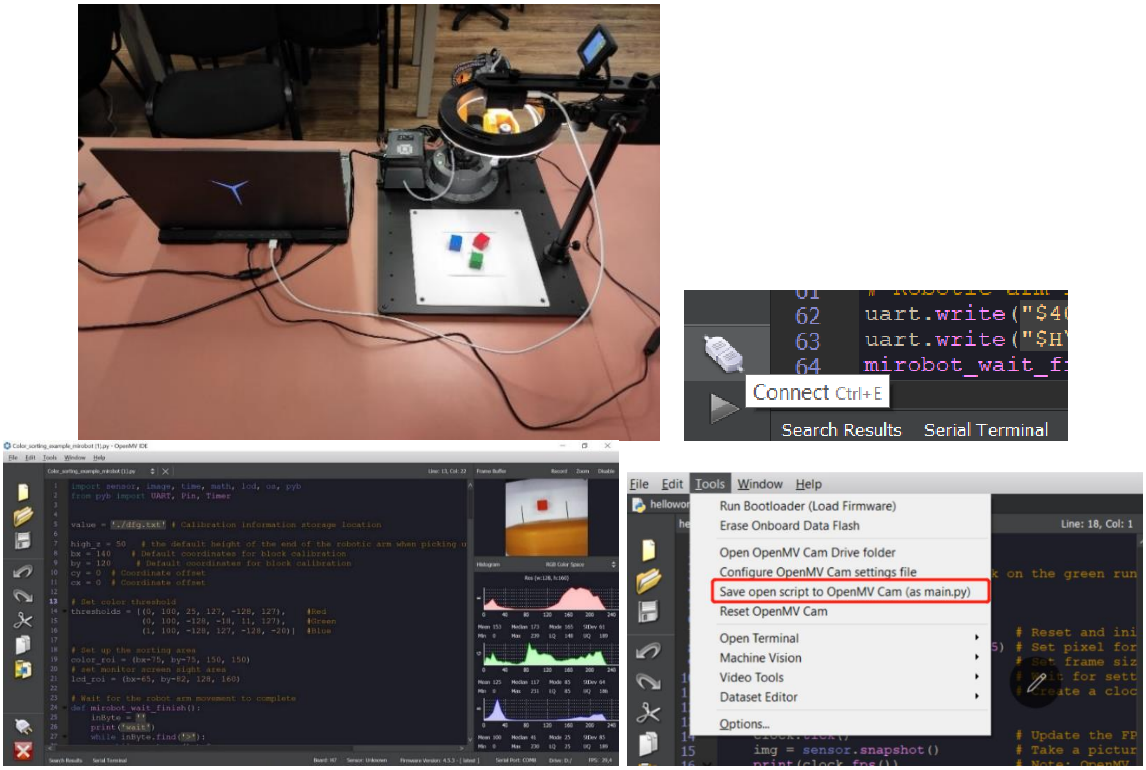

Fig. 2 Hardware connection of a computer with a robotic arm and a camera and calibration of camera

Testing the robotic simulation system

After successfully connecting the robots and setting the positions of removing, transferring and storing materials, we save and download the created programs to the controllers, specifically to the file folder, so that it is possible to easily access and run those programs after the robots are turned off.

Testing of the robotic simulation system takes place in the following way. The first step is checking the correct connection of the robots and turning them on with the On/Off button on their bases. The next step is to select the robot program to execute, and the program is selected via the controller from the recorded programs in the following way:

1. Click the right arrow to open the controller menu.
2. By clicking the down arrow on the files.
3. Press the center button to open the file folder where the recorded programs are located.
4. By pressing the down arrow, the program to be played is selected and then just confirm with the middle button on the controller and the program will start automatically.

This procedure applies to the robotic arm on the sliding rail, because the robotic arm that works with the camera starts the program automatically after the robot is turned on.

The following Fig.3 shows the layout of the robotic workplace, which is shown above.

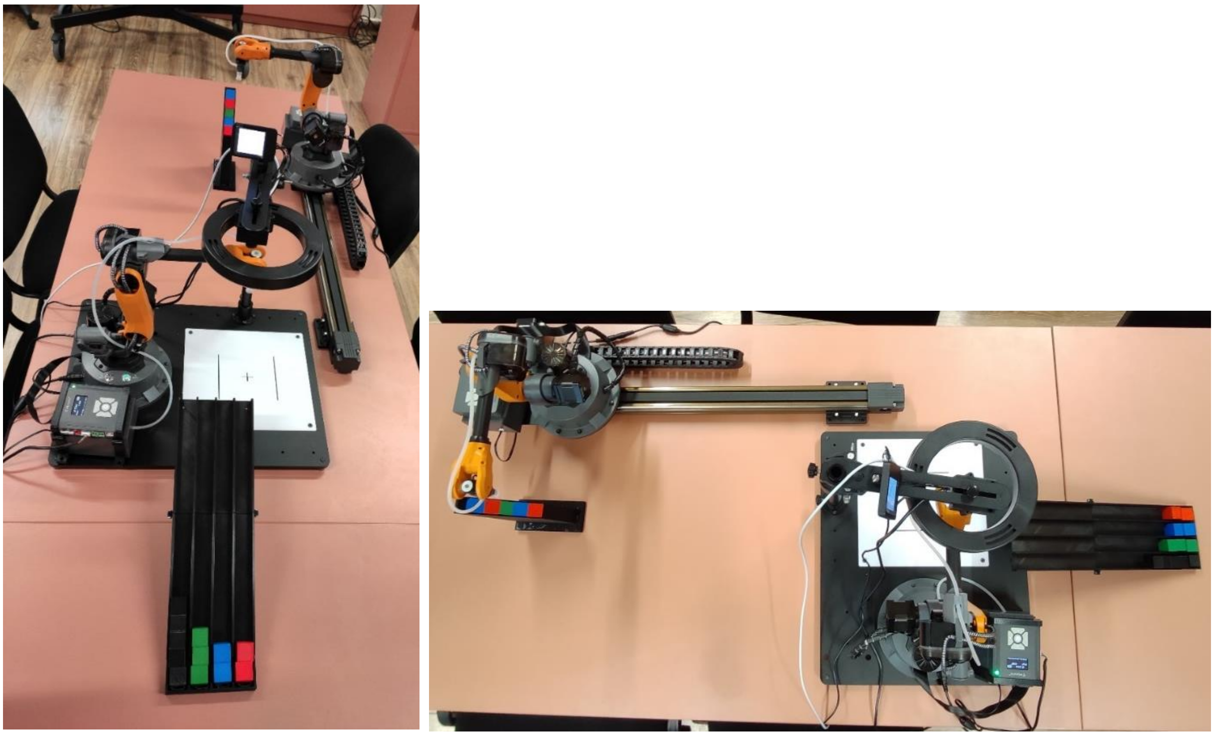

Fig. 3 Robotic workplace - view of the created workplace

The potential of a robotic simulation system for the future

Robotic simulation systems have extraordinary potential to shape and influence the future, as they provide the opportunity to test and develop various robotic applications and technologies in a secure and efficient virtual environment. There are several areas where robotic simulation systems can impact the future, such as:

1. Development and research of new applications - in laboratory conditions with simulation systems, it is possible to test and develop new applications and the use of robots in various fields such as healthcare, industrial production, construction, aviation, etc.
2. Education and training – simulation systems are an important tool for the education and training of students or employees. Students, professionals or employees can gain experience with different types of robotics and technologies in simulated environments, improving their skills and knowledge without risking damage or equipment failure.

3. Testing and prototyping – simulation systems provide rapid prototyping of new algorithms and robotic systems without the need for physical models. This means developers can test new ideas and concepts more quickly, reducing development time and costs.
4. Optimizing performance and efficiency – simulation can accurately test and optimize the performance of robotic systems in various situations and environments. It can improve the resource efficiency and functionality of robots in many fields, such as manufacturing, logistics and healthcare.
5. Development prediction and risk simulation – Simulation systems can be used to estimate and simulate various risks associated with the use of robots in the real world. This can include dangerous situations such as collisions, hardware failures or risky interactions with people. Simulations can be used to improve safety measures and minimize risk, injury or damage.

Conclusion

In the article analyzed and investigates a robotic simulation system created using Wlkata Mirobot in a specialised laboratory. This work provided a thorough overview of the possibilities, challenges and potential offered by the use of Wlkata Mirobot in robotics and automation simulation applications. One of the main findings was that Wlkata Mirobot offers flexible and efficient solutions for simulating various robotic operations, from simple tasks to complex industrial applications. With its advanced features and programming capabilities, this robotic system allows you to simulate and optimize different scenarios and conditions, which is invaluable for design and development in a real industrial environment. Despite these advantages, several challenges and limitations were also identified, such as technical aspects, calibration and integration with existing systems. It is important that future research works and implementations consider these factors and develop strategies to overcome and optimize them.

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SOFTWARE TOOLS FOR DIGITIZATION NEEDS

Juraj KOVÁČ, Peter MALEGA, Jana KRONOVÁ, Erik VARJÚ

Abstract: Digitization is becoming an integral part of modern industry, and its importance is continuously growing in various areas of manufacturing, logistics, and recycling. This article focuses on software tools that support the digitization of physical spaces, enabling the creation of virtual 3D models, the simulation of manufacturing processes, and the optimization of layouts. The article analyzes various software packages, such as Autodesk Factory Design Suite, visTABLE®, and Tarakos taraVRbuilder, which offer a wide range of tools for designing, visualization, and simulation.

Keywords: Software, digitalization, virtual reality.

Introduction

Modeling manufacturing systems and their subsequent 3D visualization is a necessity in today's world. All large, modern, and advanced companies strive to model and visualize their operations not only for simulating material flow or controlling production processes but also as virtual training rooms for new employees or as a showcase for potential investors. The use of visualization in research, education, engineering, and other fields is growing daily. Computer graphics is a typical application domain for visualization. The importance of 3D industrial visualization in the mechanical design process is increasing with the daily advancements in technology. This is so that designers and innovators can optimize and visualize mechanical models before launching their products. The value of 3D industrial rendering also lies in how it supports creativity and enables companies to develop products faster and with higher quality. Large companies use data optimization solutions that process industrial data, such as CAD files, which rely on precise parametric surfaces (also known as BREP or NURBS), and convert them into mesh data, which is a triangular representation of 3D objects. This data can be appropriately used for augmented reality (AR) and virtual reality (VR) devices, as well as for phones and tablets. Teams are able to collaboratively analyze designs in an immersive way, examining models from all angles, and ultimately making better decisions before taking action in the real world.

Software support for the digitization of physical spaces

Tarakos taraVRbuilder

The Tarakos taraVRbuilder software is a tool designed for creating and simulating virtual 3D environments, particularly in the fields of logistics and manufacturing. It allows users to quickly and easily model various logistics and manufacturing processes using an intuitive interface and pre-built components. The software provides the capability to simulate real processes in a 3D environment, enabling detailed visualization and analysis of logistics and manufacturing systems. It supports the import of CAD files, allowing users to work with precise and detailed models of equipment and objects. It is suitable for both small and large projects, from simple logistics processes to complex production lines. Users can navigate through the created environments using virtual and augmented reality devices, enhancing interactivity and understanding of the processes. The software’s workspace is shown in Figure 1.

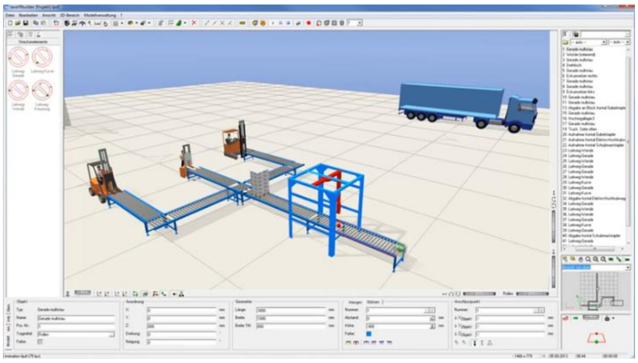

Fig. 1 3D visualization of a production hall in taraVRbuilder

Main advantages of the software:

• Simple 3D visualization for factory and logistics design,
• Visually realistic project presentations,
• Usage without the need for programming or 3D CAD system knowledge,
• Approximately 500 parameterized objects ready for use,
• Basic simulation of production and transportation operations,
• Easy extraction of video sequences.

Software visTABLE®

The visTABLE® software is designed for planning, visualization, and optimization of layouts in manufacturing and logistics environments. The software is user-friendly, allowing for simple and quick planning without the need for extensive training. It provides the ability to create and visualize planning environments in both 2D and 3D views, which helps in better understanding and analyzing spatial arrangements. It supports the import and export of CAD files, ensuring accuracy and detail in layout planning and enabling the use of existing models. The software is modular, meaning it can be customized and expanded according to the needs of a specific user or project. Through the visualization and simulation of various solution variants, the software aids in decision-making and planning changes in production layout. The software's workspace is shown in Figure 2.

Fig. 2 3D visualization of a production hall in visTABLE®

Main advantages of the software:

• Intuitive user interface,
• 2D and 3D visualization,
• Layout optimization,
• Integration with CAD systems,
• Material flow simulation,
• Team collaboration.

Autodesk Factory Design Suite software

Autodesk Factory Design Suite is a comprehensive software package designed for designing, visualizing, and optimizing factories and manufacturing plants. This suite includes various tools and applications that enable the creation of detailed models and simulations of production spaces, aiding in the efficient planning and execution of manufacturing processes. It allows for the simulation of production processes and the visualization of factory layouts, helping to identify potential issues and optimize arrangements before actual implementation. The suite includes extensive libraries of standard components and equipment, which speed up the design process. It also features tools for analyzing manufacturing processes, helping to identify and eliminate inefficiencies and improve overall performance. The software's workspace is shown in Fig. 3.

Fig. 3 3D model of a hall created using the Autodesk Factory Design Suite software package [5]

Main advantages of the software:

• Realistic visualization,
• Quick access to components from an extensive library,
• Efficient search and reuse of design and engineering data,
• Supports teamwork on projects,
• Includes presentations of machines, transportation and safety systems, and workplace equipment from various manufacturers, with the option to expand with custom sets.

Digitization of a selected hall designated for recycling specific products

The Institute of Recycling Technologies (Fig. 4) was established as part of the organizational restructuring of the Faculty of Metallurgy by merging the Department of Chemistry and the Department of Non-Ferrous Metals and Waste Processing. In the interest of achieving sustainable development in the designated area in accordance with applicable legislative and environmental requirements, the mission of the Institute of Recycling Technologies (IRT) is to carry out contemporary educational and scientific research activities, enhance them, develop, and advance. In compliance with the Act No. 79/2015 Coll. of the National Council of the Slovak Republic on waste management, the Institute of Recycling Technologies addresses the issues of waste processing and recycling with the aim of material recycling of individual components. The IRT is located in the university's production hall building, specifically in hall PK12. [5]

Fig. 4 Recycling Center [5]

The total number of digitized devices is 13. Each machine in this hall has its specific purpose and classification. The following machines are located in this recycling center:

• Two-rotor crushers,
• Three-rotor crushers,
• Four-rotor crushers,
• Jaw crushers,
• Knife mill,
• Friction mill,
• Hammer mill,
• Filtration devices.

The CAD system SolidWorks was used for the digitization of the equipment.

Fig. 5 Digitized equipment of the recycling center [5]

The digitization of equipment and layout planning was based on the methodological approach of 3D visualization of manufacturing systems (Fig. 6).

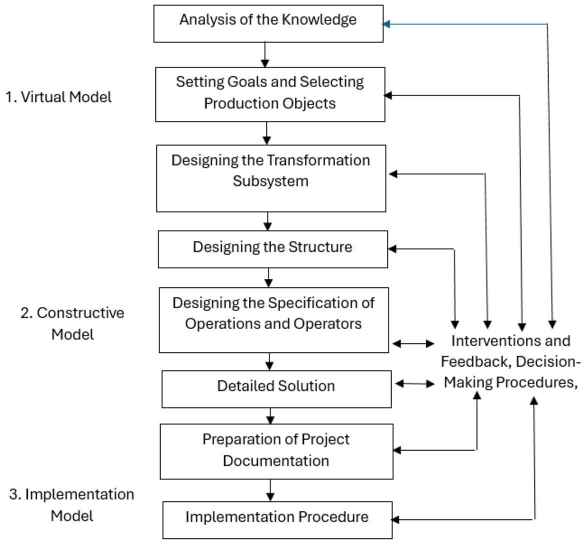

Fig. 6 Stages of the systematic process of creating a manufacturing system

The Autodesk Factory Design Suite software was used for modeling the layout of the hall. This software allows for designing in both 2D and 3D. A 2D view of the hall is shown in Fig. 7.

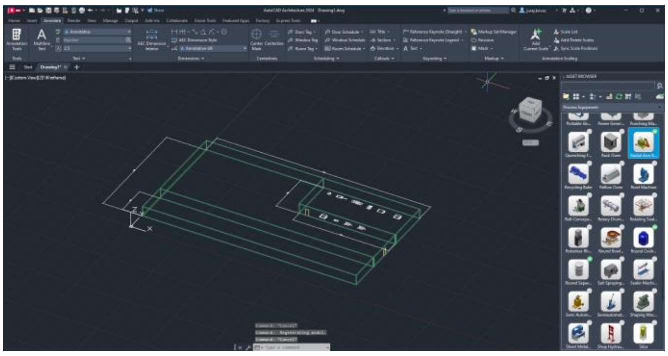

Fig. 7 2D layout of the hall and the entire institute [5]

The 3D models of recycling equipment, created using CAD software SolidWorks, were subsequently imported into the space. The overall digitized area consists of five separate rooms and a large central hall. Each of these individual sections is focused on the recycling of different materials and raw materials.

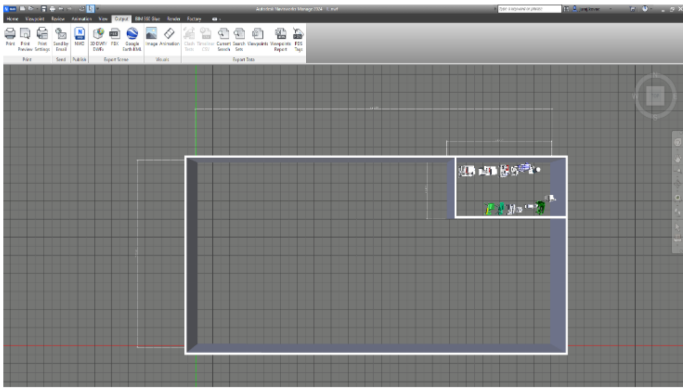

Fig. 7 3D view of the layout [5]

In Fig. 7, the recycling center is depicted after adding all necessary interior elements, such as doors and windows, following their graphic processing and the proper placement of all recycling equipment. A detailed view of the recycling workstation is shown in Fig. 8.

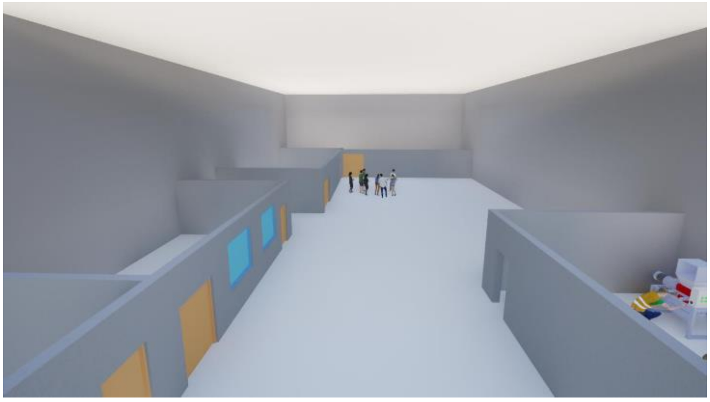

Fig. 8 3D view of the layout of the recycling hall [5]

Conclusion

A significant benefit of digitizing production and non-production spaces is not only economic efficiency but also the reduction of environmental impact through the optimization of energy and material usage. The integration of digital technologies into the manufacturing or recycling process enables quicker adaptation to individual customer needs, simulations, and training in a digital environment. Digitization is therefore an essential trend for the future of industry. Companies that invest in these technologies and transform their processes will have a significant competitive advantage in the globalized market.

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ENHANCEMENT OF MANUFACTURING PROCESS THROUGH THE APPLICATION OF SIMULATION TECHNOLOGIES

Matúš MATISCSÁK – Martin MIKUŠIAK – Michal BALUCH – Peter TREBUŇA

Abstract: The primary objective of this study is to develop a second optimization of the manufacturing process for a specific production line at an undisclosed company. Through a comprehensive analysis of the manufacturing process, review of data provided by the company, and inspection of the production facility, we were able to simulate the current production process. The simulation, conducted using TX Plant Simulation software, identified several inefficiencies within the analyzed manufacturing process. Building on the insights gained from the initial optimization, we implemented targeted improvements and proposed additional enhancements to further increase production output. These modifications were integrated into the simulation model. The results demonstrated a significant increase in production efficiency, with the output rising from an initial rate of approximately 3300 units per shift to a range of 4340 to 4469 units per shift.
Keywords: Innovation, Production, Simulation, Tecnomatix Plant Simulation

Introduction

In the contemporary landscape of digitalization, there is a concerted effort among manufacturing enterprises and companies to enhance, accelerate, and elevate their production processes. This pursuit aims to advance manufacturing capabilities to a higher level through the identification and implementation of strategies that optimize production under the most economically advantageous conditions [1]. The advent of digital technologies and sophisticated simulation programs has significantly broadened the accessibility of production optimization techniques, making them available to a diverse range of manufacturing sectors. By leveraging digitalization and advanced simulation tools, organizations can achieve more precise and effective optimization of their production systems, leading to improved efficiency, reduced operational costs, and enhanced overall performance [2,3].

In the contemporary landscape of digitalization, manufacturing enterprises are increasingly focused on enhancing and expediting their processes to achieve superior operational efficiency. One of the key tools in this pursuit is the use of simulation software, such as Tecnomatix Plant Simulation [4]. This advanced tool enables companies to create detailed digital models of their production systems, allowing for the thorough analysis and optimization of manufacturing processes. Tecnomatix Plant Simulation facilitates the exploration of various production scenarios and the assessment of potential improvements, offering insights that are crucial for making informed decisions. The availability of Tecnomatix Plant Simulation makes sophisticated process optimization techniques accessible to a broader range of manufacturing sectors, driving advancements in production performance and operational excellence [5,6].

Research Methodology

Currently, the average production rate on the manufacturing line is approximately 3300 units per shift. Based on our results [7], we have demonstrated that initial optimization efforts increased the production rate by over 1200 units per shift. With four shifts, this optimization allowed for an exact increase of 2741 units. While the proposed optimization meets the current

production demands, companies often anticipate future growth and have requested further capacity enhancements.
To devise additional innovations and optimizations, a follow-up visit to the facility was conducted, focusing on the physical layout and operational spaces where production occurs. This comprehensive analysis enabled us to design further optimization strategies utilizing the Tecnomatix Plant Simulation software. This advanced simulation tool was employed to verify the effectiveness of proposed improvements and to assess their impact on increasing the production process efficiency. By leveraging simulation, we aim to validate and refine these strategies to ensure they meet both current and anticipated production needs.

Current View of the Production Process

Currently, this line can be characterized as a semi-automated production line, comprising four distinct workstations. The initial workstation is manually operated by a human operator, while the remaining three workstations are automated, utilizing robotic arms and sensor systems to perform various tasks. The production process is facilitated by a conveyor belt system, which transports a series of pallets, each containing three nests designed to hold specific components. These components are sequentially processed and adjusted at each workstation according to the specific operations required at that station. This production line (see Fig. 1) functions as the preliminary segment of the main production line, dedicated to preparing components for the manufacturing of the primary product.

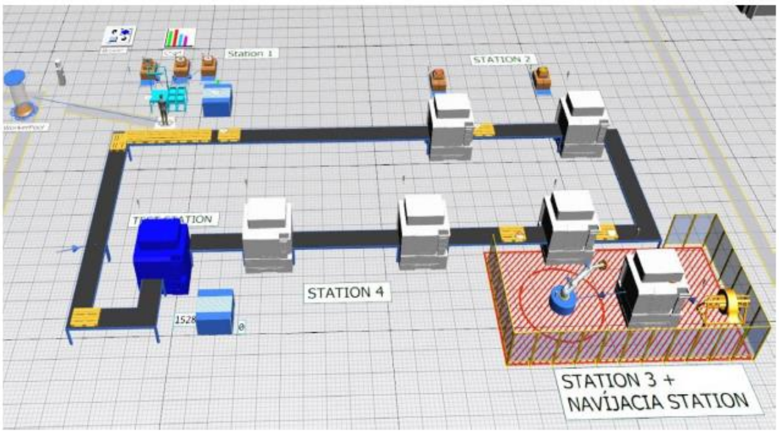

Fig. 1 3D representation of the production line

The product manufactured on this line is classified as a pre-production component, specifically a stator. The stator assembly comprises six distinct components, each of which is inserted during various stages of the production process. The production line is operated in two shifts, with a total cycle time of 11 seconds per completed unit at the line's output.

Innovation and Optimization of the Production Process

In this proposal, we focused on finding solutions to improve and increase the output of the production line. We implemented an additional nest on the pallet traveling along the conveyor belt. By adding a fourth nest to the pallet, we increased the number of units in the production process to two, allowing an additional unit to be produced per cycle time of the line. This expansion required adjustments to the trajectories and movements of the robots on the line, as the number of robotic operations at each station doubled.
At the testing station, it was necessary to add an additional stator tester, as this station is currently identified as a critical bottleneck with the longest production time. The next step in

the proposal was to introduce a third station along with an additional winding station. As a result of this addition, the first winding station will wind stators in nest one, while the second winding station will perform the same process for nest two. Each winding station handles four unwound stators, meaning that by adding the second winding station, the winding capacity is doubled. A visualization of the proposed innovation and optimization of the production process is shown in Fig 2.

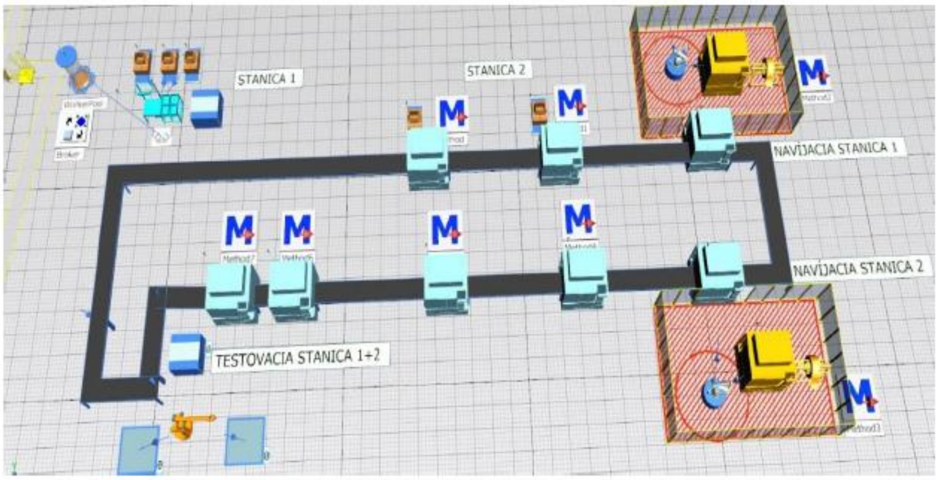

Fig. 2 3D innovation and optimization of the production process

The estimated investment for expanding the winding line is approximately 300 000 €. Considering the installation and configuration of individual stations, the total cost could reach up to 350 000 €. The cost of adding a new tester is estimated at 30 000 €. Therefore, the total investment in the proposed solution is estimated to be between 380 000 and 400 000 €.

Result

The optimized production process is on average around 75% (see Fig. 3), which shows sufficient values in the line setting.

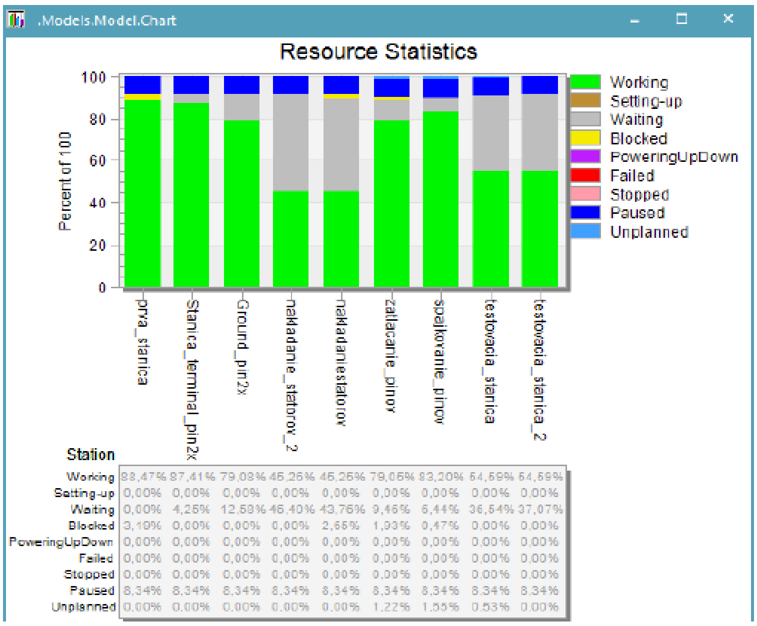

Fig. 3 Graphic representation of production in four shifts

In this variant, the simulation model includes the reassignment of one operator to Station 1. Consequently, the graph displays a dark blue color, which denotes scheduled downtime or breaks. Another prominent color is gray, primarily observed at the winding and testing stations. This is due to the addition of a second unit per pallet, while each of these stations handles only one unit per pallet at a time. As a result, waiting occurs for the unit currently positioned at these stations in an idle state. This waiting time at these stations has increased to nearly 50%. However, it is important to note that this waiting does not adversely affect the final performance metrics obtained from the simulation results.
The performance metrics of the production process prior to optimization are detailed in Table 1 below.

Tab. 2 The result of production during four work shifts at the current state

At the current state	Shift A OK / NOK (pcs)	Shift B OK / NOK (pcs	Shift C OK / NOK (pcs)	Shift D OK / NOK (pcs)
Per hour / average	306 / 8	294 / 8	285 / 7	294 / 8
Per shift	3367 / 86	3231 / 83	3140 / 81	3232 / 83
Per day	6598 / 169		6372 / 164	
Per 2 days	12 970 / 333			

During the simulation, an operator was reallocated to the initial station, thereby adjusting the net operational time on the production line to 11 hours. The addition of an extra nest per pallet resulted in an increase in the number of finished products per pallet from one to two. Consequently, the processing time for a pallet with two items was effectively doubled, which extended the duration of individual operations. To address this, stations characterized by the longest processing times, such as the winding and testing stations, were also duplicated to achieve the targeted outcome of enhanced capacity and reduced cycle time. Comprehensive results are presented in Tab. 2.

Tab. 2 The result of production during four work shifts after the implementation of the optimization

At the current state	Shift A OK / NOK (pcs)	Shift B OK / NOK (pcs)	Shift C OK / NOK (pcs)	Shift D OK / NOK (pcs)
Per hour / average	404 / 8	395 / 8	395 / 8	294 / 8
Per shift	4449 / 91	4344 / 88	4345 / 89	4469 / 91
Per day	8793 / 179		8814 / 180	
Per 2 days	17 607 / 359			

Based on the statistical report generated from the TX Plant Simulation software, it is observed that production increased by more than 1200 units per shift, which translates to an increase of over 2400 units per day. With the operation of four shifts, a growth of over 35% was recorded, equating to an additional 4637 units produced.

Conclusion

Analysis of the data provided by the TX Plant Simulation software indicates that the optimized production process achieves an operational efficiency rate of approximately 75% across four shifts. This optimization was realized through several enhancements, including the integration of a fourth nest per pallet, the addition of an extra stator tester, the introduction of a third station in conjunction with a winding station, and the refinement of robotic movements. These modifications resulted in a notable increase in production, with output rising by over 1200 units per shift, which translates to a daily production increment of more than 2400 units. The total production increase over the course of four shifts is precisely 4637 units.

In comparison to the initial proposed innovation, the subsequent optimization led to an additional increase of more than 550 units per shift. This translates to an approximate additional output of over 950 units per shift. Cumulatively, over four shifts, this optimization resulted in a precise increase of 1896 units. These improvements underscore the effectiveness of the applied enhancements in significantly boosting production capacity and operational efficiency.

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INNOVATION OF WAREHOUSE MANAGEMENT IN THE COMPANY

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Abstract: The aim of the presented article is to evaluate warehouse management in a specific company in order to reveal deficiencies and then propose measures to eliminate these deficiencies and propose a new warehouse management system. The investigated enterprise focuses on the sale of spare car parts. Currently, the current premises are no longer enough to cover all orders, so it will be moving to new premises. Therefore, our sub-goals are also the design of the distribution of warehouse stocks in new premises, the design of handling routes and the implementation of an internal company information system.

Keywords: *logistics, warehouse design, warehousing, inventory management*

Introduction

The current era is characterized by high competition in the market economy. Every company tries not to succumb to the competition, but on the contrary to succeed. She should carefully consider the tactics she chooses to do this. Quality management in the field of supply is also the basis of success. Inventories affect the economic result of the company, for many companies they represent a large investment that ties up financial resources. No less important is access to supplies in terms of their availability in time. In connection with this, it is necessary to think about the size of stocks and the method of their replenishment, because here too many potential difficulties arise for the company.

Warehouse management is a very comprehensive area that includes a large number of different business processes. We can meet warehouse management in all kinds of businesses. If a business operates warehousing and inventory management effectively, these areas can become its competitive advantage. Efficient warehouse management leads to inventory optimization. Deciding on the amount of inventory can affect the company's further operation on the market. If the company keeps a disproportionately high stock level, it ties up a large amount of funds in these stocks. However, if a business keeps little inventory, it loses profit because it cannot meet market demand.

1. Analysis of the current state of warehouse management

The current store building, with an area of less than 110 m², proved to be insufficient for the needs of a dynamically growing business. Its internal arrangement does not meet the modern standards of the business environment and has limited capacity for efficient storage and presentation of the assortment.

Customers often face limited space when browsing goods and limited comfort when shopping. Employees, on the other hand, face limited opportunities in administrative tasks and unsuitable working conditions.

In the company, we are facing a serious problem regarding the lack of transparency and efficiency in the processes of storing and selling goods from our warehouses (Fig.1). This problem also manifests itself disadvantageously inside the warehouse, where there is unnecessary chaotic movement and difficult communication. The lack of proper use of storage space is evident and can lead to unnecessary losses and waste of resources. Furthermore, we encounter outdated procedures for receiving and issuing goods, which are no longer adequately adapted to current needs. Also, the computer systems that process data about the goods and their location in the warehouse are outdated and need modernization. It is essential to address these deficiencies and implement more efficient and transparent processes in order to achieve better control over our inventory and increase the overall efficiency of the company's operations.

Fig. 1 Distribution of goods in the company GARANT K&K s.r.o.

2. Storage space innovation proposal

Due to the lack of space and the inefficient arrangement of warehouse spaces, it was necessary to consider investing in a larger and more modern building. Therefore, the company GARANT K&K s.r.o. decided to change its headquarters and premises in 2024 through the construction of new premises, which will not only be larger, but also more optimal for better clarity and improved handling of goods. Complete project documentation is currently being prepared and is awaiting assessment by the building authority, therefore our task in this proposal is to process a project plan for warehouse spaces, which will be an innovation for this company. The new space should be designed to better meet the needs of both customers and employees. With the proposal, we should ensure enough space for the comfortable movement of customers, as well as their relaxation while handling the requested order and ensure efficient storage of goods.
The front part of the sales area should be optimized for the display of products with smaller dimensions. Our proposal is therefore also to create attractive exhibition spaces and improve the visual presentation of the goods in order to increase the attractiveness of the store and to improve the visual presentation of the goods in order to increase the attractiveness of the store which could attract more customers. Part of this proposal is a detailed project plan of the storage areas.
We propose to implement modern inventory tracking and order planning systems to ensure sufficient availability of goods to meet customer demand. It is also important to monitor

demand trends and adapt supply strategies according to market needs. And therefore, at the same time, the goal of this innovation proposal is also to include the use of an information system, the task of which is the continuous control of warehouse stocks and the transparency of the location of goods. In this information system, there is a comprehensive database of the operation's goods. Each of these products is defined under a QR code, on the basis of which the location of the given product will be searched. The information system works with the stock of goods and the available assortment and is therefore developed to streamline and speed up the work with the given goods in the warehouse during distribution. This information system also ensures the automatic navigation of the autonomous robot, whose task is to weigh the goods to the employee or customer. The autonomous robot works based on information about where the goods are stored and moves along a predetermined path of movement.
When creating visualizations of the company's warehouse space, we worked with the Solid Works and Siemens Process Simulate programs. With the help of these programs, a detailed layout of warehouse spaces as well as spaces for customers was developed. These visualizations in the practical part, as we mentioned above, are developed based on the drawings of the project documentation provided by the company GARANT K&K s.r.o.
When creating the operation model, we were based on the complete dimensions of the project documentation provided by the company. The total operation thus extends to 293.29 m2. In the model created by us, the areas intended for the storage of goods, areas for sales purposes and areas for customers or complete technical equipment, including an office, a dressing room, toilets and showers, are depicted. We drew and modeled these spaces in the Solid Works program, which we can see in Figure 2.

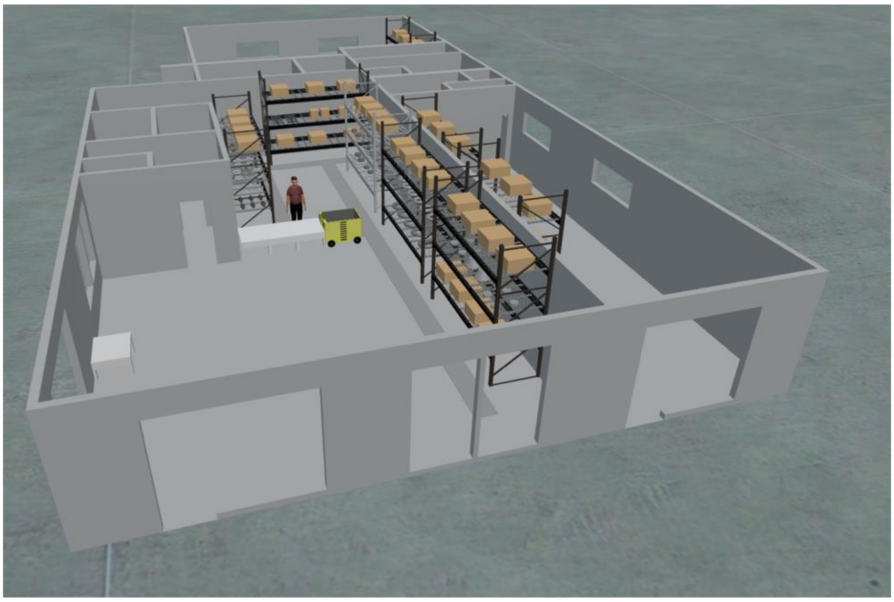

Fig. 2 New operation model

For the company GARANT K&K s.r.o. we proposed the application of the use of a computer information system, intended for inventory management, with the help of which the exact location of specific goods will be defined. We included this proposal, as the current distribution of goods in the company is difficult to understand, which also affects the very speed of the processes of distribution of goods to the customer.
The marking of the goods, which is currently used in the operation, is a handwritten registration number on the labels kept on each type of offered goods, with the help of which the goods are

then searched for in the economic program Pohoda. The current labeling of the goods and its search proved to be insufficient due to the growing number of available assortments for the customer.

Our proposal is therefore an information system in which the search for goods is managed using QR codes that will indicate the specific location of each stored product (Fig.3). In this way, we will increase efficiency and reduce time when searching for a specific product according to the customer's needs. It is important to note that this information system will also record the availability of specific requested goods. The advantage of this label is the defined specific location where the employee can find the stored goods and deliver them to the customer.

Fig. 3 Detailed view of the shelf with QR codes

As an aid to the employee, we proposed, as already mentioned above, the use of an autonomous mobile robot whose task will be to weigh goods from the warehouse directly to the sales counter (Fig.4). Weighing of goods from the warehouse will be carried out based on the employee's request through the information system.

Fig. 4 Robot in warehouses

The robot is moving independently in a defined space and will be oriented using a defined path when transporting cargo. Thanks to its sensors and navigation system, it can safely maneuver around obstacles and precisely control its movement, all the way to the destination along the designated path. The role of the robot is to increase efficiency in customer service and automation of warehouse processes. The robot will cooperate with the information system and, based on the employee's request, will be able to search for the given goods thanks to the markings and QR codes on the shelves. Subsequently, the robot will be able to deliver the goods safely to the designated place. The robot will be integrated with the information system of the operation, through which the robot is able to respond quickly to the requests of the employee.

3. Comparison of the current state and the design

Compared to the current state, the innovation proposal is aimed at maximizing the efficiency of handling goods and distribution. With the help of our innovation proposal that we submitted, we managed to streamline the process of finding goods and fulfilling the customer's request. Stocks of goods will be more systematically and clearly placed in shelves marked with the help of QR codes. Also, handling will be easier, enriched with an autonomous robot, which the employee can use for searching by entering commands into the computer, which simplifies and modernizes the distribution process. Through the implementation of the proposed innovations, we believe that we will achieve an overall improvement in the operation compared to the previous conditions. All these measures, in addition to everything else, also modernize the operation and can thus increase customer satisfaction through faster and more accurate service. Our proposed innovations at GARANT K&K s.r.o. they also bring a significant improvement in the time management of processes. The table expresses the expected changes in the time average of the duration of the processes after the implementation of our proposals. A significant reduction in the time needed to process orders, fulfill customer requests, monitor stock levels and manage warehouse space shows the efficiency and effectiveness of the proposed innovations.

Before the implementation of our proposals, the average time duration of processes would range from 600 to 864 seconds. Once implemented, these times are expected to drop significantly, with the new values ranging from 237 to 422 seconds. These data clearly show that our proposals contribute to a significant acceleration of processes and improve the overall efficiency of the company's operation.

Tab. 3 Time management of processes

Process	**Before the proposal (seconds)**	**After the proposal (seconds)**
Order processing	72 – 120	24 – 48
Verification of the availability of goods	120 – 168	48 – 96
Search for a part in stock	168 – 240	45 – 110
Issue of the part to the customer	240 – 336	120 – 168
Overall time frame	**600 – 864**	**237 – 422**

With improved processes, the time required to process a customer's order has been reduced from the original 600-864 seconds to just 237-422 seconds, an average of more than half the time saved. A faster order fulfillment process means that customers can expect significantly shorter waiting times and faster access to the parts they require. This contributes to overall customer satisfaction, which is a key factor in increasing the company's success on the market.

Conclusion

In this post, we analyzed the current state of GARANT K&K s.r.o., we proposed innovations for more efficient use of spaces and processes. The goal was to plan more space for storage as efficiently as possible and to improve the handling of the goods itself. At the same time, the goal was to increase the competitiveness on the market by more efficiently used warehouse space thanks to the possibility of a greater supply of requested goods to customers and at the same time to reduce the time duration of order delivery. We compared the current state with proposed innovations that emphasized clarity and efficiency in the warehouse space.

The benefit of the work is identifying problems and offering solutions that could lead to improved company performance. The work provides concrete proposals and innovations that can improve the company's more efficient use and management of space. Which can lead to improved customer experience with the company, increased operational efficiency, increased competitiveness, improved working conditions, better control over stocks, but also improved cooperation with suppliers.

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INCREASING THE PASSABILITY OF THE PRODUCTION PROCESS VERIFIED USING SIMULATION MODELS

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Abstract: The paper deals with the mapping of production processes and procedures in an unnamed company. The bottlenecks that were detected through the analysis are then transferred to the simulation models. On the basis of simulation models, options and variants are compared for the design of solutions to improve the passability of bottlenecks and thereby increase production output. Variants and production efficiency are compared when supplementing the production possibilities with new equipment, and the most effective variant for improving the production possibilities of the given company is proposed.

Keywords: *simulation, bottleneck, engraving, printing form*

Introduction

Most companies today strive for the most efficient management possible. This also includes striving for the highest possible efficiency in the field of logistics. The era of digitization and Industry 4.0 offers these companies a number of tools for their effective management and design. One such tool includes the digital twin and simulation method. In this work, the Tecnomatix Plant Simulation program is used, in which the material flow can be simulated based on the creation of a model for a specific production system. This simulation can be set for any period of time, and after its completion, the program will generate comprehensive information in the form of a table. In order to use the program effectively, it was necessary to become thoroughly familiar with the production technology used in the department and also with the complete machinery. The paper describes the production of packaging and means and preparations for their production, such as gravure printing forms.

1. Production of printing forms

The production of printing forms for gravure printing takes place following the gravure printing schedule of the ORION system, based on the confirmed binding deadlines for the end of production at the center of gravure printing and material security. Based on the schedule, the order of gravure printing forms is formed, which is binding for the department when assigning priority to individual orders.

Tab. 1 Time of production processes

Operation	Device	Number of devices	Average production time
Milling on the polishmaster	Polishmaster	2	20 min.
Degreasing before galvanic copper plating	Acigraf Martin	3	5 min.
Galvanic copper plating	Acigraf Martin Kaspar Walter	9	50 min.
Polishing after galvanic copper plating	Acigraf Daetwyler	3	10 min.
Engraving	Hell K500 3G Hell K500 4G	5	75 min
Degreasing before galvanic chrome plating	Acigraf Martin	2	5 min.
Galvanic chrome plating	Acigraf Martin	3	15 min.
Final treatment by polishing	Daetwyler	1	15 min.

All the machines are arranged in their groups behind each other in two halls. Only the devices for electroplating and degreasing devices are built in two lines as follows. In the first line, there is one degreasing device and five galvanic copper devices. In the second line, there are two degreasing devices and four galvanic copper devices.
The block diagram according to which the production process was created in the Plant simulation program is shown in figure number 1.

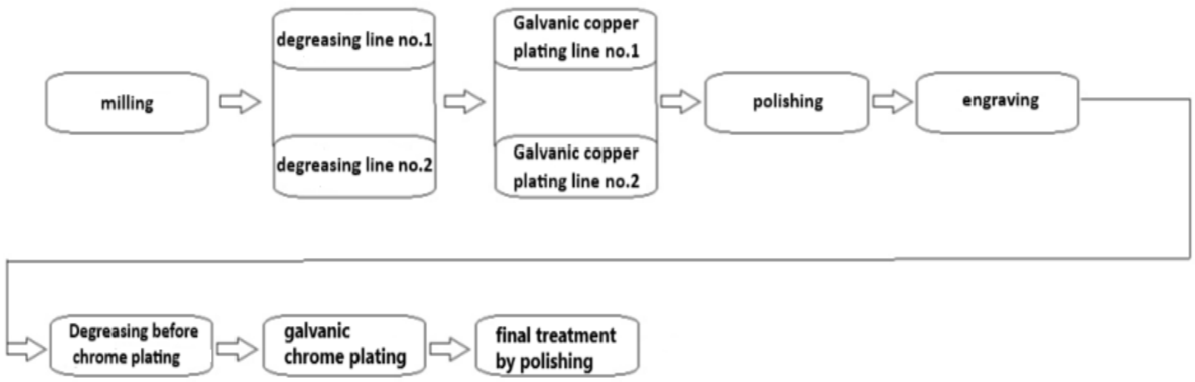

Fig. 4 Block diagram of production of printing forms

According to the block diagram, a simulation was created in the Plant simulation program, where intermediate warehouses between individual workplaces represent free storage places for developed gravure printing forms. When entering workplace parameters, average times were entered according to table number 1. The basic material flow is shown in the program in figure number 2.

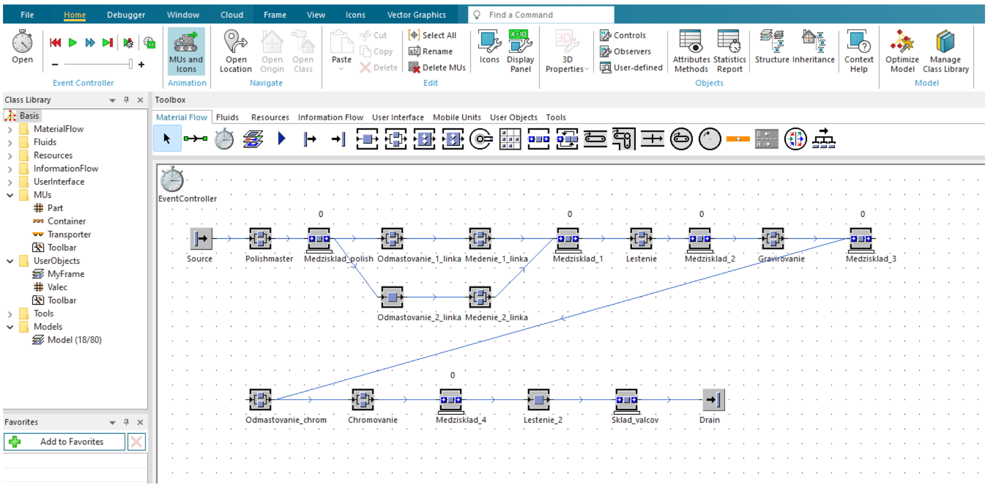

Fig. 5 Material flow in Plant simulation software

Since the time period that the simulation examines for one work shift or one work day with three-shift operation would not be sufficient to detect bottlenecks, the simulation time was set to one work week. In other words, five days of continuous operation were set. With such a setup, bottlenecks in production have already started to appear. As can be seen in picture number 3, the biggest problems were in engraving, where gravure forms began to accumulate waiting to be processed.

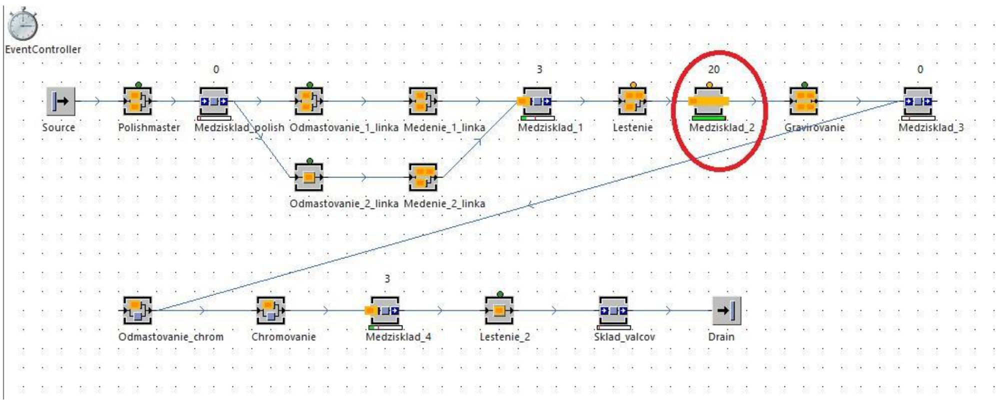

Fig. 6 Marked production bottleneck

The state as shown in picture number 3 occurred after one and a half days, that is, after approximately four full shifts. Subsequently, gravure printing forms gradually began to be speared in intermediate storage 1, that is, before polishing and also in intermediate storage before electroplating. On the contrary, work activities after engraving had no problem to pursue production. After simulating the entire working week, you can clearly see which part of the production process is holding back the entire production. Although there are quite a lot of engraving machines (5 pieces) and they form the main component of the production process of the intaglio mold preparation department, their average production time of one hour and fifteen minutes is long.

2. Proposed solution

Eliminating the problem in engraving would improve the entire production process of producing gravure molds. Therefore, the proposal to improve the flow of production consists in the purchase of another engraving device.

HELL Gravure Systems currently offers two machines that are relevant to the company's needs. One of them is the HELL K500 4G engraving machine, with which Chemosvit Folie has experience, and in addition to this model, the company also has the HELL K500 3G (the third generation machine. The other machine is the HELL Cellaxy C500 (picture number 4). This latest machine of theirs does not create an image using engraving into the copper substrate, but using a laser, which is faster and, under certain circumstances, more accurate.

Fig. 7 HELL Cellaxy C500

HELL Cellaxy C500 defines high-end in gravure printing. Cellaxy also meets the highest surface treatment requirements. The universal design of the Cellaxy laser system allows adjustments to be made based on intelligent algorithms without any mechanical changes. This ensures that a high-powered, high-quality laser beam can be used to optimum effect in any application.

Tab. 2 Comparison of times of individual devices

Device	Time
HELL K500 4G	1h15min
HELL C500 1laser head	60min
HELL C500 2 laser heads	40min

Regarding the comparison of times, they are shown in table number 2. This table shows that the current engraving equipment used at Chemosvit Folie engraves an average gravure form in one hour and fifteen minutes. The Hell Cellaxy C500 with one laser head can engrave the same gravure mold in 60 minutes, and the Hell Cellaxy C500 with two laser heads can do it in about 40 minutes.

As the first solution, it was proposed to purchase the Hell K500 4G engraving device. Among the main advantages of this solution were the simple integration of the machine into the production process, as these machines are already in use in the company. It would represent a simple training of operators as well as maintenance workers. Also, the same spare parts used in current machines would also be available.

However, one fundamental disadvantage was revealed during the simulation in the program. After adding this machine in the Plant Simulation program, the production showed some improvement but after two days the engraving appeared to be a bottleneck.

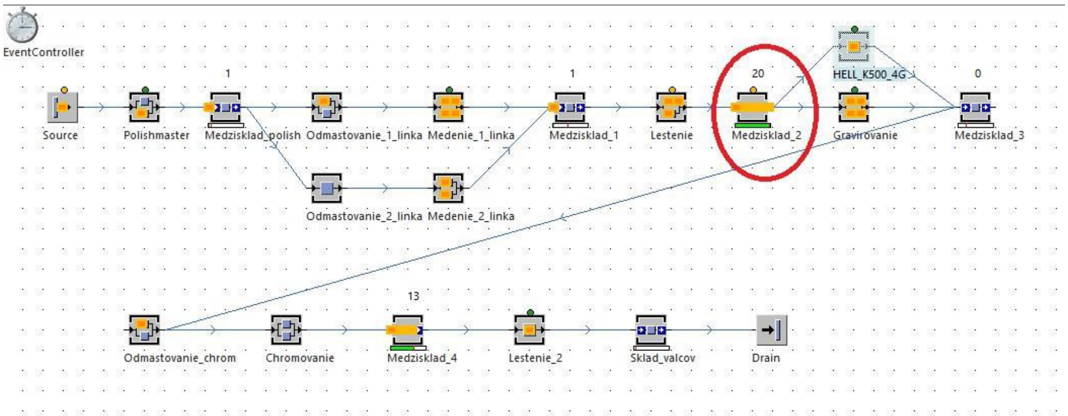

Fig. 8 Ongoing bottleneck issues

In view of the persistent problems with the bottleneck, a second proposal was adopted, namely the purchase of a Hell Cellaxy C500 machine with two laser heads. This machine has a faster engraving production of the average intaglio die by about 35 minutes compared to the machine of the original design.

This adopted proposal proves to be effective, which is also documented in figure number 6. It turns out that even with the production of intaglio forms after two and a half days, the engraving section stopped having a problem with the waiting forms.

For the company GARANT K&K s.r.o. we proposed the application of the use of a computer information system, intended for inventory management, with the help of which the exact location of specific goods will be defined. We included this proposal, as the current distribution of goods in the company is difficult to understand, which also affects the very speed of the processes of distribution of goods to the customer.

The marking of the goods, which is currently used in the operation, is a handwritten registration number on the labels kept on each type of offered goods, with the help of which the goods are then searched for in the economic program Pohoda. The current labeling of the goods and its search proved to be insufficient due to the growing number of available assortments for the customer.

Our proposal is therefore an information system in which the search for goods is managed using QR codes that will indicate the specific location of each stored product (Fig.3). In this way, we will increase efficiency and reduce time when searching for a specific product according to the customer's needs. It is important to note that this information system will also record the availability of specific requested goods. The advantage of this label is the defined specific location where the employee can find the stored goods and deliver them to the customer.

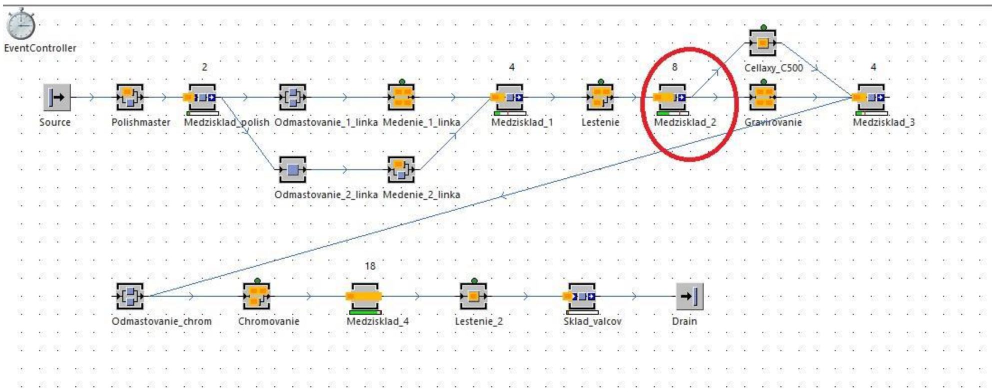

Fig. 9 Process with Cellaxy C500

After running the simulation further, after three and a half days, another production bottleneck became apparent. During the final polishing, the Daetwyler sander stopped chasing (Fig. 7). Until the Cellaxy C500 machine was included in the production process, it was sufficient to have only one of these grinders, since no more intaglio forms passed through the engraving department.

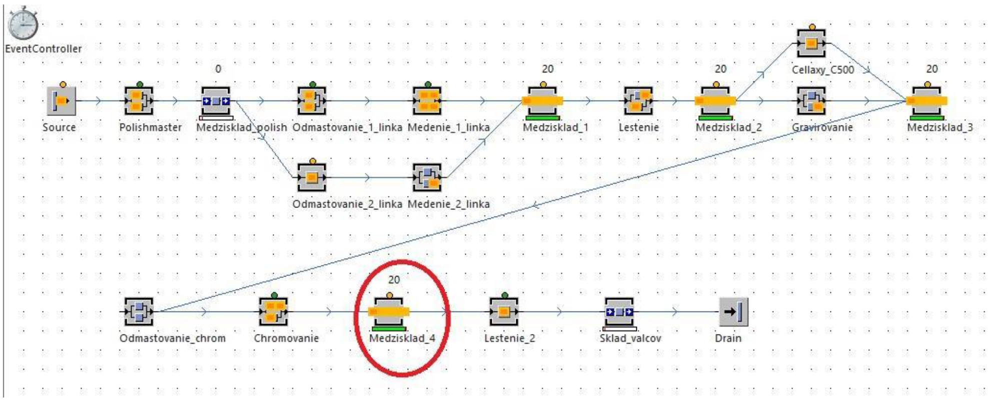

Fig. 10 Another bottleneck found

In the future, it would be necessary to consider the purchase of one more sander for final polishing. After adding one more grinder to the Plant Simulation program, it turned out that the production process remained tuned even after a week of simulation. The total production compared to the original model has increased by almost 13% as documented in figure 8.

.Models.Model

Simulation time:5:00:00:00.0000

Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Drain	Valec	18:04:52.8105	459	4	30.44%	0.00%	69.56%	17.97%	

Cumulated Statistics of the Parts which the Drain Deleted

.Models.Model

Simulation time:5:00:00:00.0000

Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Drain	Valec	10:04:47.6777	633	5	43.16%	0.00%	56.84%	30.66%	

Cumulated Statistics of the Parts which the Drain Deleted

Fig. 11Comparison of simulation results

In the upper part of the picture number 28 is the result of the original simulation before applying the Hell Cellaxy C500 machines and the Daetwyler grinder. In the lower part of the picture in the table is the result of the simulation after applying these two machines.

Conclusion

A bottleneck in the engraving workshop was defined in the company in question, and specifically in the gravure mold preparation department. Gravure printing molds were piled up there, and the current number of engraving machines could not keep up with the remaining production. Using the Plant Simulation program, the most effective solution was designed, although it was not the most economical from the point of view of initial expenses. According to the program, conventional engraving equipment, such as is used in current production, would not solve the problem, but would only delay its consequences. Therefore, a solution was proposed in the form of the procurement of a HELL Cellaxy C500 laser device with two laser heads. This measure eliminated the bottleneck.

Since until now the production process and machinery were defined without the purchased laser, the Plant Simulation program revealed another bottleneck that will arise when it is installed. The final polishing workshop works with only one polishing device, and it stopped chasing the gravure molds. Therefore, it is at the discretion of the company's management to purchase one more polishing device and thus balance the new production system.

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THE MATERIAL FLOW SIMULATION IN AN INDUSTRIAL ENTERPRISE USING THE TECNOMATIX PLANT SIMULATION PROGRAM

Bohdana BOBINICS – Daniela MARASOVÁ – Dagmar CAGÁŇOVÁ – Natália HORŇÁKOVÁ

Abstract: The main goal of this article was to create a simulation model of assembly in automotive manufacture using the Tecnomatix Plant Simulation program, conduct three experiments and achieve outputs of 25 cars per hour in those experiments. The second and third experiments were successful. Based on the savings, Experiment 2 is the most advantageous with 2 AGVs.
Keywords: Tecnomatix Plant Simulation, Material flow simulation, AGV, automotive industry.

Introduction

Many authors deal with AGV simulations. Authors Kim and Jae applied an object-oriented simulation modeling environment to simulate various alternative automated guided vehicle (AGV) systems. They used modeling in AgvTalk for a tandem configuration, and in publication [1], they described the characteristics and design methodology in a job shop environment.

Bao, BZ, Duan, Z, and Chen, W, in their publication [2], examine the mission planning problem of a multi-AGV system in dynamic simulation. The planning problem is formulated as an optimization problem, with the objective of minimizing the time required to complete the missions. The objective function takes into account the time an AGV needs to perform missions in four phases, as well as the number of missions a single AGV can execute, with battery status information considered as a constraint factor. To solve this problem, a genetic algorithm is applied, and a dynamic simulation methodology is proposed, which contributes to improved efficiency. Two experiments are conducted to verify the algorithm, with a discussion on parameter settings.

López, J; Zalama, E and Gómez-García-Bermejo, J in their publication [3] offer flexibility for the simulation of transport systems that are based on AGVs. The framework that has been used allows not only to simulate the behavior of the system, but also to test various strategies and algorithms in the control system. Complex transport systems in which vehicles have to perform multiple tasks at once also collide. When analyzing the control system, it is not necessary to simulate each AGV in detail. Therefore, many researchers do not use complex modular systems such as ROS to simulate the entire system, but prefer to rely on specific simulation tools.

As Moshayedi AJ; Li, JS and Liao, LF, writes in their publication [4], AGVs are a very well-known type of robots and are often used for very different applications such as industries, hospitals or even libraries. AGVs primarily consist of fixed components, and for this they use addons that increase the functionality of the robot. One of the most important components of AGVs is their control system. Many studies lack a comprehensive approach for AGV management strategies. The article details the AGV SIMULATION and PM Tune process, which uses the Ziegler-Nichols method and empirical techniques.

Methods and methodology

An assembly line in the automotive industry requires efficient systems of transporting components. These systems need to ensure a smooth automotive production process. The input flow consists of car bodies and components that are supplied to the line. Assembly line consists of a few important components like a conveyor belt in which car body is transporting through different assembly stations. At this station different parts are assembled for the car, for example front and rear bumpers etc.

One of the most important parts in automotive industry is a component delivery system, which can guarantee that the right parts arrive to the right place in the right time. AGVs are used for parts delivery from the storage to the assembly lines.

Fig. 1 Schematic representation of the assembly line

Results and Discussion

The simulation model was created in Tecnomatix Plant Simulation program.

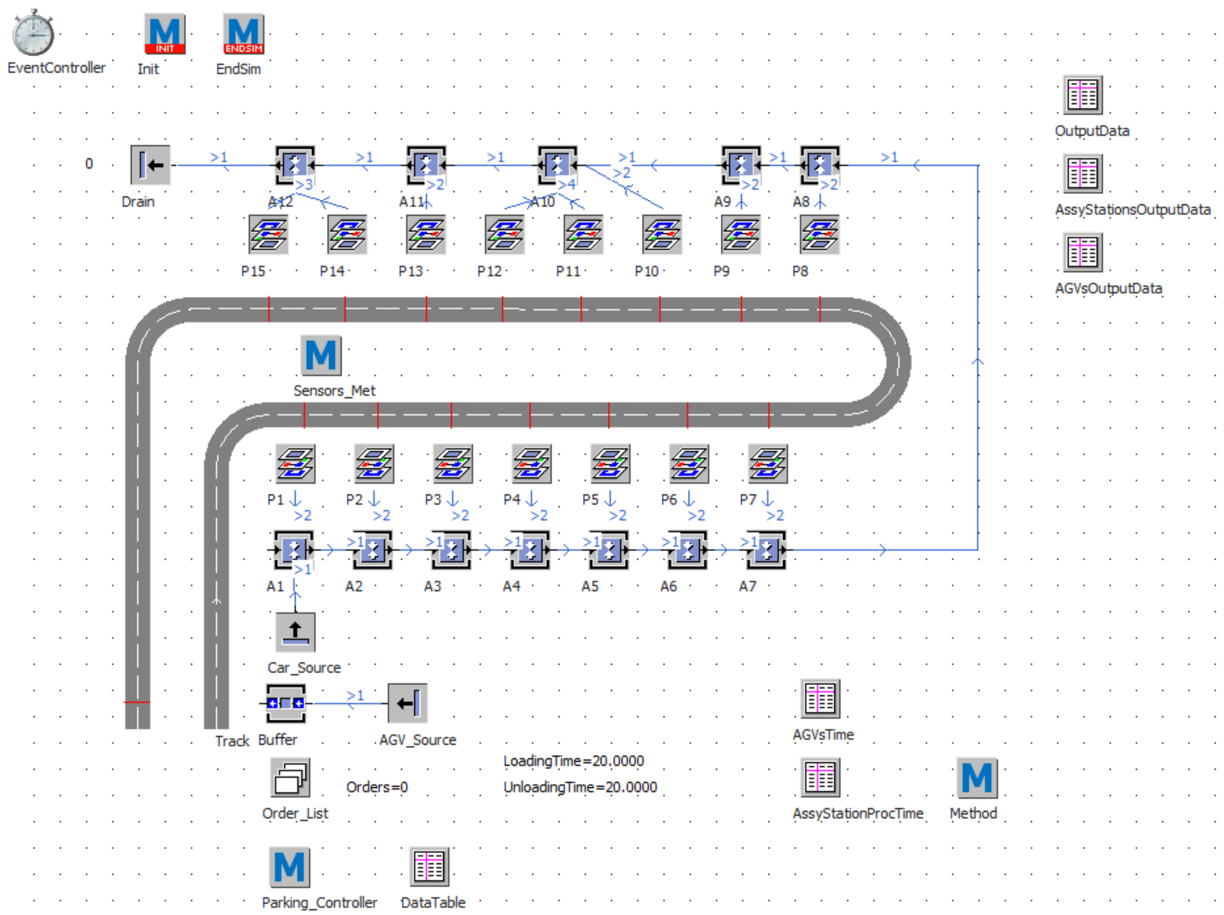


Fig. 2 Simulation model print screen

The simulation model consists of the following parts: a data list, a track, different blocks, programming methods, tables, variables, parts and transporters.
Blocks which are used to create the model:

- EventController is used to manage the flow of time;
- Source is used to generate cars body (Car_Source) and AGVs (AGV_Source);
- AssemblyStation is used to assemble cars body with parts (A1..A12);
- Frame is used to group and manage components of a simulation model (P1..P15);
- Station is representing processes, such as loading/unloading process or any other type of processes;
- Interface is used to connect frame with blocks;
- Connector is used to connect blocks;
- Drain is used as exiting point for cars;
- Buffer is used as a exchange place where AGVs can wait for the order and although full containers are loaded and empty containers are unloaded on AGVs there;
- Track is a path where AGVs with materials can move;
- Sensors are used to detect and respond to the presence or passage of entities, so when AGV will go through sensors, the method which is inside of it will be activated;
- Method is a programming space of the simulation model;
- Part can represent anything that moves through the simulation, such as components etc.;
- Transporter refers to a mobile entity (AGVs) used to move parts from one location to another;
- Display is used as visually representation for example: display can show throughput per hour.
- Init is a method which is activated at the beginning of the simulation, initial setup of the simulation model;
- EndSim is a method which is activated at the end of the simulation, end setup of the simulation model;
- DataTable is a table to store the data (DataTable, AGVsTime, AssyStationProcTime, OutputData, AssyStationsOutputData, AGVsOutputData);
- DataList is a small table with only one column to store the data (Order_List);
- Global variables are used to store the data which are affecting the model.

Explanation of the logic:
Cars body move through all assembly lines one by one starting from the A1 assembly in direction to the A12 assembly. In assembly blocks cars are assembled with different components. A stockpile of parts is essential to ensure that they are available when required. AGVs deliver containers with components (parts) to the assembly stations. P1..P15 frames represent a place where AGVs can unload a full container with parts and take the empty one. So the assembly lines are connected with P1..P15 frames to take parts from them. After passing all assemblies, the cars exit from the simulation through the drain block.
AGVs movement starts from “Exchange” which is represented in model as “Buffer”. When the order to deliver the parts to the assembly line is sent to the Buffer, AGVs begin loading the required parts. After loading they move to the right assembly to unload a full container. After unloading they take an empty container and move back to the exchange.

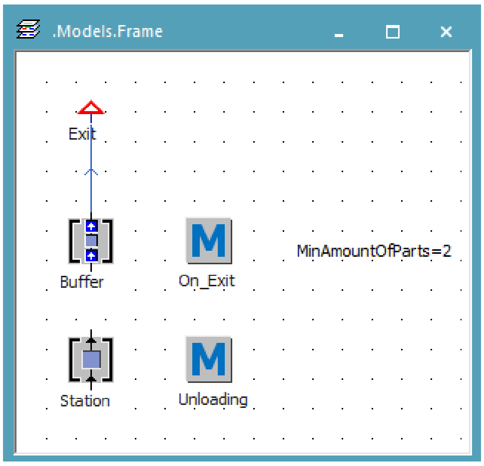


Fig. 3 P1..P15 Frames print screen

When AGV enter the frame on Station block it unloads a full container to the Buffer block and exits from the frame to the Track.

Input data for simulation:
Simulation time 365 days.
Loading time for AGV is 20 sec.
Unloading time for AGV is 20 sec.
Track length is 83.566 m.
AGVs speed is 1 m/sec.
15 different parts in Part List.
12 Assembly Stations.
No breakouts.
No shifts.

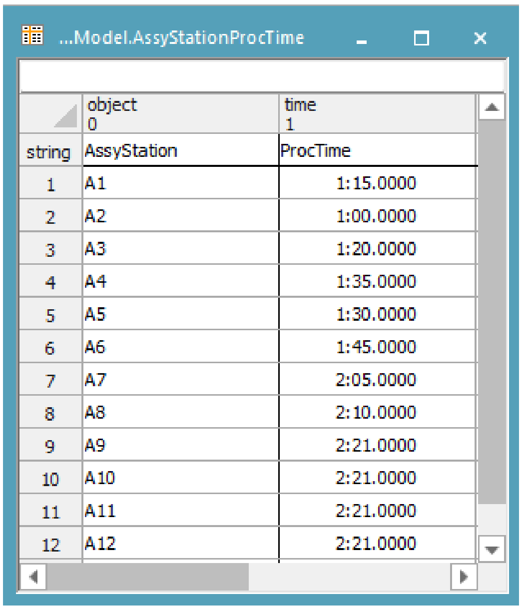
.Models.Model.DataTable

	string 0	integer 1	object 2	integer 3	real 4	object 5	integer 6	string 7
string	PN	EntranceSensorID	EntrancePoint	AmountOfParts	ExitPosition	Track	MinAmountOfParts	ConsumptionPerCar
1	PN1	2	P1	15	62.00	Track	2	1
2	PN2	3	P2	15	59.30	Track	2	1
3	PN3	4	P3	25	56.50	Track	2	1
4	PN4	5	P4	20	53.50	Track	2	1
5	PN5	6	P5	10	50.60	Track	2	1
6	PN6	7	P6	10	47.50	Track	2	1
7	PN7	8	P7	22	44.50	Track	6	2
8	PN8	9	P8	50	42.45	Track	12	6
9	PN9	10	P9	45	45.45	Track	8	4
10	PN10	11	P10	55	48.55	Track	2	1
11	PN11	12	P11	95	51.55	Track	2	1
12	PN12	13	P12	70	54.55	Track	2	1
13	PN13	14	P13	8	57.45	Track	4	4
14	PN14	15	P14	20	60.55	Track	4	2
15	PN15	16	P15	24	63.45	Track	4	2

Fig. 4 DataTable print screen with input data

Figure 4 shows important information about parts and places to which they are connected. The column “PN” means part number, unique number to each type of part. The second column “EntranceSensorID” shows a sensor on the track which is connected to the part.

“AmountOfParts” shows how many parts are inside of one container or one box. “ExitPosition” is a position on Track to which AGV will exit from the assembly. “Track” represents a track name, this column is needed only if we have more tracks in simulation. “MinAmountOfParts” shows in which moment assembly station will call AGV to deliver a full container, for example: in assembly there are only 2 parts of PN1 left, so based on the figure 4 it means that the assembly will call the AGV to deliver a full box with parts. “ConsumptionPerCar” indicates how many parts the assembly station needs to put into one car.



...Model.AssyStationProcTime

	object 0	time 1
string	AssyStation	ProcTime
1	A1	1:15.0000
2	A2	1:00.0000
3	A3	1:20.0000
4	A4	1:35.0000
5	A5	1:30.0000
6	A6	1:45.0000
7	A7	2:05.0000
8	A8	2:10.0000
9	A9	2:21.0000
10	A10	2:21.0000
11	A11	2:21.0000
12	A12	2:21.0000

Fig. 5 AssyStationProcTime print screen

Figure 5 shows the process time for every single assembly station. In the column 1 on the figure 5 there are the names of every single assembly station, in the column 2 the process times for putting some parts into one car is indicated.

The main goal is to reach 25 throughput per hour with less AGVs.

Experiment 1
Input data:
1 AGV
Output data:
Throughput per hour – 18,4
Produced cars - 161368

Tab. 4 Consumption Experiment 1

PN	Consumption per day	Total consumption
PN1	442,13	161379
PN2	442,13	161378
PN3	442,13	161377
PN4	442,13	161376
PN5	442,12	161375
PN6	442,12	161374

PN7	884,24	322746
PN8	2652,69	968232
PN9	1768,45	645484
PN10	442,11	161370
PN11	442,11	161370
PN12	442,11	161370
PN13	1768,43	645476
PN14	884,21	322736
PN15	884,21	322736

The table 1 indicates that the highest consumption is for PN8 with value of 968232 parts. The lowest consumption is for PN10, PN11, PN12 with the same value of 161370 parts.

Tab. 5 Assembly output data Experiment 1

Assembly name	Working %	Waiting %	Blocked %
A1	38	0	62
A2	31	0	69
A3	41	0	59
A4	49	0	51
A5	46	0	54
A6	54	0	46
A7	64	0	36
A8	67	3	31
A9	72	3	25
A10	72	1	27
A11	72	28	0
A12	72	28	0

The most productive assembly stations based on the table 2 are the following: A9, A10, A11, A12 with working time 72%. But there are some assembly stations that have a high value in the last column of the table 2, this column shows that the cars were blocked probably because of some other assembly stations. Column “Waiting %” shows, that this blocking point can be in A11 and A12, because these assemblies don’t have any blocking points. It can happen because of different reasons such as: there are not enough AGVs, time for calling AGV to deliver new parts is not enough, or wrong settings of process time in assembly stations.

Tab. 6 AGVs output data Experiment 1

AGVs name	Orders per day	Total orders	Working %	Waiting %
*.UserObjects.AGV:1	640,85	233911	98,11	1,89

Table 3 shows that one AGV can do 233911 orders per 365 days, or 640,85 orders per day. With working time 98,11 % which is really high value.

Experiment 2
Input data:
2 AGVs
Output data:
Throughput per hour – 25,4
Produced cars – 222857

Tab. 7 Consumption Experiment 2

PN	Consumption per day	Total consumption
PN1	610,60	222869
PN2	610,60	222868
PN3	610,59	222867
PN4	610,59	222866
PN5	610,59	222865
PN6	610,59	222864
PN7	1221,17	445726
PN8	3663,48	1337172
PN9	2442,31	891444
PN10	610,58	222860
PN11	610,58	222860
PN12	610,58	222860
PN13	2442,29	891436
PN14	1221,14	445716
PN15	1221,14	445716

According to the table 4 as in Experiment 1 the part numbers are the same, because of the same consumption per car, the highest consumption is for PN8 but with different value 1337172 parts, and the lowest consumption is for PN10, PN11, PN12 although, but with value 222860 parts.

Tab. 8 Assembly output data Experiment 2

Assembly name	Working %	Waiting %	Blocked %
A1	53	0	47
A2	42	0	58
A3	57	0	43
A4	67	0	33
A5	64	0	36
A6	74	0	26
A7	88	0	12
A8	92	0	8
A9	100	0	0
A10	100	0	0
A11	100	0	0
A12	100	0	0

Based on the table 5, the most productive assemblies are the same as in Experiment 1 (A9, A10, A11, A12) but with higher value of working time which is 100%. Values in the “Waiting %” column are equal to 0, which is good, values in the last column are although better than in the first Experiment, but still not good. Thus, assumptions about the number of AGVs were right.

Tab. 9 AGVs output data Experiment 2

AGVs name	Orders per day	Total orders	Working %	Waiting %
*.UserObjects.AGV:1	442,63	161561	67,76	32,24
*.UserObjects.AGV:2	442,40	161477	67,74	32,26

In the table 6 there are two AGVs. There are less total orders for one AGV now, but the value of produced cars is bigger than in the Experiment 1. Working time per one AGV is now 68%, and waiting time is longer.

Experiment 3

Input data:
3 AGVs
Output data:
Throughput per hour – 25,5
Produced cars – 223648

Tab. 10 Consumption Experiment 3

PN	Consumption per day	Total consumption
PN1	612,77	223660
PN2	612,76	223659
PN3	612,76	223658
PN4	612,76	223657
PN5	612,76	223656
PN6	612,75	223655
PN7	1225,50	447308
PN8	3676,49	1341918
PN9	2450,98	894608
PN10	612,74	223651
PN11	612,74	223651
PN12	612,74	223651
PN13	2450,96	894600
PN14	1225,47	447298
PN15	1225,47	447298

The highest consumption (See table 7) is for PN8 with value 1341918 parts. The lowest consumption is for PN10, PN11, PN12 with value 223651 parts.

Tab. 11 Assembly output data Experiment 3

Assembly name	Working %	Waiting %	Blocked %
A1	53	0	47
A2	43	0	57
A3	57	0	43
A4	67	0	33
A5	64	0	36
A6	74	0	26
A7	89	0	11
A8	92	0	8
A9	100	0	0
A10	100	0	0
A11	100	0	0
A12	100	0	0

Based on table 8 and tables 2 and 5 there are no big differences between Experiment 2 and Experiment 3, but there are still some blocking points.

Tab. 12 AGVs output data Experiment 3

AGVs name	Orders per day	Total orders	Working %	Waiting %
*.UserObjects.AGV:1	296,14	108090	45,35	54,65
*.UserObjects.AGV:2	296,05	108058	45,32	54,68
*.UserObjects.AGV:3	295,99	108037	45,33	54,67

Table 9 shows that there are more orders in total, but working time is less than 50%, so these results are not satisfactory, because there is no reason to have 3 AGVs for delivery. The waiting time is more than 50%.

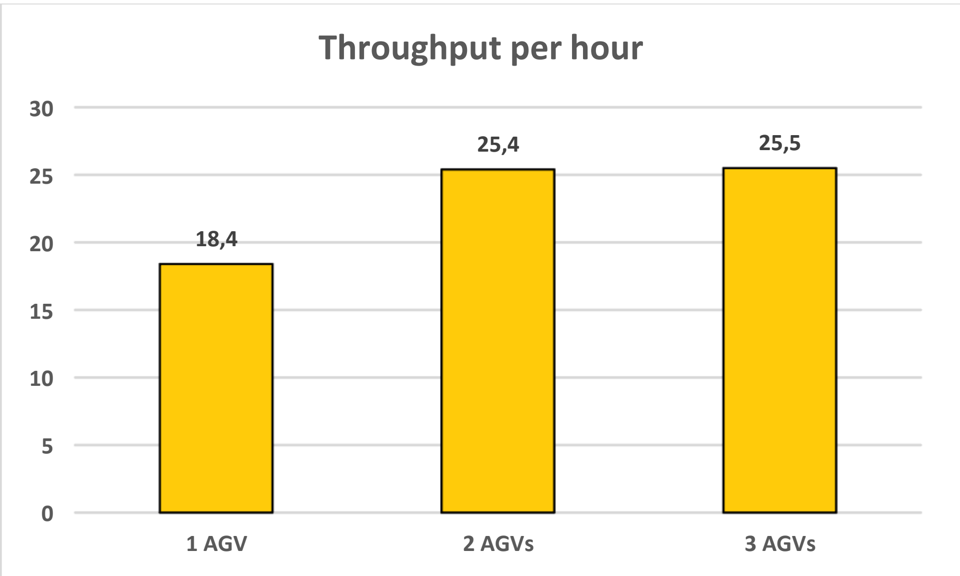


Fig. 6 Throughput per hour comparison

Figure 6 shows the most important indicator “throughput per hour” in comparison for three experiments. The first “candle” shows throughput per hour for Experiment 1 with one AGV, throughput was 18,4, but the goal was 25, so Experiment 1 did not reach the goal. The second “candle” is from Experiment 2 with two AGVs, and throughput 25,4 is much better than in Experiment 1 and the goal was not only reached, but exceeded. The third “candle” shows the results from Experiment 3 with throughput of 25,5 which is not so bigger than in Experiment 2, so there is no reason to use 3 AGVs in this situation.

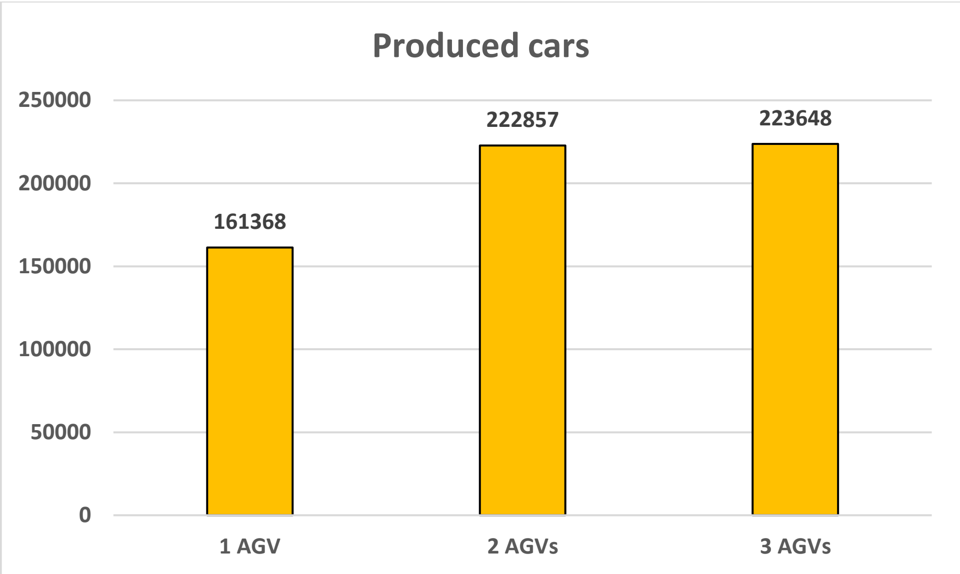


Fig. 7 Produced cars comparison

Figure 7 shows how many cars were produced during three simulation experiments. The best result was achieved in Experiment 3, but this result is only a slightly better than in Experiment 2. Experiment 1 showed the worst results.

Conclusion

Based on the results of three experiments, the best way was to use 2 AGVs, because if only 1 AGV was used, it was not sufficient for a number of reasons, such as: the main target was not achieved (throughput per hour was only 18,4, and goal was 25), sometimes the assembly stations were stopped due to lack of material and AGV worked for 98,11%, so its means, that there were not enough AGVs. The third experiment with 3 AGVs showed, that there were too many AGVs which was showed in the table 8 with working time of every AGV less than 50%, the result was not good, and although throughput was not much better than in Experiment 2. Thus Experiment 2 was a winner with 2 AGVs and working time 67,7% and with throughput 25,4.

But there were still some not good points with assembly stations working times, so it is required to change the settings of assemblies.

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INTEGRATION OF DIGITALIZATION AND SIMULATION FOR ENHANCING BUSINESS PROCESS EFFICIENCY

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Abstract: This study explores the application of digitalization and simulation technologies, specifically utilizing Tecnomatix Plant Simulation, to enhance business process efficiency. The research methodology involved identifying inefficiencies through data analysis, followed by the development of a detailed simulation model using Tecnomatix. The results indicated a significant improvement in operational performance. Specifically, the replacement of the 8-component unit led to a fourfold reduction in painting time, increased equipment active time from 20% to 80%, and reduced maintenance costs. Overall production output increased by 19%, from 74 to 88 units. Additionally, idle time for the painting process decreased from 80% to 8%, while forging and drilling efficiencies improved by 8% and 14%, respectively. The efficiency of the assembly process improved by 12% with the consolidation of stations from three to two. The study demonstrates that integrating digitalization and simulation effectively optimizes production processes and reduces costs.
Keywords: Digitization, Optimization, Production, Simulation

Introduction

Modern executives are tasked with making complex managerial decisions that have profound implications for both the immediate operations and long-term trajectory of their organizations. The increasing intensity of competition, coupled with the rapid advancement of technologies and the accumulation of new knowledge, has compounded the complexity of the decision-making process [1]. To navigate these complexities, a variety of methodologies are employed to diagnose and address systemic issues within organizations [2].

Simulation modeling provides several key advantages for decision-making and process optimization. Firstly, it allows for the creation of a risk-free experimental environment, where scenarios can be tested without the potential negative impacts on actual operations or the environment. This capability is particularly beneficial for assessing the potential outcomes of different strategies and interventions before their implementation [3,4].

In recent years, the integration of digitalization with simulation technologies has further augmented their effectiveness. Digitalization involves the adoption of digital tools and technologies to capture, analyze, and leverage data more effectively. When combined with simulation, digitalization allows for real-time monitoring and adjustment of models based on actual data, leading to more accurate and actionable insights [5].

In summary, the integration of simulation and digitalization provides a robust framework for enhancing organizational efficiency and decision-making. These advanced methodologies enable organizations to better understand and optimize their processes, leading to improved performance and competitive advantage. As the complexity of business environments continues to evolve, the adoption of simulation and digitalization will be crucial for navigating these challenges and achieving sustainable growth [6].

Research Methodology

This research employs a comprehensive methodology that integrates digitalization and simulation to enhance business process efficiency, utilizing Tecnomatix Plant Simulation as a key tool. The study commences with problem identification, focusing on detecting

inefficiencies and bottlenecks in current processes through extensive data collection and preliminary analysis. This initial phase involves gathering quantitative data on production times, equipment utilization, and maintenance costs.
Simulation modeling is then carried out using Tecnomatix Plant Simulation, which allows for the creation of a detailed and dynamic model of the existing production system. This simulation software provides a robust framework for modeling complex systems and enables the manipulation of variables to explore various scenarios. Tecnomatix Plant Simulation’s capabilities include generating statistical reports and graphical representations that aid in the visualization and analysis of process performance and interactions.
Following the development of the simulation model, digital integration is employed. Tecnomatix Plant Simulation is utilized to integrate real-time data monitoring and analysis, enhancing the model’s accuracy and relevance. The software's features support dynamic adjustments based on actual operational data, facilitating a more precise assessment of potential improvements. The software’s statistical reports and graphical outputs are used to assess changes in production output, equipment efficiency, and cost reduction.

View of Current Production

The production process (see Fig.1) begins with the felling of trees and their subsequent processing into planks. Excess wood is redirected to a scrap yard, while the planks are transferred to an intermediate storage area. After the sawing phase, the planks are divided into two main streams: one portion is sent for further processing into pegs, while the other portion undergoes milling, lacquering, and painting. In the steel processing section, the process starts by sending steel rods into a furnace, where they are heated to approximately 1100°C and then forged. Subsequent steps include drilling holes into steel workpieces and grinding, which are performed manually by workers. Once all components for the future hammers are prepared, they are sent to three assembly stations, where workers assemble them. The finished hammers are then moved to an intermediate storage area, where they are gathered and packaged in sets of 15 hammers per package. The packaged hammers are then transported by rail to a warehouse, from where they are shipped to the final customers. The manufacturing process operates continuously every day, lasting 16 hours per day with two shifts and two breaks.

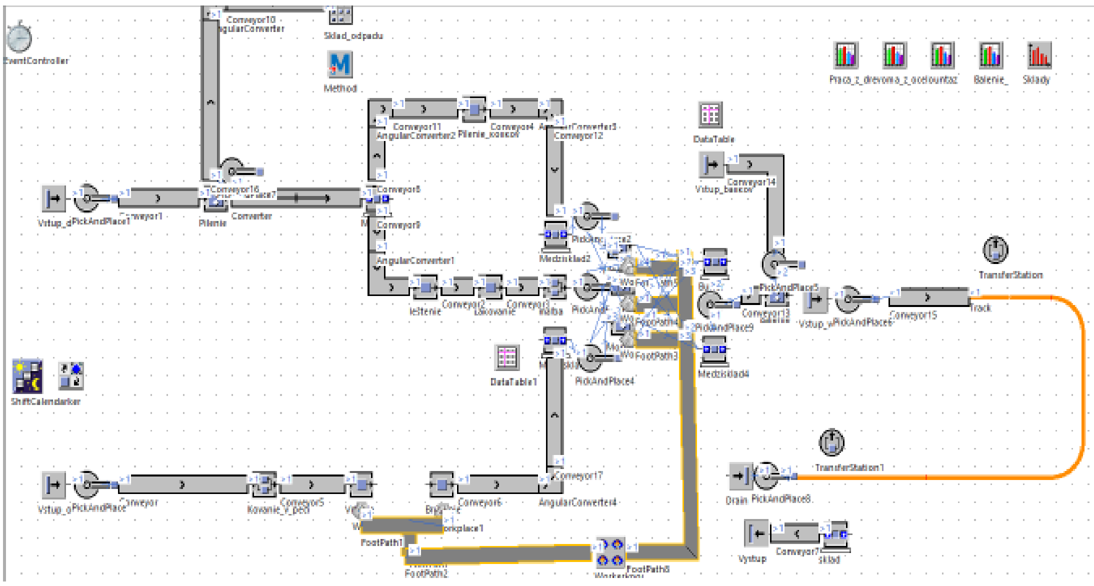

Fig. 1 2D current production in the TX Plant Simulation software

Three distinct components are manufactured in two separate workshops within the facility. These components are then assembled into a single product in a third workshop, the final product is packaged and dispatched.

Enhancing Efficiency through Optimization

The optimization process will be addressed incrementally, beginning with the wood processing operations. Analyzing the data from the graphs (see Fig. 2), it is observed that the final process, "painting," spends 80% of its time waiting for material. This issue is attributed to the high capacity of the painting station, which has eight cells and frequently remains idle while awaiting replenishment.
To address this problem, we have two potential solutions. The first option is to increase the production rate of the preceding stations, while the second option involves reducing the capacity of the painting station.

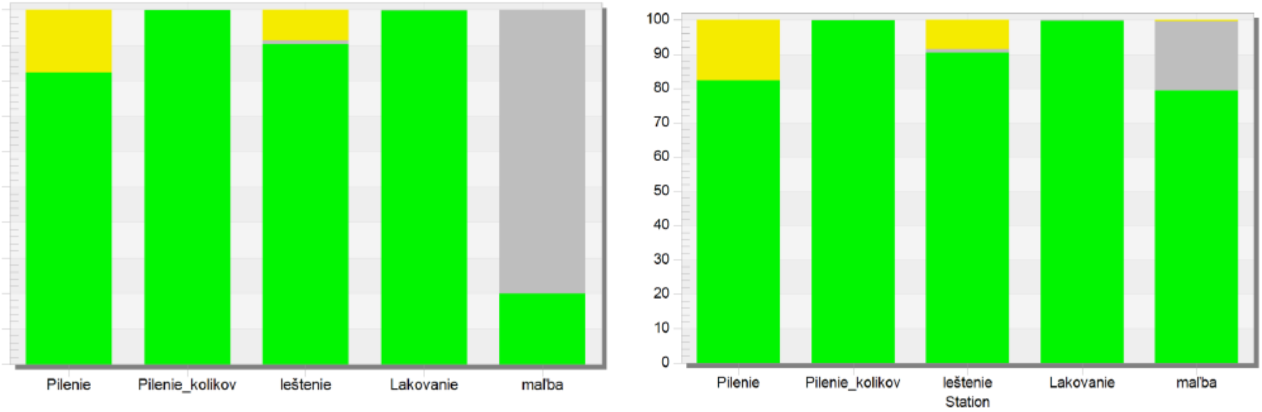

Fig. 2 Current production process and optimized production process

Another area that requires optimization is the hammer assembly stations, as indicated by the analysis performed using the TX Plant Simulation software. The results of this analysis are shown in the graph in Fig. 3. This graph provides valuable insights into the performance and potential bottlenecks in the assembly process, which can be improved through further optimization.

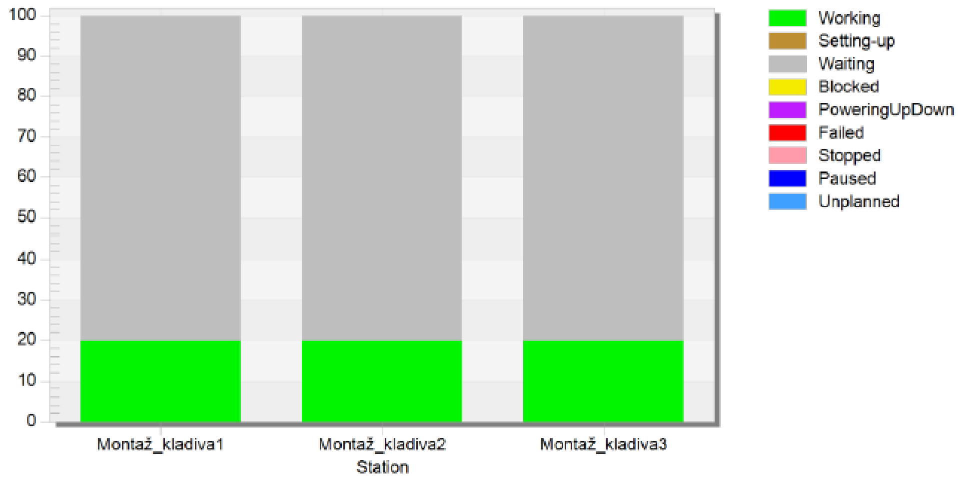

Fig. 3 Assembly process

This suggests that material must be supplied to the production processes more rapidly, which leads us to analyze processes that operate continuously. Among such continuous processes are "Painting" and "Polishing." Since "Polishing" is positioned before "Painting" and has a duration that is 5 seconds shorter, it is necessary to first align the duration of these processes by replacing the "Painting" machine with a more efficient model. After implementing these changes, the efficiency of the assembly stations increased, but this improvement was not sufficient to achieve the desired performance level. Therefore, we proceeded with further analysis to identify processes that operate continuously and prevent other processes from receiving material in a timely manner. It was found that the "Sawing" process, which takes 20 seconds, represents such a bottleneck. The goal is to determine a new optimal duration for this process. Based on the tests conducted, the optimal time was determined to be 17 seconds, which allows the total production volume to increase to 88 units per cycle. This optimization results in a significant improvement in the performance of the machine and the overall production process.
In the optimized production model (see Fig. 4), unnecessary components that occupied space and required regular maintenance have been removed. This has created opportunities to implement more efficient solutions, which opens new possibilities for reducing operating costs and investing in equipment upgrades.

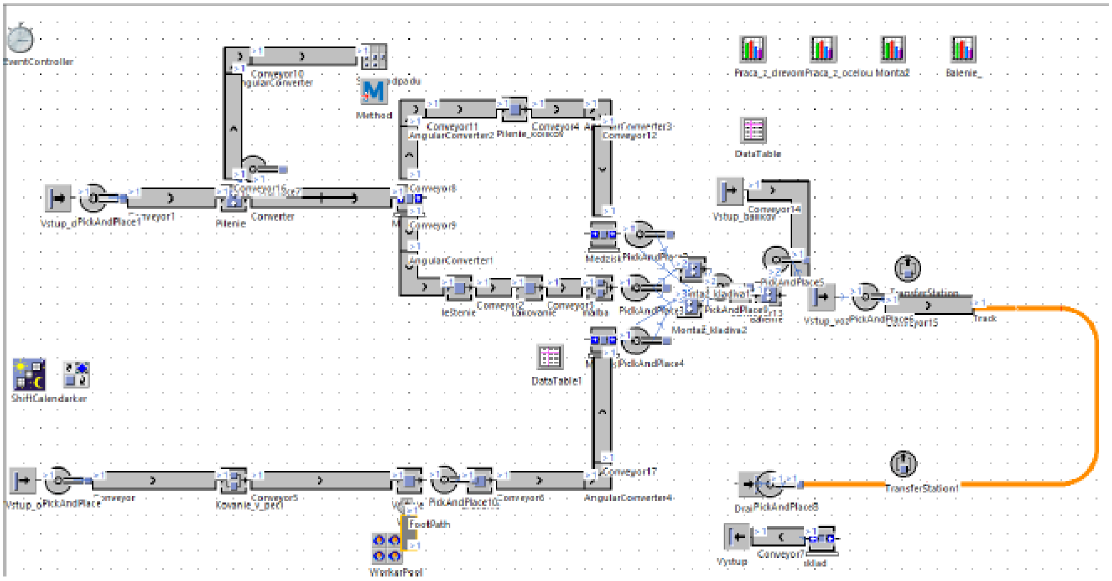

Fig. 4 2D representation of the production layout after optimization

This approach not only increases production capacity but also allows for better utilization of existing space and resources. By installing new equipment that reduces cycle time and enhances productivity, we can further maximize production potential while also improving the flexibility of the production process for future expansions or adjustments based on changing market demands.

Result

The comparative analysis of the two proposed options demonstrated that the first option had no effect on the total product output; it merely led to an increased production rate of a single component, which proved non-beneficial in the broader context. Conversely, the second option, which involved replacing the 8-component unit with a 2-component unit, resulted in a fourfold reduction in painting time. This modification significantly enhanced the operational efficiency

of the equipment, increasing its active time from 20% to 80%, while simultaneously reducing maintenance costs due to the lower operational and maintenance requirements associated with smaller equipment.
The optimization led to a substantial transformation in the production layout. The removal of extensive pathways and a redundant machine resulted in decreased maintenance expenditures and labor costs, while also liberating substantial floor space. This newly available space holds potential for future production expansion, should significant investments be made.

Simulation time:16:00:00.0000

Object	Name	Mean Life Time	Throughput	TPH	Production	Transport	Storage	Value added	Portion
Vystup	Zabalene_kladiva	16:53.2662	88	6	64.41%	35.59%	0.00%	1.48%	

Fig. 5 Results of the optimization of the production process

Quantitatively, the overall production output (see Fig. 5) increased by 19%, from 74 units to 88 units. The painting process experienced a reduction in idle time from 80% to 8%. Additionally, the efficiency of the forging process improved by 8%, and the drilling process saw a 14% increase in efficiency. The assembly process was streamlined to utilize 2 stations instead of 3, resulting in a 12% enhancement in efficiency. Through the implementation of production digitalization and simulation techniques, we successfully optimized production parameters, increased overall output, and achieved cost reductions across various operational facets.

Conclusion

The comparative analysis of the proposed optimization strategies demonstrated that replacing the 8-component unit with a 2-component unit significantly improved production efficiency. This change reduced painting time by a factor of four, increased equipment active time from 20% to 80%, and lowered maintenance costs due to the reduced complexity of the smaller equipment. The reorganization of the production layout eliminated unnecessary pathways and machinery, resulting in reduced maintenance and labor costs, and freed up valuable floor space for potential future expansion.
Quantitative results indicate a 19% increase in overall production output, with a rise from 74 to 88 units. The painting process's idle time was reduced from 80% to 8%, while forging and drilling efficiencies improved by 8% and 14%, respectively. The assembly process efficiency increased by 12% with the consolidation of stations from three to two. These improvements were achieved through advanced digital simulation and optimization techniques, which enhanced production efficiency, reduced costs, and maximized operational output.

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IDENTIFICATION OF PRODUCTION BOTTLENECK USING RTLS DATA ANALYSIS

Marek MIZERÁK – Jozef TROJAN – Milan FIĽO – Juraj KOVÁČ

Abstract: This article focuses on identifying and addressing bottlenecks in manufacturing processes using Real-Time Location Systems (RTLS). Bottlenecks in production represent critical points where problems and constraints accumulate, negatively impacting the flow and efficiency of production. The research examines various factors that can lead to the formation of these bottlenecks and suggests strategies for effectively resolving them using RTLS. Identifying bottlenecks requires a detailed analysis of processes and the collection of data through RTLS. Solutions to these issues may involve optimizing workflows, improving resource distribution, and enhancing material flow based on data obtained from RTLS. Successful implementation of this approach can lead to increased productivity and efficiency in manufacturing.
Keywords: Sewio RTLS, bottleneck, production, manufacturing company, hardware.

Introduction

Modern industry is actively striving for digital transformation and optimization of production processes. They play a key pivotal role in this transformation, taking into account and analyzing data in real time. One of these technologies is the Real Time Localization System (RTLS).
RTLS technology can accurately locate objects or personnel in real time using various sensors and devices. This technology has the potential to become an effective tool for digitizing industrial processes.

Production bottlenecks represent one of the biggest challenges for businesses. These locations can arise for a variety of reasons, including inadequate planning, inefficient space layout, lack of resources, or non-optimized processes. Bottlenecks often result in increased cycle times, lack of capacity, waiting for materials or lack of synchronization between different parts of the production process.

Real-time location technology (RTLS) is becoming an integral part of modern industry and plays an important role in the digitization of production. Its applications range from optimizing logistics and inventory management to increasing the efficiency of production processes.
In an industrial context, RTLS can accurately locate equipment, supplies and employees and provide information about their movement and status in real time. This enables efficient management of production operations, reduction of time delays and optimization of production flows.

The application of RTLS in various industries points to its diverse advantages. In the automotive industry, RTLS is used to track inventory movements and equipment status on production lines. In logistics and warehouse operations, this technology enables inventory management, speeds up picking and completion processes.
Integrating RTLS with digital control systems is key to the digital transformation of manufacturing. It allows you to create advanced automated systems based on the data collected

in real time. Collected data also plays an important role in analytics, which helps businesses make more informed decisions to optimize production processes and improve management operations.
Therefore, RTLS technology not only increases production efficiency, but also opens up new possibilities for better control and management of production operations, which ultimately contributes to the competitiveness of businesses on the market.

Bottlenecks in production processes

Bottlenecks in production processes represent critical points where problems and limitations that affect the flow of production are often concentrated. These locations can significantly slow down manufacturing operations, increase costs and reduce overall efficiency. Their identification and subsequent optimization are therefore crucial for the success of the company.
In practice, production process bottlenecks can arise in different ways. For example, insufficient capacity of certain production lines or equipment can cause processing queues, leading to delays and increasing time costs. Lack of skilled staff in key areas can lead to overload, lack of quality or inefficient work processes. Even minor flaws in the supply chain or logistics operations can create bottlenecks that affect the overall work flow.

Identifying these bottlenecks requires thorough analysis of manufacturing processes, data collection and evaluation, and collaboration between different departments and levels in the organization. Once identified, it is crucial to develop a strategy to deal effectively with these problems. This may include investing in technology upgrades and automation, improving work processes, expanding capacities, optimizing the supply chain or even restructuring manufacturing operations.

The successful solution of production process bottlenecks can lead to increased productivity, reduced costs and improved competitiveness of the company. Therefore, it is important to pay attention to identifying and solving these problems as part of a broader strategy for improving manufacturing processes.

Bottlenecks can arise, for example, as a result of:
- Lack of labor force or worker training.
- Insufficient capacity of production facilities or infrastructure.
- Outdated processes or technologies.
- Unstable supply chain or problems with logistics.
- Inefficient management of storage, transportation or work with material.
- Non-optimal work procedures or insufficient coordination between different departments.

The definition of manufacturing process bottlenecks varies according to the specific situation and industry. In any case, it is important to identify these bottlenecks and find ways to optimize or eliminate them in order to achieve greater efficiency, improve work flow and minimize losses and delays.

Practical measurement in a production company

The prototype and innovation center is located at Park Komenského 12/A in Košice. It is a modern manufacturing plant with state-of-the-art equipment. My main task was to use the RTLS UWB Kit system to identify production bottlenecks and help prevent them, thereby increasing production productivity and efficiency. To achieve my goal, I created a mini plan and followed it throughout the process:

1. Creating a company layout;
2. Technical preparation of the RTLS system;
3. Software installation and connection of all system components;
4. Tracking and Analysis
5. Results and decision.

Fig. 1 The prototype and innovation center

Technical preparation of the RTLS system

After determining the production intention, it was necessary to measure all the necessary dimensions for the correct way of positioning the RTLS system. In general, the RTLS system is designed for a maximum area of 25 meters, but after measuring all the dimensions of the enterprise, I came to the conclusion that its area is larger and is 34 meters. This appeared to be a problem at first, as I realized that it would cause measurement bias. This problem could be solved by zooming in. To do this, I would have to raise the tripods higher than usual, which would increase the area.

Subsequently, tripods with RTLS antennas were placed in the monitored area, which I placed on all sides to cover the entire production. I then proceeded to install the anchors. There was a separate place on the tripod for the battery, which was connected to the anchor by a cable. The battery could work continuously for 24 hours. Once the anchor was in place and connected to the battery, I could start raising the tripods.

Fig. 2 RTLS UWB Wi-Fi Kit

Placement of tags on monitored objects

This was followed by a tag placement process to determine bottlenecks, I had to place the tags correctly, which I did. I placed them in all the places needed for the RTLS system.
I started with a pallet truck that I glued to the side. Using the RTLS system, I could monitor the movement of the pallet truck in real time, its frequency, zones, based on which I could analyze and find bottlenecks. A pallet truck is often used in manufacturing because it transports goods and materials on pallets.

Fig. 3 RTLS UWB Wi-Fi Kit

Monitoring the process and its analysis

When all the tags were in their places, it was possible to continue the work and move to the next phase - tracking and analysis. Using the RTLS system, I could see the position of all the tags in the production on the layout. I could also see anchors on all sides. My job was to monitor the process on the layout and make sure all the tags worked and displayed their location correctly. I had to replace the tags in case of any problems.
After I placed the tags all over the production, it was necessary to let the system flow. My research took 3 days and here is the information to analyze it further.

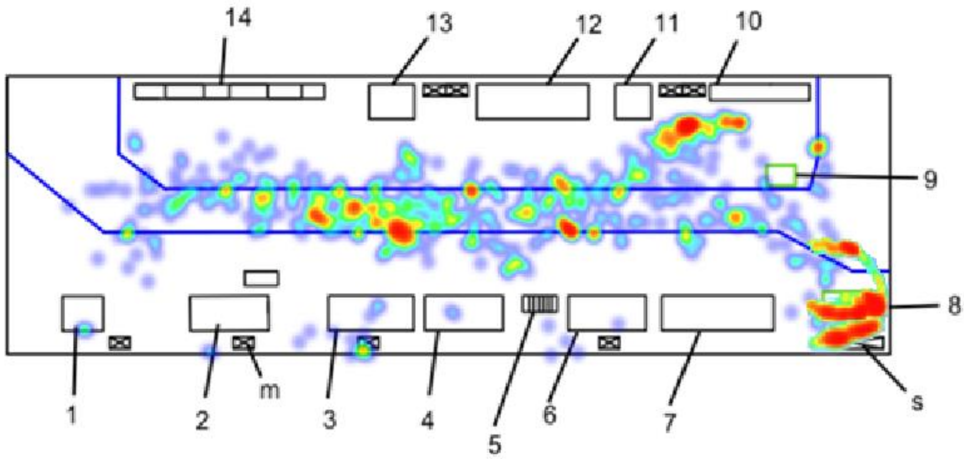

Fig. 3 Analyzes with the heatmap method

After performing the analysis, I can draw the following conclusions. The RTLS system showed me that the bottleneck is in the stock of materials and semi-finished products. This happened due to the fact that the entire production process takes place on one side of the enterprise and the worker has to go from one part of the room to another to get the necessary material for production. This creates bottlenecks that reduce the efficiency and productivity of production. There is also a warehouse of finished products, pallets and trolleys at this location, which creates a lot of congestion and lack of space at this location.

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Conclusion

Production processes are key elements for the competitiveness and success of the company. The identification and solution of bottlenecks in production processes are therefore necessary to achieve optimal efficiency and performance. This work analyzed the issue of production bottlenecks and presented an approach using Real-Time Location System (RTLS) to identify and optimize these locations. The collection and analysis of data from RTLS provides valuable information for the management of production processes and enables the effective resolution of problems associated with bottlenecks. The implementation of measures to improve the flow of work, optimize work procedures and increase the capacity of production facilities based on the analysis of data from RTLS can lead to a significant improvement in efficiency, cost reduction and an increase in the competitiveness of the company in the production environment. It is important to pay attention to the continuous monitoring and updating of processes in order to maintain production at an optimal level and contribute to the long-term success of the company.

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MESHY AS A TOOL FOR CREATING 3D MODELS FOR 3D PRINTING

Jan KOPEC – Miriam PEKARČÍKOVÁ – Jozef TROJAN – Marek MIZERÁK

Abstract: This article explores the intersection of artificial intelligence (AI) and 3D printing, examining how AI technologies are transforming this innovative industry. The article analyzes current applications of AI in the 3D printing process, such as design optimization, manufacturing process automation, and predictive maintenance. Particular emphasis is placed on AI's ability to improve the accuracy and efficiency of 3D printing processes, as well as its contribution to personalization and materials innovation. Challenges associated with AI integration, including ethical and safety issues, are also discussed. The article provides an overview of the potential and future trends at the intersection of AI and 3D printing, contributing to a better understanding and use of these technologies in the industrial and research spheres.
Keywords: *Artificial Intelligence, 3D Printing, SolidWorks, Meshy AI*

Introduction

Artificial intelligence is becoming a part of the technology industry nowadays, and 3D printing is no exception. The combination of these two innovative technologies is revolutionizing the way we design, optimize, and manufacture products. AI is enabling more accurate and efficient modeling, process automation, and even prediction of results, opening new possibilities not only for industry but also for individual makers. This article focuses on how artificial intelligence is transforming 3D printing and what its main benefits and challenges are in this dynamic environment.

Linking AI with 3D printing brings several benefits that improve the entire process from design to the final product:

- **Design optimization:** AI can analyze massive amounts of data and design optimized geometries that human designers might not immediately consider. These designs are often lighter, stronger, and more efficient in terms of materials. AI also enables generative design, where algorithms create thousands of designs based on specified parameters, leading to innovative and often counter-intuitive solutions.
- **Increased accuracy and quality:** Thanks to artificial intelligence, a high level of precision can be achieved in 3D printing. AI monitors the entire printing process in real-time and can identify and correct potential errors before they show up in the final product. This reduces waste and improves the quality of the output.
- **Automation and efficiency:** AI can automate the entire 3D printing process, from model preparation to print completion. This frees up time for engineers and designers to focus on more creative and strategic tasks. Automation also leads to reduced costs and faster production, which is especially key in mass production.
- **Prediction and maintenance:** AI can predict the wear and maintenance needs of 3D printers based on historical data analysis. This predictive maintenance allows you to prevent downtime and extend equipment life, which reduces operating costs and increases production reliability.

- **Personalization and customization:** AI makes it easy to personalize products according to specific customer needs. Algorithms can quickly adapt designs based on individual requirements, which is particularly useful in the fields of medical devices, fashion, or architecture.

The interconnection of artificial intelligence and 3D printing thus brings not only technical improvements but also a paradigm shift in how we approach design, manufacturing, and consumer preferences. These advantages make this combination a powerful tool for the future of manufacturing and the creative industries.

MESHY AI

MESHY AI is an innovative software tool that uses artificial intelligence to streamline and automate processes related to 3D modeling and 3D printing. It is designed to assist designers, engineers, and manufacturing professionals in creating, optimizing, and preparing 3D models for printing, saving time, and improving the quality of the resulting products.

Some of the main features of Meshy include:

Tab. 13 Description of options for creating 3D models

Feature	Description
Text to Texture	A new way to create textures for your 3D models. Simply type in a descriptive text prompt of the texture you want and upload your model, and Meshy will generate a texture for you in 3 minutes.
Image to Texture	Designed for artists and designers, without breaking the original workflow. Meshy allows you to create textures from concept art images and a base model in less than 10 minutes.
Text to 3D	Empowering creators of all skill levels, even those without any prior 3D experience, to generate fully textured 3D models from a simple text prompt within 2 minutes.
Image to 3D	Creating 3D models with only a single image. Meshy will infer the 3D structure of the object from the image and generate a fully textured 3D model in less than 15 minutes.

The main features of MESHY AI:

- **Automatic model correction:** MESHY AI can identify and automatically correct errors in 3D models such as holes, overlapping surfaces, or unsealed geometries that could cause problems in 3D printing. This feature ensures that models are always ready to print without the need for manual intervention.
- **Geometry optimization:** the software uses AI to optimize the geometry of models, which can include reducing the number of polygons, improving surface texture, and reducing the weight of the model without sacrificing its structural integrity. This leads to material and time savings in printing.

- **Generative Design:** MESHY AI supports generative design, where the user specifies certain parameters to the model and the software generates different designs that are optimized for specific needs. This process can yield new and unexpected design solutions that a human designer might not have discovered.

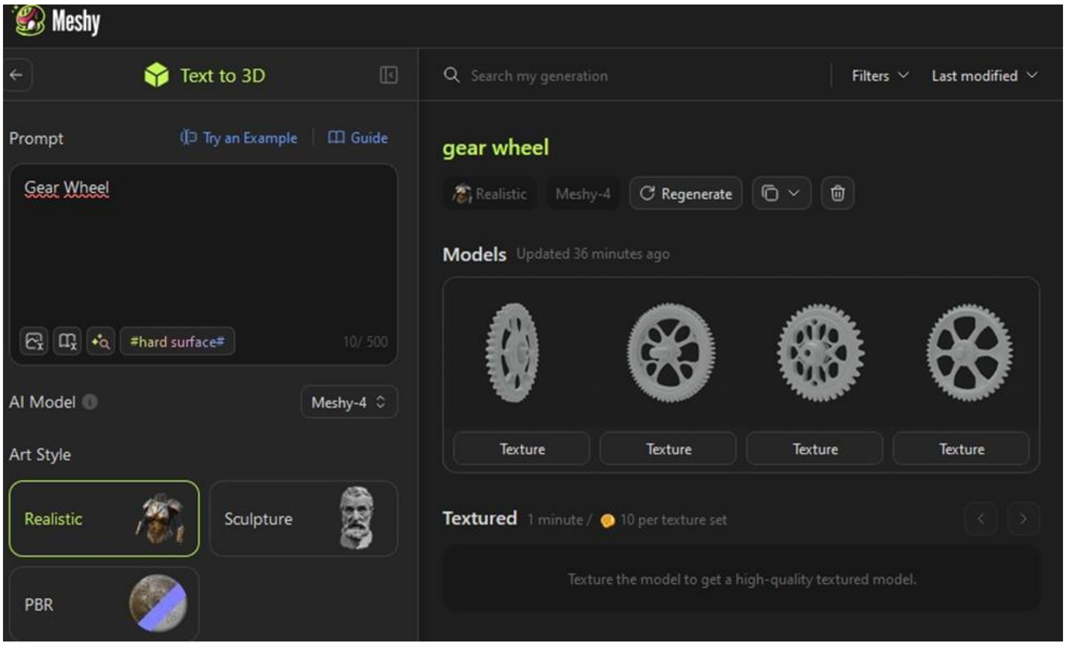

Fig. 1 MESHY home environment

- Analysis and simulation: The program offers tools for structural strength analysis and simulation of model behavior under different conditions. This allows potential problems to be identified before production, reducing the risk of failure and minimizing the need for repeated iterations.
- Integration with 3D printing platforms: MESHY AI is compatible with a variety of 3D printing platforms and file formats, making it easy to prepare and export models directly to 3D printers. This integration simplifies the entire process from design to final printing.

Benefits of MESHY AI:

- Efficiency
- Quality
- Creativity
- Cost savings

In our case, I chose to create a 3d model using the Text to 3D tool. As in the case of other artificial intelligence platforms, you just need to define how you want the model to look like, what features, properties, or visual properties it should have, and select the generate option.

The MESHY AI platform generates 4 models at once according to the user's specifications. It is possible in case of dissatisfaction with the shape of the model, just specify the text again and generate a new model.

If the generated model meets the requirements, just select the Download icon. The platform offers several types of formats to choose from that can be downloaded, fbx, obj, glb, usdz, stl and blend. In our case, we chose the stl model because this type of format can be further modified in 3D modelling software such as SolidWorks or AutoCAD Inventor.

Fig. 2 Model created according to a specific text in the MESHY platform

MESHY AI is a powerful tool for anyone involved in 3D printing, from amateurs to professionals, and contributes significantly to streamlining and improving the entire process of creating and producing 3D models.

The next step in preparing a model for 3D printing is to set its parameters in SolidWorks. In this program, it is possible to change the size because the MESHY platform will generate an optional size but if it is defined the platform will take it into account.

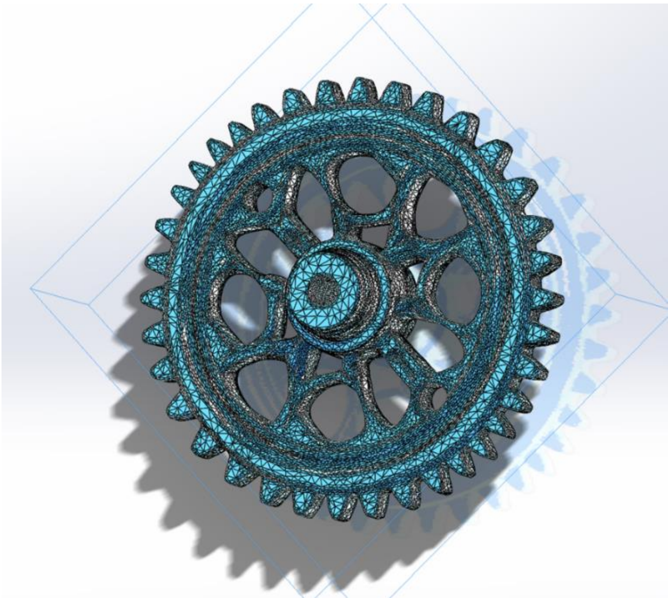

Fig. 3 Model stl. in SolidWorks after size adjustment

In SolidWorks, the Scale tool can be used to adjust the size of the model to prepare it for the slicer, which generates a .gcode format that can be processed by the printer.

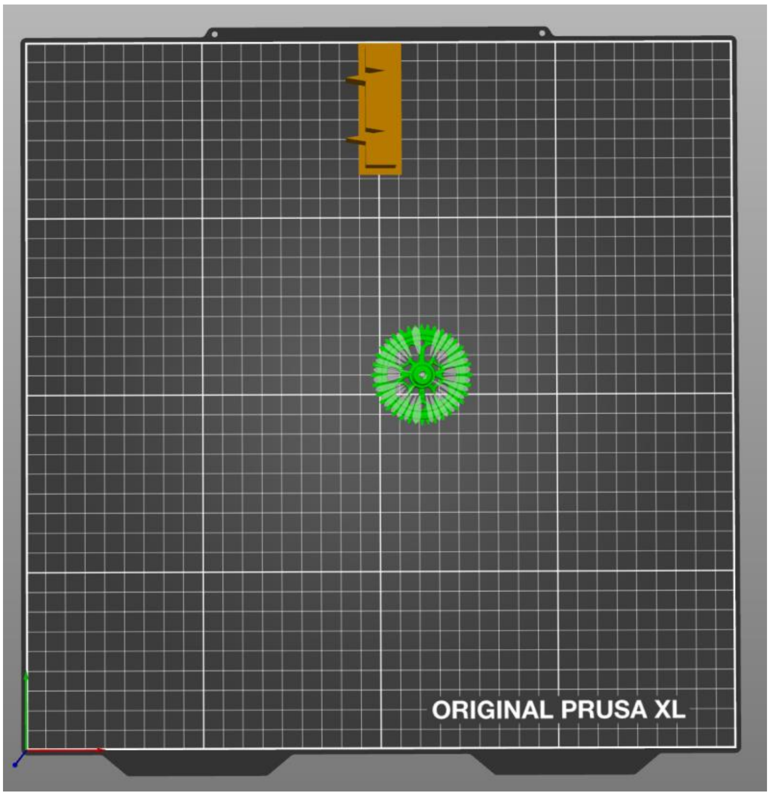

Fig. 4 Model in PrusaSlicer in .gcode format

Conclusion

The Meshy tool represents a significant contribution to the creation of 3D models for 3D printing, especially in the context of its integration with CAD software such as SolidWorks. While SolidWorks is a powerful design and modeling tool, Meshy offers additional features that make it easier to prepare models for printing. The tool enables the conversion and optimization of complex geometric shapes that are typical of designs created in SolidWorks while ensuring that the models are error-free and compatible with a variety of 3D printing technologies.

Meshy also provides useful tools for correcting and editing files that may contain errors created during export from CAD software to formats that 3D printers can handle, such as STL or OBJ. This avoids problems that could arise during actual printing, saving time and material.

Combining the capabilities offered by SolidWorks in creating complex models with the flexibility and efficiency of Meshy in preparing these models for printing creates a robust workflow. This workflow not only improves the quality of the resulting 3D printed objects but also significantly improves the overall efficiency of the process, which is especially valuable in industrial applications where accuracy and reliability are key. The combination of these two tools thus opens new possibilities in 3D printing and contributes to its further development in various fields.

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COMPARISON OF RESULTS AND CONDITIONS OF SCANNING WITH SIMPLE 3D SCANNERS AND THEIR APPLICABILITY TO REAL OBJECTS

Marek KLIMENT – Michał SĄSIADEK – Waldemar WOŹNIAK - Daniel DEBOWSKI

Abstract: Reverse engineering and 3D scanning represent two powerful technological fields that have become an integral part of modern industry and research in recent years. These methods enable detailed analysis of existing products and objects in order to better understand and use them. The work focuses on two specific scanners, identifying their basic parameters and providing a brief guide to their use and handling. In the final phase, the work is focused on the evaluation and comparison of the achieved results.

Keywords: *Reverse engineering, 3D scanning, comparison, lighting conditions, display quality*

Introduction

At the present time, where digital transformation permeates every sphere of our lives, 3D scanning plays an important role in the process of digitizing real objects and the environment. This technology, combining elements from the fields of informatics, photogrammetry and engineering, opens new perspectives for various sectors from industry to culture. The aim of the practical part of the work is to compare procedures in reverse engineering processes. Within this work, procedures for working with two specific scanners - Matter and Form and Sense (Fig. 1) are described in detail. In addition, the work also deals with the comparison of the dimensions of scanned and then printed objects in order to find out how accurately the printed models are.

Matter and Form Sense

Fig. 12 Compared 3D scanners

1. Procedure for working with individual devices

The following chapter compares the ways of working with individual devices.

1.1 Scanning with Matter and Form

In this section, we will learn how to scan in the MFstudio environment. We will discuss the individual steps that need to be applied for successful scanning of various objects. We will also look at the available options and functions of the MFstudio software that facilitate this process.

The production of printing forms for gravure printing takes place following the gravure printing schedule of the ORION system, based on the confirmed binding deadlines for the end of production at the center of gravure printing and material security. Based on the schedule, the order of gravure printing forms is formed, which is binding for the department when assigning priority to individual orders.

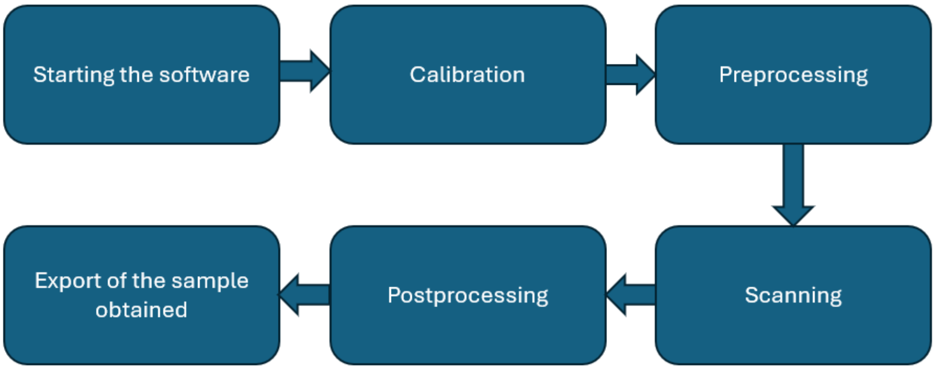

Fig. 13 Scheme of the progress of activities through MFstudio

After the scan is complete, the result of the scanned object will be displayed on the screen. However, if the scanned object is not perfect, we have the possibility to improve it by adding more scans to the project, thus obtaining a better result. A brush tool is available to remove unwanted points from the scanned object, which allows us to precisely adjust the result according to our requirements. We can also clean the noise using the slider. If we have cleaned the scans, we can align them by clicking the A icon on the main scan and then the A icon on the scan that needs to be aligned. Finally, the software provides us with the option to perform the networking process. This process will automatically close all holes in the model. The meshing function is simple and contains only two main editing options. The first is the quality slider, which allows you to set the level of detail and accuracy of the created model. The second option is a checkbox that allows you to enable or disable texturing of the model.
After completing all the steps, only the step of exporting the scanned object remains. We can export point clouds in PLY or XYZ file formats, while we can export mesh models in STL or OBJ file formats. Figure 3 e shows the final scan of the scanned part.

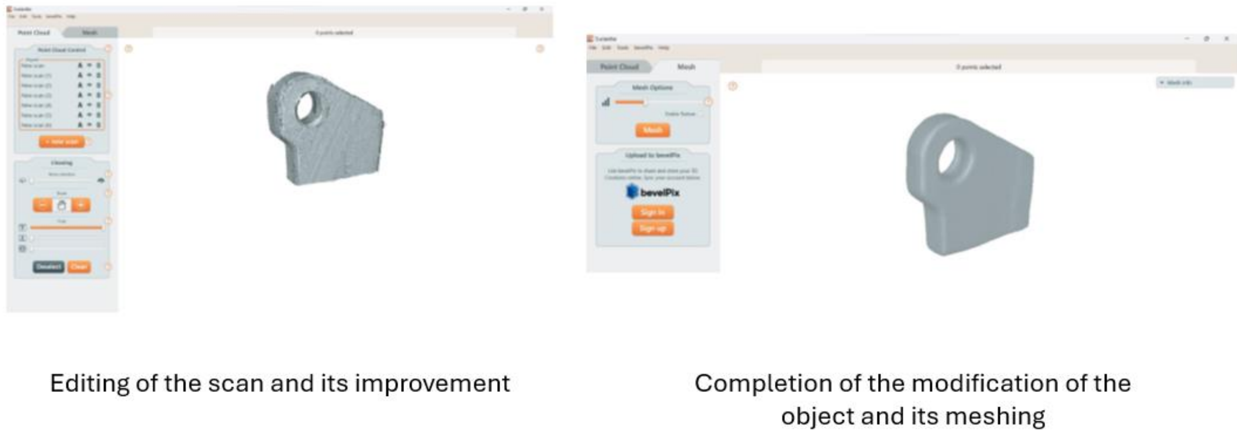

Fig. 14 Editing and finishing the scan into the final form

The influence of lighting conditions on the quality of the scan with Matter and Form

Scanning with the Matter and Form scanner was carried out in different lighting conditions. This process was carried out in daylight, where the scanner was able to use natural light to capture the details of the objects with high quality. Artificial lighting was also used so that scanning could be performed indoors and under different lighting conditions. In addition, scanning was also performed in the dark to investigate the scanner's ability to work in limited light conditions. The Matter and Form scanner has proven to be able to scan even in total darkness, which is a significant advantage. However, it is important to note that even if the scanner is able to capture the details of an object in poor lighting conditions, the lack of light has its limitations. In complete darkness, the scanner cannot capture the color of the scanned object.

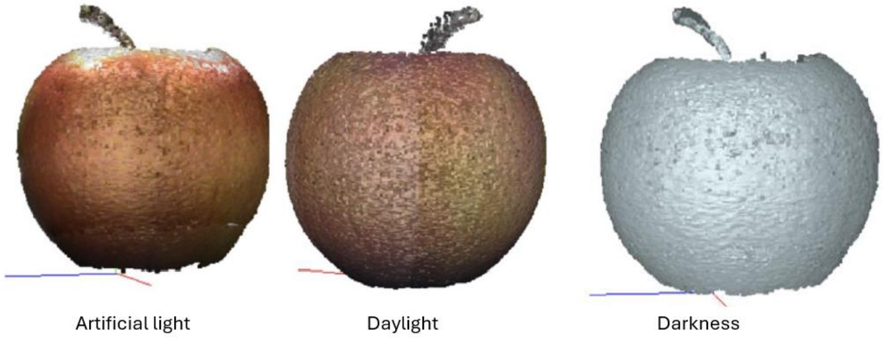

Fig. 15 Comparison of lighting conditions when scanning objects with the Matter and Form scanner

1.2 Scan with Sense

The 3D scanner Sense 3D is a product of the company 3D Systems, which works on the principle of structured light, which sends light rays to the scanned object and captures their reflection on the scanning sensor. This scanner is compact, easily portable and affordable, making it an attractive choice for a wide range of users. In this section, we will explore the scanning process in the 3D Systems Sense environment. We will explain the individual steps that must be followed for successful scanning of various objects. In addition, we will look at the available options and functions of the 3D Systems Sense software that make this process easier.

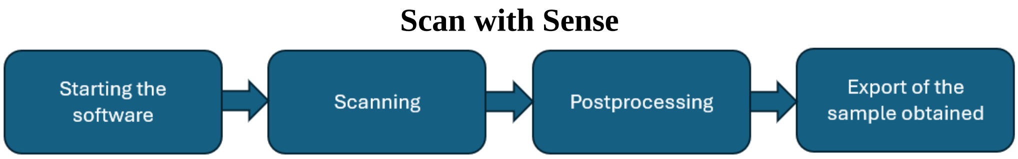

Fig. 16 Flow chart of activities through 3D Systems Sense

After starting the software, you will be presented with three options to choose from: scan object, head or body. After choosing one of the options, a turquoise square appears on the screen, indicating the successful recognition of the given object by the software. After successfully recognizing the object, just press the "scan" button, which will start the countdown and then start the scanning process.

Scanner Sense allows you to scan objects by manually circling around them. Another option is to place the scanner on a tripod and place the object on a turntable. In this way, it is possible to gradually rotate the object while the scanner captures points from different angles.

After the scanning is finished, the software provides us with several options for editing the created model. One of the first available options is the scan crop option, which allows us to mark and remove a specific part of the scanned object. This function is useful if we want to eliminate unnecessary parts of the model or adjust its shape according to our needs. If we need to remove unwanted areas from the scanned object, we can use the cut option. This function allows us to create a line that defines the area we want to remove. After creating a line, the software will automatically identify and remove all parts of the scan located in this area.

In addition to the two previous options, there is also the "delete" function, which offers similar options for editing the scanned model. This function allows us to mark the points of the scan that we want to remove with the cursor. After marking these points, the software automatically deletes the selected parts of the scan. The "delete" function is useful in case we need to remove specific parts of the scanned object.

The “solidify” tool prepares the scan for printing by filling all the holes and closing the model to make it solid. It also automatically detects the bottom plane of the model and converts it to a flat surface. The last option is the "color" function, which allows us to change the brightness and contrast of colors. Changing the brightness and contrast can be useful to highlight details or achieve more balanced color tones in the final model. Figure 6 shows the scan editing options.

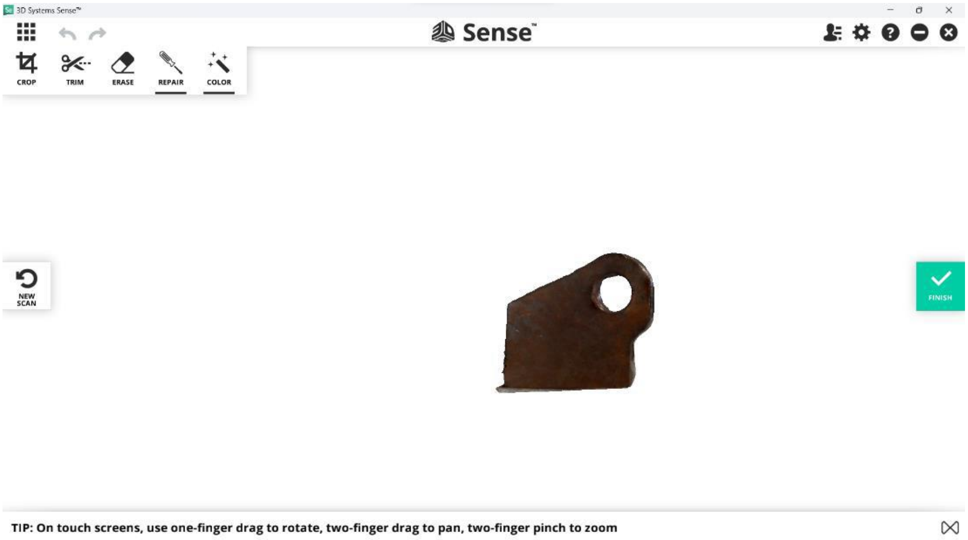

Fig. 17 Scan editing in 3D Systems Sense

The effect of lighting conditions on the quality of the scan with the Sense scanner

Lighting problems are the most common obstacle to obtaining quality images. Diffused white light with a minimum of shadows is suitable for 3D scanning. Conventional indoor ceiling lighting generally works well. Too bright light could cause blurry scans and missing information, and too dark an environment could also cause missing points or make the scanned object appear darker than it is.

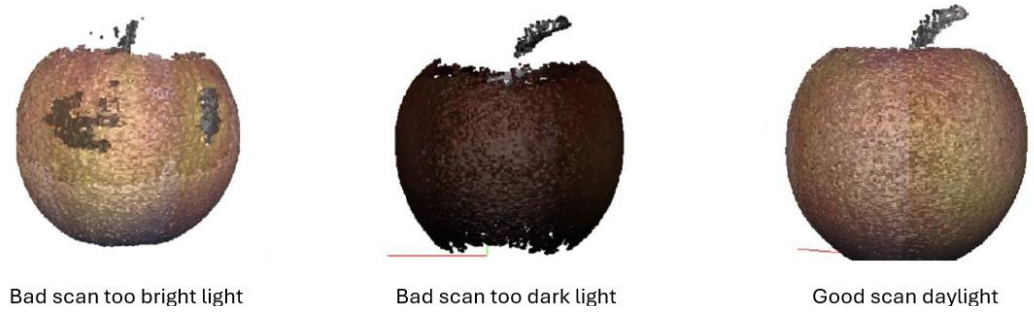

Fig. 18 Comparison of lighting conditions when scanning objects with the Sense scanner

The lighting conditions for the Sense 3D scanner are quite important because they affect its ability to accurately capture the details of objects. Scanning took place in daylight and under artificial lighting. Being a handheld scanner, scanning in the dark was not possible as the lack of light limits its ability to capture clear and accurate images of objects. Light is essential for the scanner to function properly and achieve optimal scanning results.

When scanning in daylight, the process was smooth and efficient, with the scanner immediately recognizing the scanned part. This type of light provided optimal conditions for the scanner, which was also reflected in the quality of the resulting scan. Details were clearly captured and reproduced with precision. However, it is important that the sunlight is sufficient, as a lack of light can lead to insufficient illumination and a decrease in the quality of the scan. For optimal results, it is necessary to keep in mind that even if daylight is present, its intensity is crucial for successful scanning.

Scanning under artificial light encountered certain problems that affected the smoothness of the process. The scanner often stopped and interrupted scanning because it had difficulty recognizing the object. These difficulties may have been caused by insufficient lighting or inadequate lighting conditions that did not allow the scanner to clearly identify and capture the details of the object. This resulted in incomplete or poor-quality scans.

2. Verification of the accuracy of scans using 3D printing

The resulting scanned models in STL format were printed on a TRILAB DeltiQ 2 3D printer, which has a printing deviation of only 0.008 cm, which ensures high accuracy of the resulting printed objects.

The part that was scanned using the Sense scanner was recorded in a vertical position and was then also oriented in this way for printing on a 3D printer. When printing in a vertical position, it is important to ensure the stability and accuracy of the print. The resulting model also contained supporting structures. The supporting structures were subsequently removed to have a smoother and more aesthetic final product.

With the Matter and Form scanner, we scanned the part in several positions, but the resulting model was stored at an angle to the horizontal position. Due to this fact, the model had to be supported, since it was not placed horizontally. This support had to be subsequently removed. Because the model was stored horizontally, its surface was rougher than the one captured with the Sense 3D scanner.

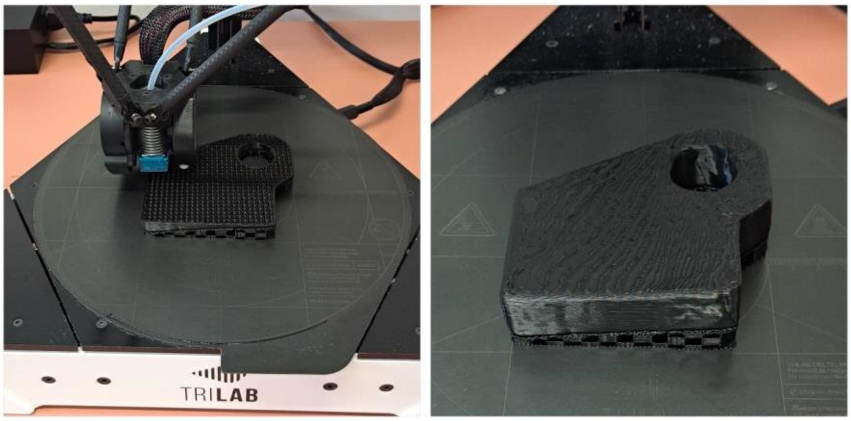

Fig. 19 Print the scanned object

In Figure 9, it is possible to observe a sample part together with its 3D printed scans.

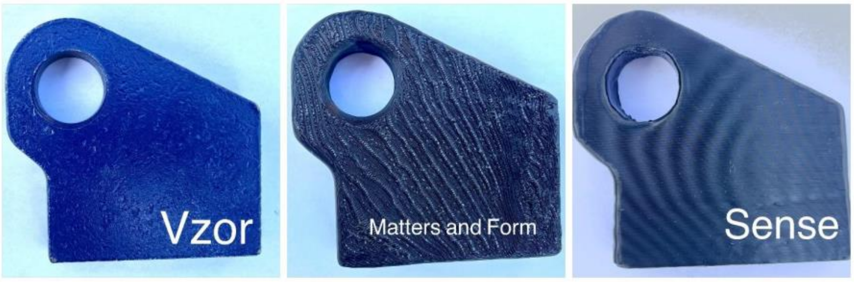

Fig. 20 Comparison of the printed models with the pattern

3. Comparison of dimensions

Subsequently, we moved on to measuring and recording the dimensions of the sample part. We then compared these data with the dimensions of the printed models. Such a comparison allowed us to evaluate the accuracy of the scan with respect to the original dimensions. Figure 10 shows the dimensions that were measured.

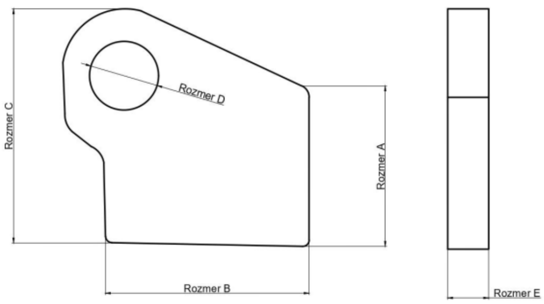

Fig. 21 Examined object and compared dimensions

Individual dimensions were measured using a Mitutoyo digital caliper at three different locations on the scanned part. These measurements were carried out in order to obtain sufficiently accurate and reliable data on the dimensions of the part. Subsequently, an arithmetic mean was calculated from these measurements, which provided a representative value for the given dimension. Table 1 shows the measured deviations compared to the values of the sample part.

Tab. 3 Overview of measured values of individual objects

	Rozmer [mm]	Sample model	Matters and Form	Sense
Measured values	A	63,23	0,008	4,518
	B	87,47	0,605	1,481
	C	97,31	0,475	5,508
	D	27,38	1,288	2,271
	E	20,2	-2,3045	-1,085

Table 2 is finished with the resulting average of the absolute values of deviations of individual dimensions. The lower value of 0.9361 clearly indicates that the part scanned by the Matters and From scanner achieved better dimensional accuracy compared to the Sense scanner.

Tab. 4 Absolute value of deviations

	Absolute value of deviations	
	Matters and Form	Sense
A	0,008	4,518
B	0,605	1,481
C	0,475	5,508
D	1,288	2,271
E	2,3045	1,085
Average absolute deviation	**0,9361**	**2,9726**

Conclusion

Working with the Matter and Form scanner was easy. After successful software installation and calibration, the scanner was ready to scan. The scanning process was simple - just place the scanned object on the turntable and the scanning process could begin. One of the advantages of this scanner was the possibility of repeatedly scanning the object, which made it possible to capture a greater amount of detail and improve the accuracy of the resulting model. However, it should be noted that the plate is part of the scanner, which limits the size of the scannable objects.

On the other hand, the scanner had some shortcomings, especially when it comes to certain types of surfaces and colors. He had problems with some surface colors, especially if they were a bit shiny. It also had a problem with capturing the holes, which is also evident on the printed model.

Working with the Sense scanner was significantly more demanding compared to the Matter and Form scanner. The first problem was the difficult process of starting the software because the support for this scanner ended on December 31, 2022. The problem was solved by installing the older version. The advantage of this scanner is the scanning of larger objects.

Compared to the Matter and Form scanner, Sense does not allow repeated scanning of the object, which was manifested by insufficient details and inaccurate dimensions of the printed model, as we can see in Table 4. In addition, this scanner often had a problem with the recognition of the scanned object, although after several attempts the part was able to be scanned. Like Matter and Form, this scanner also had problems with glossy surfaces.

Analyzing the differences between these dimensions provided us with important insights into the accuracy and reliability of the scanners used. In addition, we also compared processes and procedures when using individual types of scanners, which allowed us to evaluate their effectiveness and suitability for specific applications in the field of reverse engineering. At the end of our work, we developed several proposals for improving the conditions for 3D scanning, which we derived from the acquired knowledge and experience. These suggestions include a wide range of recommendations that address various aspects of scanning, including lighting conditions, scanner settings, surface treatments, and equipment calibration. Overall, our designs were aimed at ensuring consistent and reliable performance of 3D scanners and maximizing the quality of the resulting scan. These recommendations could provide users with a useful framework for improving their scanning processes and achieving better results.

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THE USE OF TOPOLOGICAL SHAPE OPTIMIZATION IN THE PRODUCTION OF A FIXTURE FOR MEASURING THE GEOMETRY OF CUTTING INSERTS USING MULTI JET FUSION TECHNOLOGY

Miroslav CEDZO – Jaromir MARKOVIC - Mario DRBUL - Miroslav MATUS

Abstract: Topology shape optimization is an essential tool in engineering that is changing the way components are designed and manufactured. This innovative method enables optimum results in terms of strength, weight and efficiency. With the growing emphasis on sustainability and efficiency, topological shape optimization, along with the use of additive technologies, is becoming an important element for innovation and progress. This paper presents the application of Topology Shape Optimization in the design and fabrication of a fixture for measuring the geometry of cutting inserts.

Keywords: Topology optimalization, Additive Manufacturing, Generative Design, MJF

Introduction

A significant move in additive technologies allows us to create complex objects layer by layer. This opens up limitless possibilities in a variety of industries, including medicine, architecture, engineering and many others. [1]

Using additive technologies, it is possible to create parts with precise detail and minimal waste. Among these technologies is the Multi Jet Fusion technology developed by HP (Hewlett-Packard) [1,2]. It is a highly productive additive manufacturing technology that enables the creation of complex structures with high resolution [2]. This technology is often used in industrial applications, from prototyping to mass production of components with excellent mechanical properties [3].

Additive technologies combined with topological shape optimization provide a number of benefits that are revolutionizing the way we create, design, and manufacture objects.Topological shape optimization (TO) is a computational method aimed at finding the distribution of material, changing the shape, number and shape of holes to reduce weight and save material. Topologically optimized designs lead to energy saving and efficient use of materials and faster and sustainable production. [4]

The integration of topological optimization allows the geometry of objects to be automatically analyzed and optimized to achieve maximum strength and efficiency with minimum material usage.

In order to perform topological optimization during the design of a component, the designer must specify certain constraints for the designed component in advance, such as the required geometric properties, the weight of the designed component, the load conditions, and the material. [5] Material is used only where strictly necessary due to boundary conditions. Each proposed model is thoroughly checked using FEM analysis. Material is defined only where it fulfils its purpose in terms of mechanical properties [5,6]

In practice, this means that MJF with topological optimization can create components with optimal weight and durability, thus contributing to cost reduction as well as significant improvements in product performance in various manufacturing sectors [7,8]

The aim of the present work was to use topological optimization in the design of a jig for measuring the geometry of cutting inserts using the Alicona Infinitefocus G5 3D optical measuring system.

Methodology

When measuring the geometry of the cutting inserts and detecting wear, it is important to position the insert correctly so that both the back and face of the tool can be scanned at the same time. Therefore, a 45° angle is the most suitable angle for positioning the cutting inserts. On the initial design of the measuring fixture shown in Figure 1, slots were made with this profile.

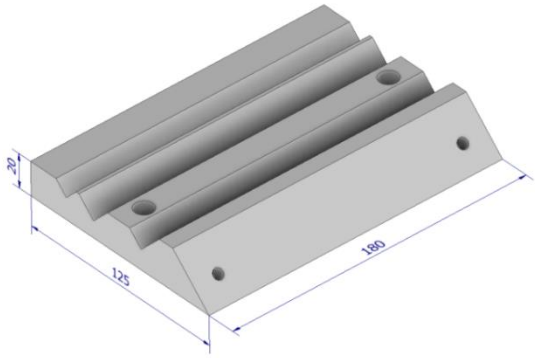

Fig. 1. Initial design of the measuring fixture

The proposed fixture for measuring the geometry of cutting inserts was designed as part of a modular system for clamping parts when measuring on the Alicona InfinitteFocus G5 3D optical measuring system. The entire assembly consists of the jig table, which was also designed using topological optimization techniques, and the insert for geometry measurement. The insert for measuring the geometry of the cutting inserts can be replaced by another insert that will be used to clamp other parts during measurement. The design of the assemblies can be seen in Figure 2.

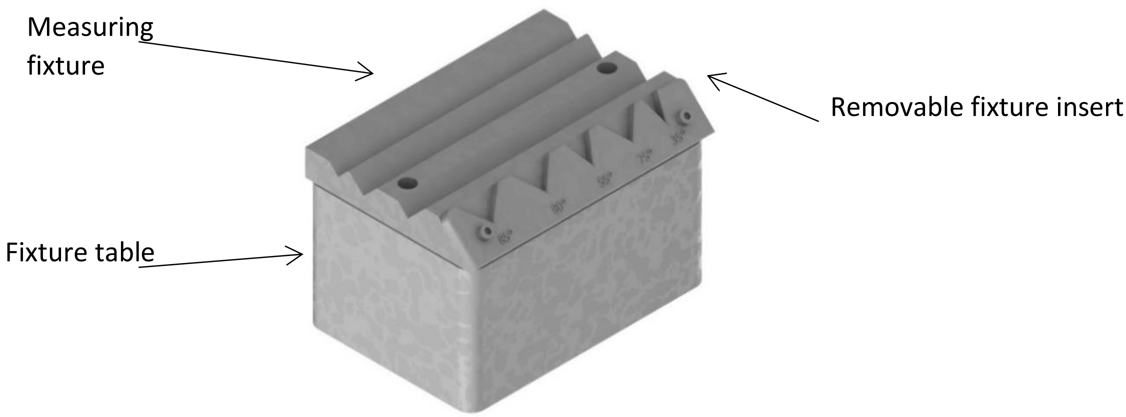

Fig.2. Assembly of the measuring fixture

The measuring fixture in Figure 2. contains slots with an angle of 45° to accommodate multiple cutting inserts or rotary tools and an interchangeable insert for measuring cutting inserts with a specific tip angle.

Material for the manufacture of the product

The use of additive MJF technology for fixture production provides the ability to produce complex designs and non-standard shapes of components that would be impossible to produce using conventional technologies. By using topological shape optimization, we are able to take advantage of the benefits that this technology brings and also reduce the weight and quantity of material used to a minimum, while maintaining its functional properties.
PA12 material was used for the production of the product. It is a polymer with good chemical properties and low coefficient of friction. Due to its high strength and good printing quality, it is widely used in industries. [9,10] The PA12 material used is further characterized by its easy and flexible processing due to its large temperature range between i the onset of melting during the heating process and the onset of crystallization during the cooling process. This property allows the material to be kept molten without crystallization until cooling, which maximizes consolidation and prevents deformation of the printed components [11,12,13] Other properties include low moisture absorption compared to other polyamides, good abrasion resistance, and good chemical resistance [11,13]. Its mechanical properties are listed in Table 1.

Table 1. PA12 powder properties [14]

Property	Value
Flexural Strength (MPa)	47
Density of solid parts (g/cm^3)	0.95
Melting temperature (°C)	185
Tensile Strength (MPa)	32
Young’s modulus (MPa)	1470
Impact strength Charpy method (unnotched) (kJ/m^3)	36

Vstupné parametre topologickej optimalizácie

The topological optimization of the proposed fixture was performed using Autodesk Inventor Professional 2022, Autodesk Fusion 360 and Ansys Discovery. In all cases, the input parameters for the shape calculation were identical. The material used for the calculation was first selected as PA12. Next, the fixed bond of each part, the load on each surface and the areas to be retained were set, which can be seen in Figure 3. The topological optimization of the individual parts of the assembly was carried out separately.

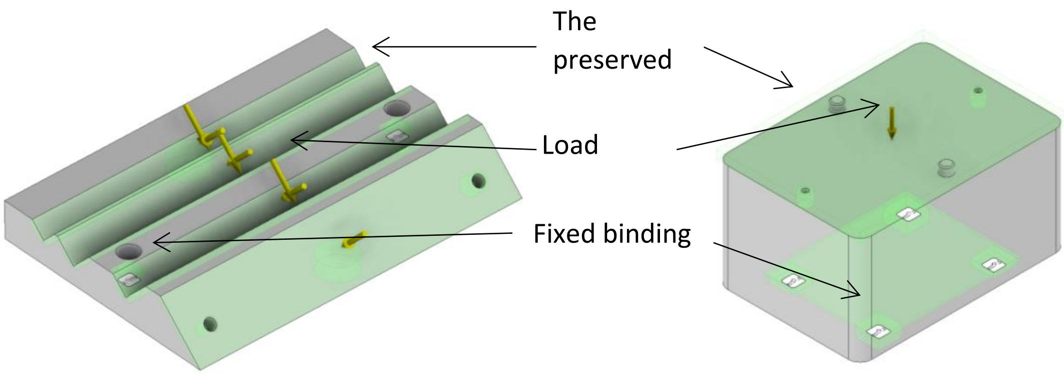

Fig.3. Input parameters for topological optimization of fixture and table

The supporting parts of the fixture for measuring the cutting inserts were loaded with a force of 50 N. The table of the fixture was loaded with a force of 300 N, which should represent the force at the maximum load of the table of the measuring device, which is 30 kg.

Output of the topological optimization of the measuring fixture

Based on the input parameters, a new fixture shape was generated in Inventor Professional 2022. The new shape is shown in Figure 4. After topological optimization, the jig had a volume of 127911.55 mm3. The calculated weight of the jig based on the selected material is 131.5g.

Fig. 4. Generated shape using Inventor Professional 2022

Using Autodesk Fusion 360 software, the mass of the generated preparation after topological optimization (Fig.5) was 104.21g and its volume was 101176.84 mm3

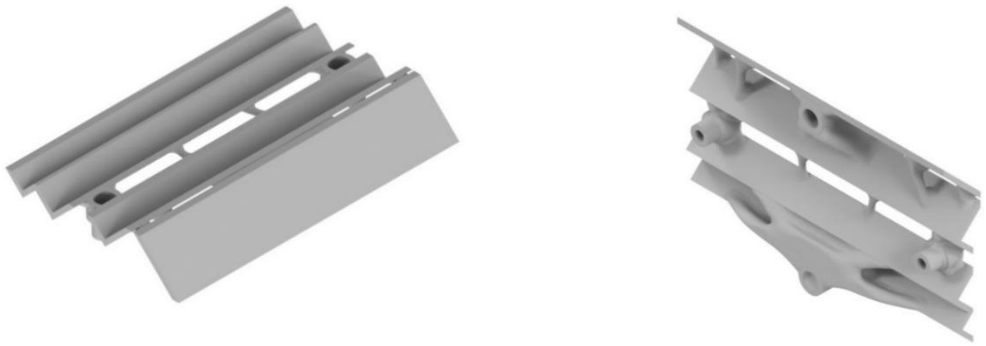

Fig. 5. Shape generated by Fusion 360

Ansys Discovery software in topological optimization generated a new shape of the preparation (Fig. 6) with a mass of 131.75 g and a volume of 127911.55 mm3.

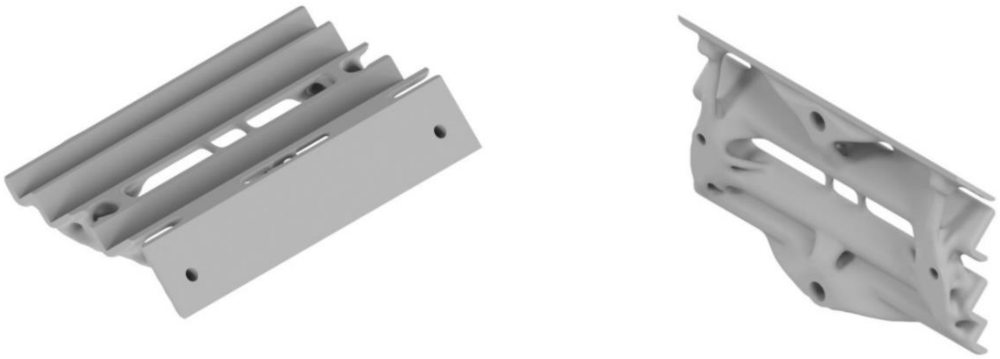

Fig. 6. Shape generated by Ansys Discovery

The same procedure was applied for the topological optimization of the benchtop fixture. The Inventor Professional software generated a new table shape based on the input parameters with a volume of 253000 mm3. This new shape can be seen in Figure 8. The mass of the shape after topological optimization is 278.35g

Fig. 8. Table shape after topological optimization with Inventor Professional 2022

Using Autodesk Fusion 360 software, after topological optimization, the volume of the generated table was 347382.04 mm3and its mass was calculated to be 357.8 g based on the volume. The shape after topological optimization is shown in Figure 9.

Fig. 9. Table shape after topological optimization with Autodesk Fusion 360 software

Ansys Discovery software generated the new table shape in Figure 10 during topological optimization. With a volume of 322598.27 mm3 and a calculated mass of 332.28 g.

Fig. 10. Table shape after topological optimization with Ansys Discovery software

The resulting shape of the fixture and stage assembly after the application of topological optimization is shown in Fig. 11. This optimized design allowed a significant reduction in excess material while maintaining the required strength and stability of the entire structure. The process of topological optimization led to a more efficient material distribution and a significant weight reduction, while the assembly meets all the specified functional and technical parameters. This has not only saved material costs, but also improved the manufacturing process in terms of its efficiency and sustainability.

Fig. 11. Assembly of the measuring fixture after topological optimization

Evaluation

The resulting volume and mass values obtained from the optimized table and fixture shapes were graphically processed and compared. From the graphical comparison in Figure 11. for the volumes and weights of the measuring jig, we can see that the lowest values were obtained with Autodesk Fusion 360 software. With this software, the fixture weight was reduced from a respectable 395.79g to 104.21g and the volume of material used was reduced from 384263.57 mm3 to 101176.84 mm3. For Inventor Professional and Ansys Dyscovery, the weights and volumes were almost the same.

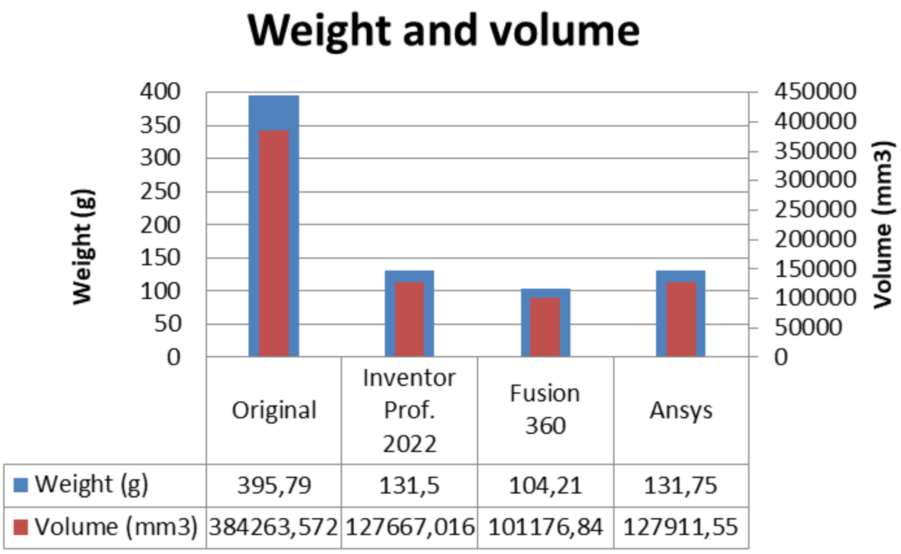

Fig. 11. Graphical treatment of volumes and weights of the preparation

For the final production, a variant developed using Ansys Dyscovery software was chosen, which had optimal properties in terms of weight, size of the fixture's settling surfaces and overall shape. For this variant, the weight of the jig was 131.75 g and the volume of material

used was 127911.55 mm3. The surface of the generated jig shape was smoother than Autodesk Inventor Professional 2022. The variant from Fusion 360 software that achieved the lowest weight appeared to be unstable with small settling areas.
Similarly, a graphical dependence was made for the volumes and weights of the generated table shapes. The lowest weight of the generated shape was when using Autodesk Inventor Professional 2022 software, where the weight was reduced from the original 2163.77 g to 278.35 g and the volume was reduced from 2100745.43 mm3 to 253000 mm3. Ansys Dyscovery software, generated a new shape with a weight of 332.28 g and a material volume of 322598.27 mm3. Using Autodesk Fusion 360, a weight of 357.8 g and a volume of 347382 mm3 was achieved, the largest of all the software used.

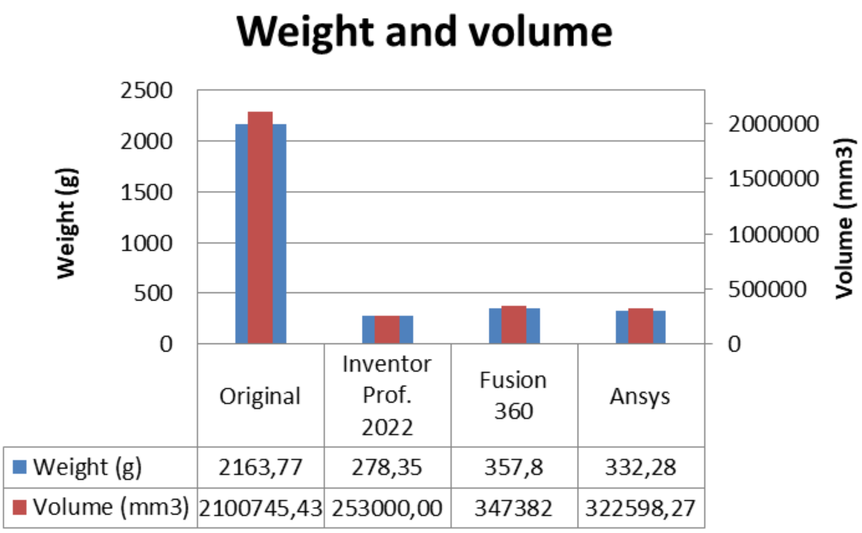

Fig. 11. Graphical treatment of table volumes and weights

A shape generated by Autodesk Fusion 360 was chosen for production, which generated a shape weighing 357.8 g.

Conclusion:
The paper presents the design of a modular fixture for measurement on the Alicona Infinitefocus G5 3D optical measurement system. The modular fixture consists of a lower stage and a measuring fixture that can be easily changed based on the part to be measured. In the publication, a measuring jig for measuring the geometry of cutting inserts and tools is elaborated. Topological shape optimization was performed on both parts of the modular fixture using three different software and the results were subsequently processed and compared.
The lowest weight of the generated fixture shape for measuring the geometry of the cutting inserts was for the shape generated in Autodesk Fusion 360 software. In this case, the weight of the generated jig shape was 104.21 g. The fixture shape from Ansys Dyscovery software was chosen as the most suitable generated shape, as its weight was the highest but its shape was the most suitable. The mass of the generated fixture was 131.75g and the volume of material used was 127911.55 mm3.
In the topological optimization of the table shape, the smallest weight was achieved using Autodesk Inventor Professional 2022 software. Autodesk Fusion 360 software generated a table

shape with a weight of 357.8 g and a volume of 347382 mm3. This was the variant with the highest generated weight, but this variant was the most suitable in terms of shape.
Using topological optimization, the weight and volume of the material used was significantly reduced while maintaining the necessary mechanical properties and structural strength. This approach allows for a more efficient use of the material, leading to a reduction in production costs, while contributing to a reduction in the environmental burden, thus improving the sustainability and overall efficiency of the production processes.

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COMPARISON OF DECLARED AND SIMULATED REAL-USE VIBRATION VALUES DURING WOOD SANDING

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Abstract: The aim of this work was to investigate the difference between the values declared by manufacturers of hand-held power sanders and the measured vibration values in actual use. The measurement of the time-averaged frequency-weighted acceleration values was carried out by human vibration analyzer (B&K, model 4447) during the sanding of beech and spruce wood with different types of hand-held electric sanders (belt, random orbital, orbital) with abrasives of coarse, medium and fine grit. By comparing the measured and declared vibration values, differences ranging from -7,9 $m.s^{-2}$ to 1,2 $m.s^{-2}$ were found for the different types of sanders. The results of the study show that the use of declared vibration emission values in risk assessment underestimates the magnitude of operator vibration exposure.
Keywords: vibration, sander, wood

Introduction

Hand-arm vibration is vibration transmitted to one or both hands from the handles of machines and tools or from the surface of objects held by the hands. Human exposure to mechanical vibration from hand-held machinery can interfere with comfort, work efficiency and, in some circumstances, health and safety. In 2023, vibration sickness - a disease of the bones, joints, muscles, blood vessels and nerves of the limbs caused by vibration - was the third most frequently reported occupational disease in Slovakia [1]. An employer who uses or operates equipment which is a source of vibration is obliged to ensure, in accordance with Section 33 of Act No 355/2007 Coll. on the protection, promotion and development of public health and on the amendment and supplementation of certain acts, as amended, that technical, organizational and other measures are taken to exclude or reduce to the lowest possible and achievable level the exposure of employees to vibration and to ensure the protection of the health and safety of employees. In fulfilling the obligations laid down in the abovementioned provision, the employer shall assess the level of vibration to which employees are exposed and, if necessary, measure that level of vibration.

Information on vibration emissions - the declared vibration emission values given by machinery manufacturers are one of the aspects that the employer takes into account when assessing the risks from exposure to vibration. Depending on his needs and information on the vibration emission levels of the machinery, the employer/user must select and choose the equipment with the lowest vibration emission, taking into account the limit and action values laid down in Slovak Government Regulation No. 416/2005 Coll. on minimum health and safety requirements for the protection of employees against risks related to exposure to vibration, as amended. The purpose of the machinery manufacturer's declaration on vibration emissions is to provide information useful for assessing the risks associated with exposure to vibration and to assist users in selecting machinery with reduced vibration emissions. In this context, however, it is important to recognize that the level of exposure to vibration cannot simply be inferred from the vibration emission statement, as other factors also influence the exposure of the operator to vibration of machinery.

Declared vibration emission values are determined under standard measurement and operating conditions as defined in the relevant harmonized vibration test code for related machines [2-3]. It may be the case that the type test method cannot identify all the mechanisms that generate

oscillations if the machinery is used in a real operating environment. Factors such as workpiece, workflow and operator can have a significant influence on the intensity of oscillation. For this reason, although type-test measurements cannot replace operational measurements that assess workplace exposure to vibration, they should be sufficiently representative to be used for preliminary risk assessment [4].
The hand-held power sander is a frequently used tool in woodworking and represents a significant source of risk in terms of dust, noise and, last but not least, vibration. The aim of this paper is to investigate the difference between the values declared by the manufacturers of hand-held electric sanders and the measured vibration values in real use.

Materials and Methods

Different types of hand-held power sanders (see Fig. 1) from Rober Bosch Power Tools GmbH, whose technical parameters and declared vibration emission values are listed in Tab. 1, were used for the vibration measurements.

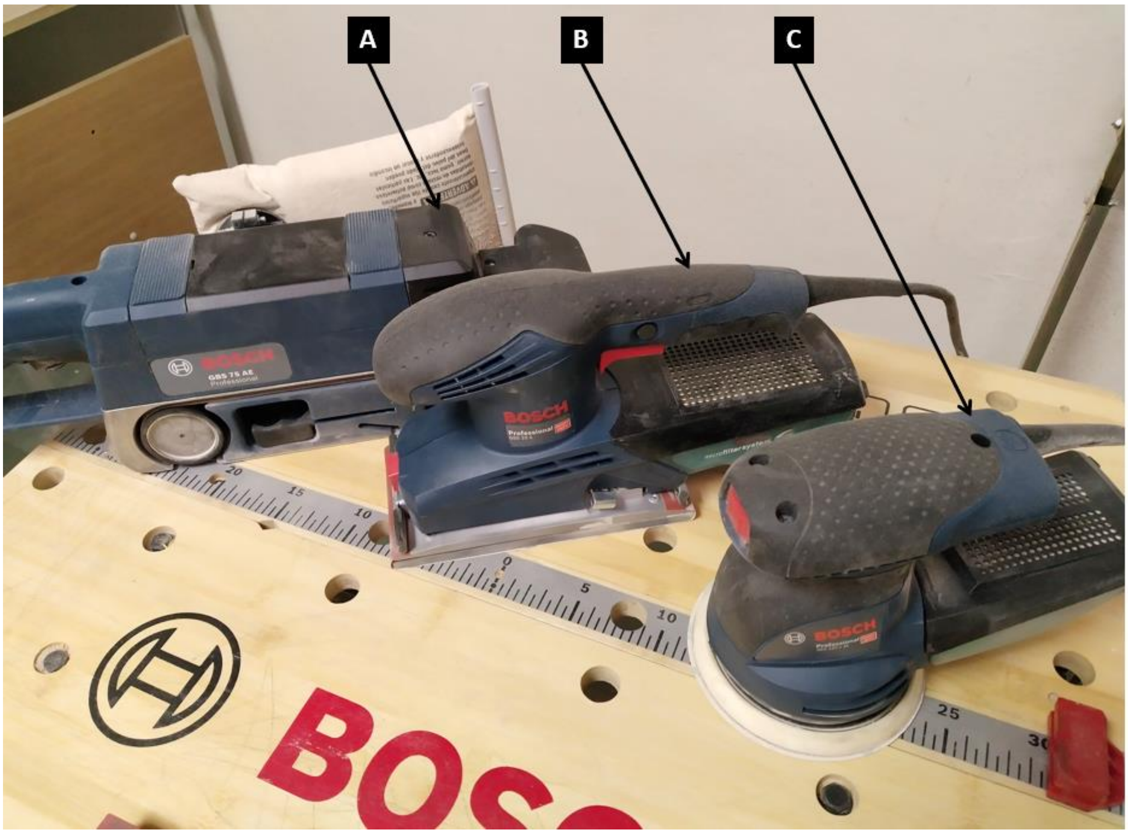

Fig. 1 Hand-held power sanders: A - GBS 75 AE, B - GSS 23A, C - GEX 125-1 [5]

The measurement of the equivalent weighted acceleration of the vibration transmitted to the hand was carried out by a vibration analyzer (B&K, model 4447 with B&K tri-axial accelerometer, model 4524-B-001). The calibration of the accelerometer was verified before and after each series of measurements using a calibrator (B&K, model 4292). The processing of the measured data was carried out by means of a software application (B&K, Vibration Explorer Software BZ-5623).

Tab. 14 Technical parameters of hand-held sanders [5]

Sander	Model	Sander Type	Rated Input Power (W)	Vibration Emission ± Uncertainty ($m.s^{-2}$)	Net Weight (kg)
A	GBS 75 AE	Belt	750	3±1,5	3,4
B	GSS 23A	Orbital	190	5,5±1,5	1,7
C	GEX 125-1 AE	Random orbital	250	5±1,5	1,3

The measurement of acceleration values was carried out by sanding test samples of beech and spruce wood with dimensions 500 mm (length) x 250 mm (width) x 50 mm (thickness) and a moisture content of 10%, which was detected by a digital moisture meter (Testo, model 606-2). The test specimens were clamped during sanding using flexible jaws on a work bench (Bosch, model PWB 600). Coarse (P60), medium (P120) and fine (P240) grits were used in the sanding process.

The location and method of fixation of the accelerometer can be seen in Fig. 2. The measurement time interval of 150 seconds was derived from the time required to sand the test specimen under the following operating conditions: sander idle (30 seconds), sander at full load (120 seconds). For each combination of factors, 5 measurements were taken. The total number of measurements was 150.

Fig. 2 Location and mounting of transducer [5]

Results

The measured average vibration values for each type of hand-held power sander are shown in Fig. 3.

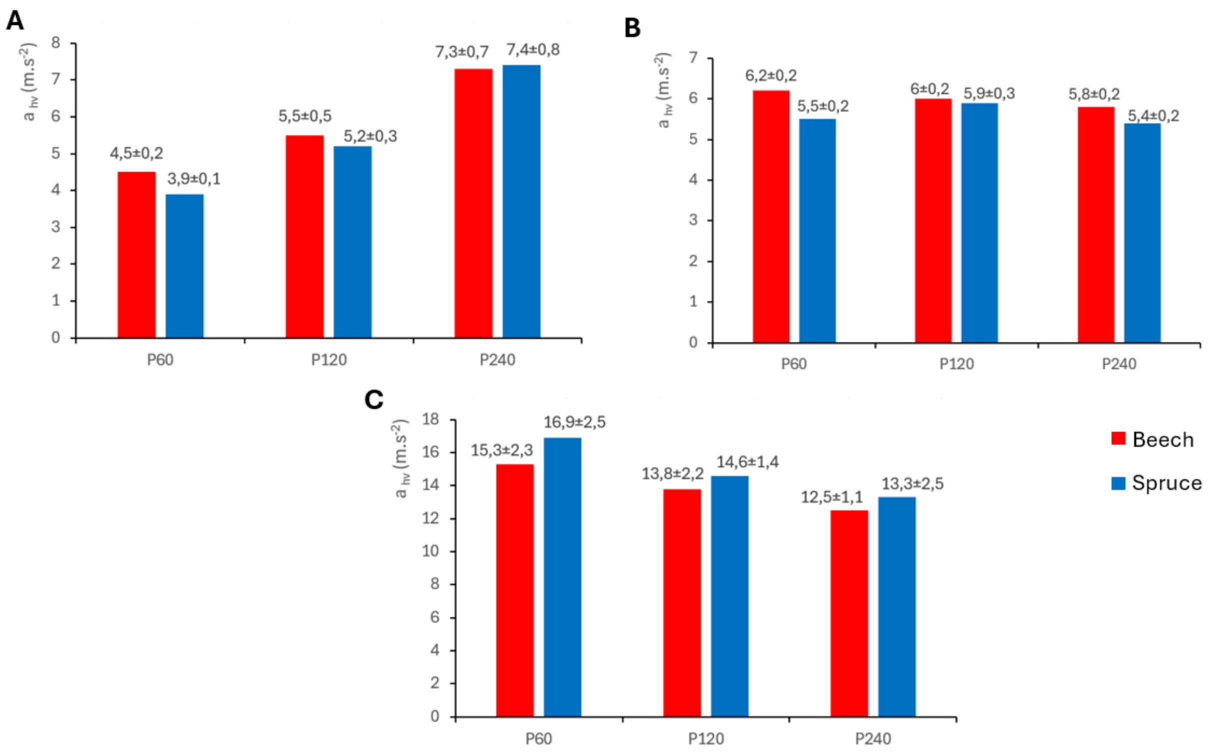

Fig. 3 Equivalent frequency weighted acceleration values (arithmetic mean ± standard deviation) during sanding with power sander: A – belt, B – orbital, C – random orbital

Fig. 4 shows the difference between the measured vibration values and the manufacturer's declared vibration values, considering the uncertainty of the declared value. A value less than zero means that the declared value may lead to insufficient protection compared to the vibration values measured during actual use of the sander.

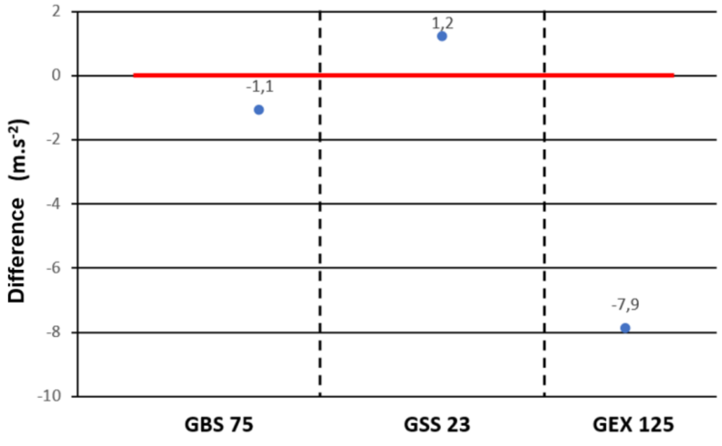

Fig. 4 Difference between the measured vibration data and the manufacturer’s declared values for each sander [5]

Conclusion

The daily exposure to vibration depends mainly on the averaged value of the vibration parameter on the surface in contact with the hand and the resulting daily time during which the employee is in contact with this vibration. Comparison of measured and declared vibration values showed differences between the different types of grinding machines ranging from -9,4 $m.s^{-2}$ to -0,3 $m.s^{-2}$, considering the uncertainty of the declared value ranging from -7,9 $m.s^{-2}$ to 1,2 $m.s^{-2}$. The results of the work show that the use of declared vibration emission values in risk assessment underestimates the magnitude of vibration exposure by transmission to the hands of the hand-held power sander operator.

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DEVELOPMENT AND IMPLEMENTATION OF THE INNOVATIVE SENDER-RECEIVER ORGANISATIONAL SYSTEM – ISNOO BY RENZ SP. Z O.O.

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Abstract: The article presents the assumptions and achieved objectives of the research project on raising the level of technology dedicated to the production of the Innovative Sender-Receiver and Organisational System (ISNOO). As part of the project, a demonstration technology line (DIT) consisting of modules designed to carry out selected technological operations was designed. The various DIT modules are characterised and the research carried out on them, which contributed to the achievement of the stated objectives of the various stages of the project is discussed. The project was implemented as part of the POIR.01.01.01-00-1380/20 project, financed by the National Centre for Research and Development.

Keywords: parcel locker, research project, ISNOO

Introduction

In recent years, there has been noticeably dynamic growth in the e-commerce market. Similarly, the number of logistic operations related to the completion of orders in B2C (business-to-consumer) relationships is increasing at the same pace. In this area, a significant role is played by devices, commonly known as parcel lockers, designed for end customers to send and receive shipments. More and more often, parcel lockers are being enhanced with additional functionalities that, on one hand, meet customer preferences while on the other hand, allow the introduction of new services, such as advertising, announcements, etc. Additionally, to ensure delivery efficiency, so-called smart parcel locker solutions are being introduced. These enable the sending and receiving of diversified goods and feature intuitive systems for secure and efficient handling.

Literature research related to the area of delivery logistics from the seller, viz., the retailer and wholesaler, to the end customer is associated with many of its fields. These areas include packaging design and production, distribution methods, technical solutions for receiving devices and communication methods. This consideration includes cost and delivery speed, the safety and reliability of deliveries, customer satisfaction and, increasingly, environmental aspects [5,7]. Another feature is the transparency of solutions. In the article [2] research was conducted focussing on the essence of planning service areas related to the use of user-friendly smart parcel locker systems. To achieve this, a developed mathematical model utilising Taguchi's method and a genetic algorithm were employed. In turn, in [8], based on the SERVQUAL model of service quality and the LSQ model of logistics service quality, the factors preceding customer satisfaction with parcel locker services were investigated. It was found that the most important factor is timeliness, followed by safety and reliability. In [9] a logistics model for delivering small parcels to collective service points was presented, assuming flexibility for the end customer, who can specify several acceptable pickup locations. It has been shown that this may contribute to reducing costs and shortening delivery time. The literature also includes studies where the main focus is on the safety and reliability of both the delivery and the retrieval of parcels from the final device. This approach is presented, among others, in [10]. Other studies address the economic aspects of end customer service, considering business processes and their cost and revenue structures [1]. In the publication [6] in e-commerce. LogForum, focussed on environmentally friendly e-commerce areas and studies were conducted on the impact of green logistics approaches in electronic commerce on customer satisfaction and loyalty. It was observed that the more attention online retailers paid to eco-friendly delivery, packaging, and returns, the more satisfied and willing customers were to make repeat purchases. In this case, price and fast delivery are not necessarily the primary determinants of choice. In the article [3], attention focussed on the development of packaging in e-commerce due to its negative impact on the environment. The research considered various aspects, including materials, both renewable and non-renewable, design, to include volume and shape of packaging and manufacturing technologies.

As previously mentioned, the e-commerce market is not just about cheap and fast delivery. There are many other factors that focus on customer safety and satisfaction while also minimising negative environmental impact.

In recent years, Renz Sp. z o. o. [4], as a manufacturer of parcel distribution systems, has focussed on designing and producing intelligent technical solutions tailored for a broad range of users. This contributed to the completion of a project involving the development of the Innovative Sender-Receiver Organisational System "ISNOO" and its proprietary production technology. In the following sections of the article, the ISNOO system and key aspects of its manufacturing technology are detailed, highlighting its functionality, safety, reliability and versatility of application.

Innovative Sender-Receiver Organisational System

The proposed solution, the Innovative Sender-Receiver Organisational System (ISNOO), was designed by the R&D department of Renz Sp. z o.o., which received project funding from the European Regional Development Fund under Priority Axis 1 "Support for R&D activities by enterprises," Action 1.1 "Enterprise R&D Projects," Sub-action 1.1.1 "Industrial Research and Experimental Development by Enterprises, within the Operational Programme Intelligent Development 2014-2020, through the National Centre for Research and Development.

The project aimed to implement the concept of multi-functional short-term storage points, permanently integrated into buildings, with the capability for bi-directional goods exchange allowing through access at shared locations, from both the external and internal sides of the building. The concept of simple and convenient receipt of ordered goods by the recipient, in line with the "no need to leave the building" concept, has garnered significant interest from designers of multi-family homes located in modern residential complexes.

The project assumptions established that the primary focus would be the integrated modular configuration of the ISNOO postal and communication system, featuring the following functionalities in the areas of:

- recipient and sender mailboxes, i.e., spaces for receiving and dispatching packages and letters,
- the dispensing and receiving of packages, i.e., enabling couriers to drop off/pick up packages and recipients to collect/drop off packages;
- intercom and/or videophone,
- a bulletin board, able to display advertisements *via* a large screen, which can contribute to generating additional revenue for the entity, such as a residential community/association, hotel, office building owner, etc.,
- making payments in at least two different ways – payment card and BLIK (a mobile payment system),
- notifying about the contents of a selected mailbox awaiting the designated recipient (remotely *via* SMS and through an indicator light).

In addition, the installation and use of intelligent electronic modules as standard equipment for the ISNOO system should enable complete control over security and the methods of opening and closing, as well as smooth regulation of temperature and humidity for the short-term storage of food and other goods requiring monitoring.

A significant functional feature of the designed ISNOO system is its modularity and flexibility in configuring the sizes of components for dispensing and receiving purposes. Figure 1 shows examples of possible ISNOO configurations with the functional areas described.

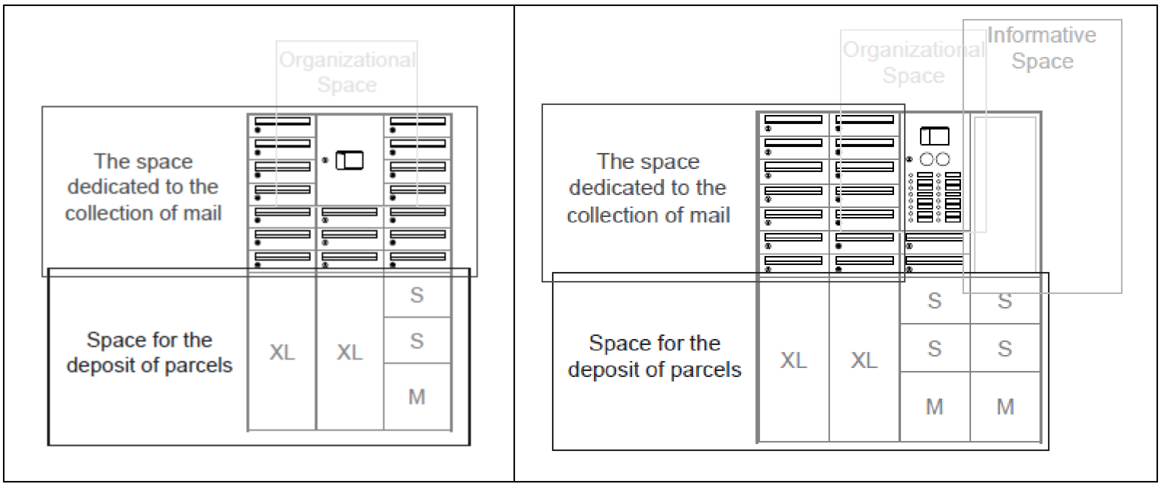

Fig. 1 ISNOO configuration options

The concept of the solution adopted, particularly the complex diversification of components and subcomponents that make up the configurability of ISNOO, necessitated the simultaneous design of manufacturing technology, focussed on the automation and robotisation of individual technological operations. This resulted from the need to address economic and organisational aspects during the individual unit production phase. To this end, another challenge and objective of the project was to develop a Demonstration Technological Installation (DIT), aimed at integrating high-efficiency production with the specifics of individualised, external orders, while taking into consideration the quantitative and temporal variability of the batches of ISNOO components and subcomponents produced.

Demonstration Technological Installation Dedicated to the Production of ISNOO Components – General Characteristics

To manufacture components and subassemblies for ISNOO that meet all project requirements (described above), the following steps were undertaken: components and technical equipment were designed and purchased, necessary technical tests were conducted and then the Demonstration Technological Installation (DIT) was configured based on the following core modules, responsible for specific technological operations: laser cutting device (1_DIT), bending cell (2_DIT), bending centre (3_DIT), corner forming devices (4_DIT), sealing cell 1 (5_DIT), sealing cell 2 (6_DIT), powder coating shop (7_DIT), laser engraving machine (8_DIT) and mechanical engraving machine (9_DIT), eccentric press (10_DIT).

The layout of the DIT, implemented at Renz Sp. z o.o., with a view of the individual modules, is illustratively presented in Figure 2.

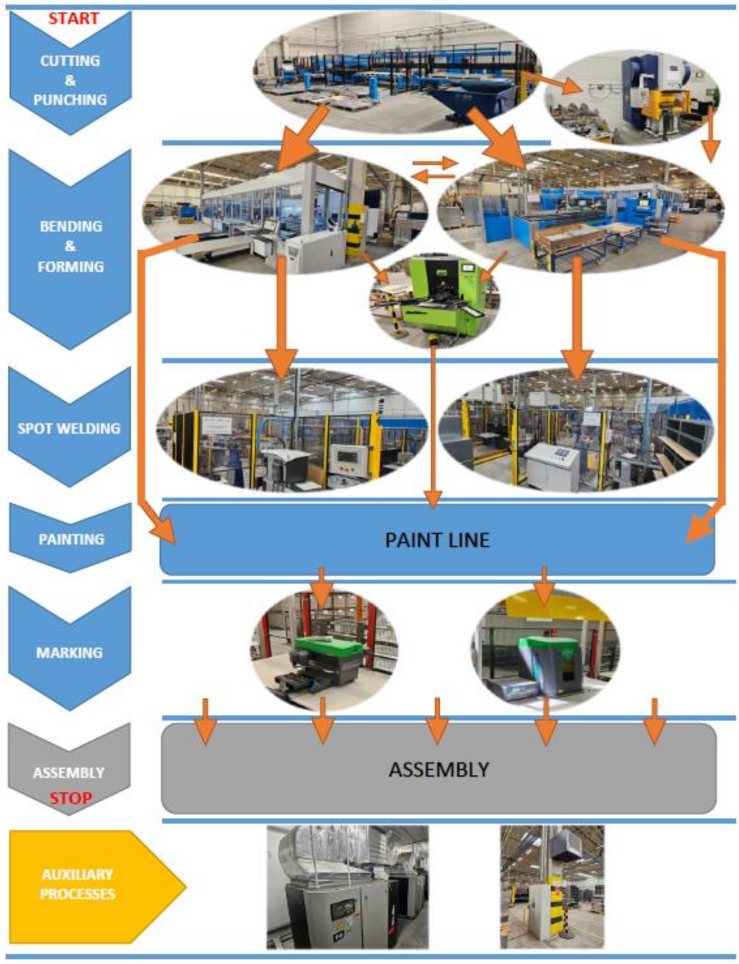

Fig. 2 Layout of the complete Demonstration Technological Installation

The technological challenge in this phase of the project was the integration of all DIT components and subassemblies, responsible for core technological operations, into a production line that ensures:

– quick tool changeovers, due to the high diversification of the ISNOO variants designed;

- stability of production flow and elimination of bottlenecks in the complete ISNOO production process, considering inter-station buffers and the need for in-house transportation.
- spatial constraints due to the dimensions and safety zones (work safety) for the assembly and operation of ISNOO components.

The construction of the technological line and its integration into the production system at Renz Sp. z o.o. also necessitated significant changes to the energy supply system and other utilities such as processed water, ventilation, etc.

Expectations regarding the performance of the DIT in producing multi-variant ISNOO were met through work organisation, adjusting material flow to production logistics and the infrastructural capabilities of the production hall and its automation using human-machine and machine-machine communication in line with the Industry 4.0 concept.

Results of the Project Achieved - description of design and technological difficulties overcome

In the first stage of the project, research work was conducted, focussing specifically on the experimental evaluation of the strength of the designed components. This involved performing Finite Element Analysis (FEA) of the ISNOO components and subassemblies, in the following areas:

- static-dynamic analyses, fatigue analyses and impact load assessments of ISNOO fronts, based on which the condition of allowable reduced stresses <=120 MPa was maintained.
- designing a new innovative, collision-free locking method characterised by increased durability, defined by a specified number of cycles of fault-free operation of the hinge mechanism at a level of >= 50,000,
- designing new hinge solutions and their mounting system characterised by increased durability, defined by a specified number of fault-free cycles of the locking mechanism at a level of >= 50,000.

Based on the research and Finite Element Analysis (FEA), the design of ISNOO components was verified and modified. These revised designs were then used to develop three defined variants of ISNOO.

Subsequently, spot welding studies were conducted in the DIT-cell module. For this purpose, a Yaskawa robot, purchased according to the designed specifications, was utilised. The studies focussed on achieving stability and quality in the spot welding process. The final result of the studies conducted was the analysis and selection of the acceptable strength of samples made from two sheets spot-welded at a single point, with a focus on quality. These actions confirmed with a 95% probability, that the sheet metal joint would withstand a tensile force of at least 4264.44 N. This value was achieved for the joint of 1.00 mm thick sheets with the following process parameters: welding current of 5.5 A, electrode pressure of 1100 N and a welding time of 1400 ms.

Subsequent studies focussed on high-efficiency and quality powder coating technology using the designed and purchased DIT module—powder coating equipment. In this case, it was possible to apply the intended coating thickness (at a level of 80 μm) to ISNOO components and achieve a corrosion resistance rating of class C5.

In the next step, studies were conducted on corner forming technology using the DIT module—corner forming equipment. In this area, the work aimed to achieve the smallest possible corner radius, especially for XL ISNOO fronts. On the basis of the test performed, it was confirmed that it is possible to achieve formed corners with a radius of 4 mm.

The activities described above pertained to achieving specific measurable partial goals of the completed project. On the other hand, tests were carried out on the remaining DIT modules to stabilise the respective processes while simultaneously achieving acceptable quality. This included, among other things:

- bending technology, implemented on the DIT module - bending centre, where the work concerned achieving conformity both qualitative and dimensional of the manufacture of dedicated ISNOO components, taking into account adjustable process parameters.
- cutting technology, implemented on the DIT module - laser cutting machine, where research, based on pre-designed plans, was carried out on the automated precision cutting of sheet metal for the preparation of ISNOO blanks for further technological operations.
- bending technology, carried out on a bending cell, where research was carried out into the selection of process parameters that eliminate the formation of micro-cracks and the intactness of the surface structure in the bending zone of the processed ISNOO components.
- engraving technology, both mechanical and laser, where research work was carried out on making various types of markings on ISNOO items in order to achieve the right quality of visual values, as well as resistance to adverse environmental conditions.
- on the eccentric press module, the quality and efficiency of the production of ISNOO locking elements was examined above all in view of their precise and responsible purpose.

The project also assumed the possibility of developing a thermally insulated front structure dedicated to ISNOO boxes. Thermally insulated fronts in size S were manufactured, achieving the targeted heat transfer coefficient of 0.8 [kW/m^2*K].

A subcontractor representing a scientific research unit was also invited to the project, which undertook to model the ISNOO production process on the DIT demonstrator designed and perform numerical simulations aimed at determining the dependent variables for optimising operation of the technological solution designed and commissioned (DIT). The KPIs (Key Performance Indicators) proposed by the subcontractor, the numerical simulations carried out and determination of the values of the dependent variables formed the basis for the development of tools to monitor our own (Renz Sp. z o.o.) progress in optimising the ISNOO production process on the DIT as designed and commissioned. As a result of the co-operation between R&D Renz Sp. z o.o. and the subcontractor selected, a model of the complete DIT was created and the numerical simulations carried out indicated the possible flow of optimal logistics units in terms of materials between its components. The solution diagram is shown in Figure 3.

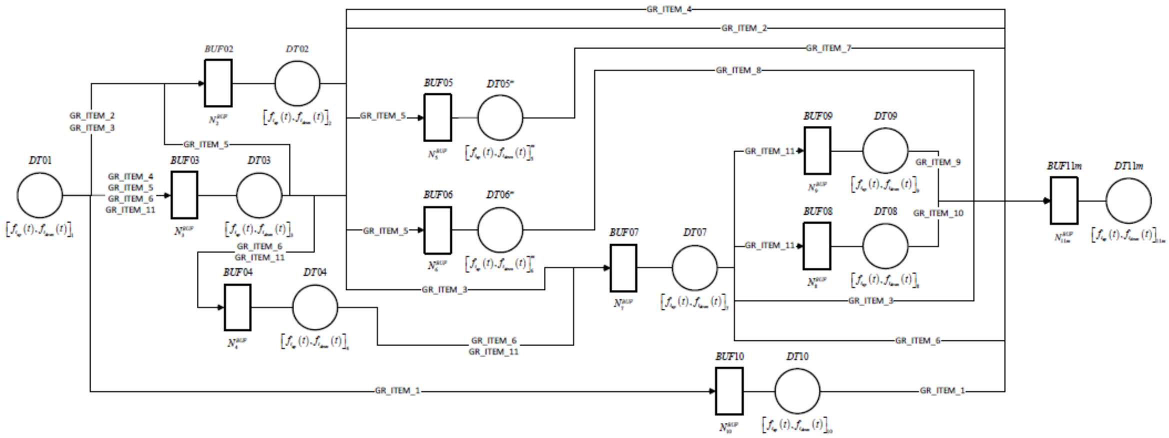

Fig. 3. Graphical model of DIT and possible flow between its modules

The numerical simulations carried out were complemented by establishing the production plans of ISNOO variants enabling the OEE coefficient to be achieved at a level of no less than 70% for the entire process, while achieving the quality indicators of process capability Cp (process parameter dispersion index) and Cpk (process parameter distribution position index) at the assumed level. The study of these indicators was planned in two stages, *viz.*, during the production process stabilisation stage and during the process optimisation stage. Both the theoretical results, namely the calculated indicators based on the mathematical model and the measured values during the industrial implementation of DIT confirmed their achievement, i.e., the relative Cp and Cpk indicators reached values above 1.0, as assumed in the project’s objectives.

Summary and Final Conclusions

This article characterises the implementation process of the Demonstration Technological Installation dedicated to the production of components and subassemblies for the Innovative Sender-Receiver Organisational System, along with the measurable outcomes associated therewith. The individual modules of the DIT are described, with particular emphasis on the research that contributed, among other things, to: **increasing the strength, resistance, and durability of selected ISNOO components, enhancing the strength of welded steel sheet joints, reducing the amount of paint coating while simultaneously improving the corrosion resistance of ISNOO components, developing the design of thermally insulated fronts dedicated to ISNOO enclosures**.

The implementation of individual DIT modules and the research conducted on them significantly enhanced the technological capabilities and level at Renz Sp. z o.o. Consequently, in line with the project’s objectives, this led to the development of a multi-variant ISNOO design, which provides Renz Sp. z o.o. with a competitive edge in the market of customised sender-receiver systems.

Acknowledgement
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THE APPLICATIONS OF DATA MINING AND DATA SCIENCE IN INDUSTRIAL ENGINEERING

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Abstract: This article explores the transformative role of data mining and data science in enhancing engineering processes. It emphasizes the importance of these modern techniques in optimizing complex systems, reducing costs, and improving quality. Data mining, which involves analyzing large datasets to uncover hidden patterns, and data science, which integrates statistical, mathematical, and computational techniques, provide new tools for industrial engineers to address complex challenges. The article delves into specific application in manufacturing process optimization, and supply chain improvement, highlighting the methodologies and benefits of implementing data mining in production processes. By leveraging data mining and knowledge discovery, production processes can achieve significant improvements in efficiency and performance.

Keywords: data science, industrial practice, process mining, improvement, knowledge-based discovery

Introduction

In the current era where technology and innovation are driving progress, data mining and data science are playing a key role in transforming various industries, including industrial engineering. Industrial engineering, which is concerned with optimizing complex systems and processes, finds immense potential in these modern approaches to improve efficiency, reduce costs, and increase quality.

Data mining, which involves analysing large data sets to uncover hidden patterns and relationships, and data science, which combines statistical, mathematical and computational techniques to process and analyse data, offer industrial engineers new tools to solve complex challenges and problems. In this article, we look at how these disciplines contribute to innovation in industrial engineering, specifically in areas such as predictive maintenance, manufacturing process optimization, and supply chain improvement.

Data science

Data science is an interdisciplinary field that combines mathematics and statistics, specialized programming, advanced analytics, artificial intelligence (AI) and machine learning with domain-specific expertise to uncover actionable insights hidden in an organization's data. These insights can be used to guide decision-making and strategic planning. The following figure (Fig. 1) depicts the five stages of the data science lifecycle.

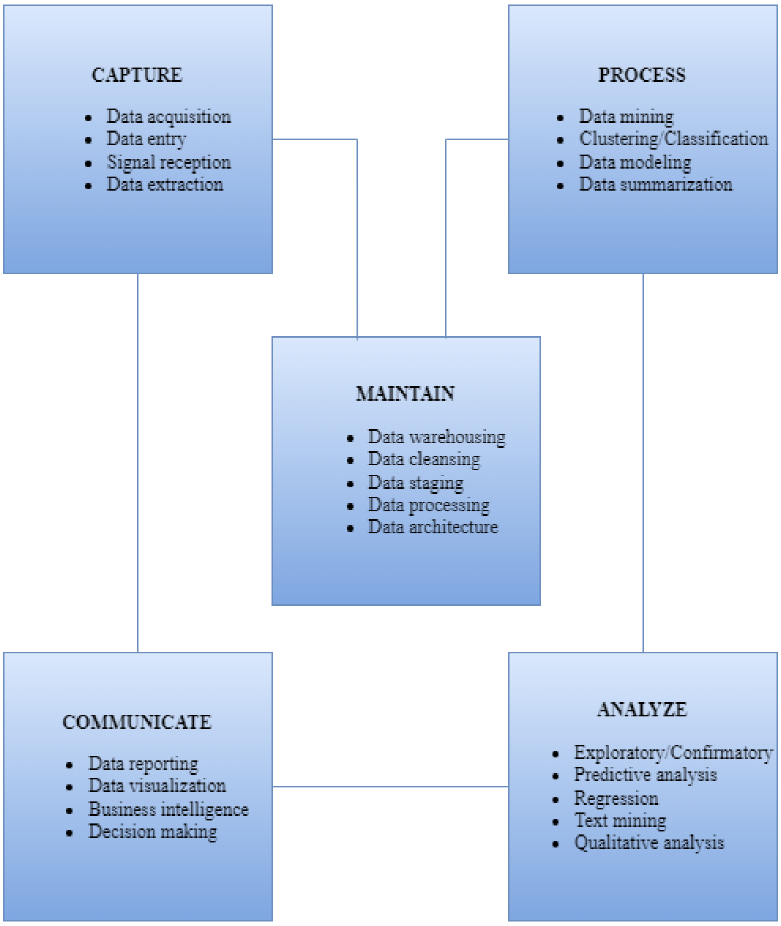


Fig. 1 5 stages of the data science lifecycle

Data mining through knowledge discovery in databases

Data mining is a set of exploratory techniques based on advanced analytical methods and tools for processing large volumes of information. These techniques can find new patterns that can help a business better understand individual processes and can also help in forecasting. Many data mining techniques are closely related to some of the machine learning techniques that have been developed over the last 50 years. Others are related to techniques that were developed earlier and were designed to work with limited amounts of data. Nowadays, these techniques have been adapted to deal with large amounts of data.[1]

Knowledge discovery in databases (KDD) is the process of semi-automatic extraction of knowledge from databases [2]. The knowledge that is extracted must be:

• Valid,
• Not yet known,
• Potentially useful for a given application.

Thus, data mining is one phase of the process of knowledge discovery in databases, in which hidden patterns or models in the data are searched for through various techniques under given constraints. The goal of data mining is verification, exploration, description and prediction. According to the knowledge sought, data mining methods are classified into:

• Summarizing and generalizing,
• Search for dependencies,
• Classification and clustering,
• Regression in the sense of statistical analysis,
• Detection of changes and outliers,
• Searching for similarities in temporal databases.

The overall process of knowledge discovery in databases is visualized in the following figure (Fig. 2).

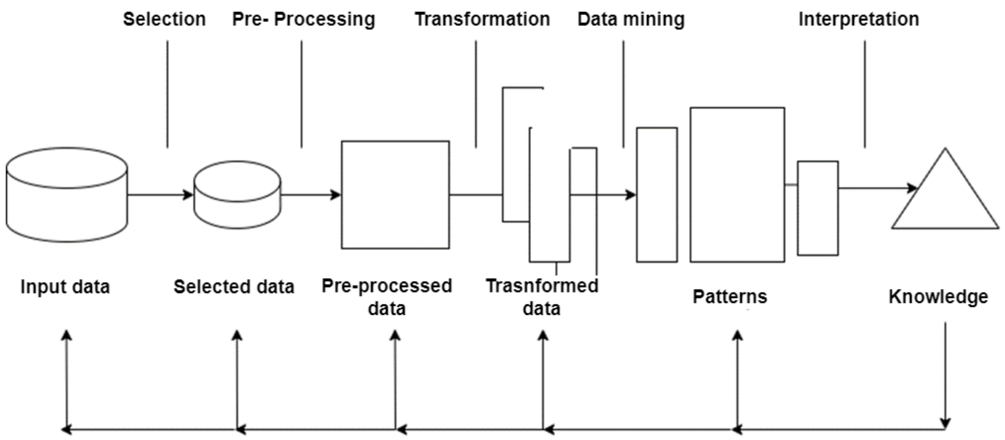


Fig. 2 Process of knowledge discovery

Methodology for implementing data mining in production processes

When mining process data, it is important to follow the following process methodology:

• Defining KPIs,
• Beginning the analysis,
• Selection of data sources,
• Process analysis. [6]

Key performance indicators such as work-in-progress, lead times, and order lifecycle need to be defined to align with organizational objectives, thus the goals and the questions of the analysis can be established, targeting the understanding of manufacturing processes, therefore the deficiencies could be identified, and improvement opportunities sought.

To be able to carry out comprehensive analysis, it is vital to identify relevant data sources like logs from information systems, sensor data or system records (ERP, MES etc.).

For comprehensive analysis it is important to use data mining software solution, which can create process maps and analyze data to assess inefficiencies identification.

Process mining algorithms

Process data mining software solutions employ a variety of algorithms that can be used to discover the underlying structure of a process, identify inefficiencies or bottlenecks.

Some of the most used process mining algorithms include the Inductive Miner, the Alpha Miner and the Heuristic Miner.

Each of these algorithms is designed to extract different process models from an event log.

The Inductive Miner is an algorithm used in process mining to derive process models from event logs. It is particularly known for producing sound process models (i.e., models that are free of deadlocks and other execution problems). The key concepts are event logs, directly follows graphs and process trees. Event logs are representing a collection of traces, where each trace is sequence of events. Each event typically has attributes like an identifier, activity name and time stamp. The directly follows graphs is a graph where nodes represent activities and directed edges represent the directly follows relation between activities (i.e., activity A is followed directly by activity B in at least one trace). The process tree is a tree structure representing the hierarchical decomposition of a process model. Each node represents a process construct (e.g., sequence, parallelism, choice). [3]

The Alpha Miner, or Alpha Algorithm, is a foundational algorithm used in process mining aimed at reconstructing causality from a set of event sequences. It was first introduced by van der Aalst, Weijters, and Maruster. Alpha Miner was one of the first algorithms introduced in the field of process mining and serves as a foundation for more advanced techniques. This algorithm also has its limitations where it assumes that the event log is noise free, which is often not the case in real world scenarios, it also has trouble discovering complex structures and due to computational complexity can be inefficient for large-scale events. [4]

The Heuristic Miner discerns the most likely model from an event log by employing a combination of techniques such as frequency analysis, causal relationships, and data clustering. It operates by constructing a Petri net model with the minimal number of elements necessary to accurately represent the model's features within the event log. This process involves three stages: mining the dependency graph, merging relations, and identifying ar-reaching dependence interactions.

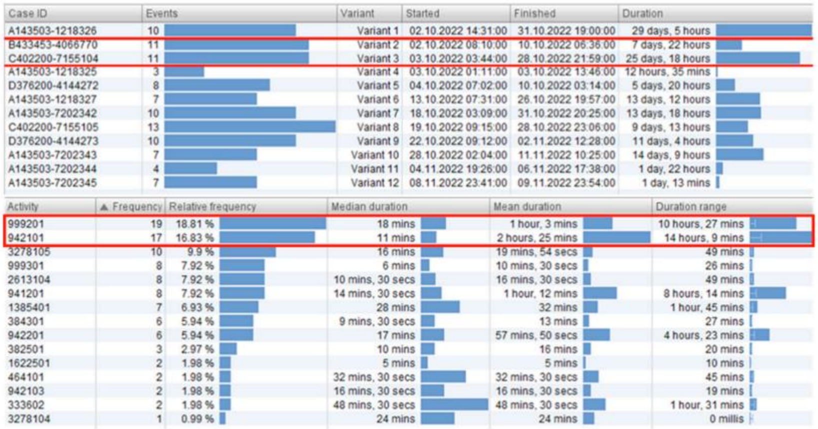
Use case of process mining implementation into industrial practice

A manufacturing company sought to improve its production efficiency and resource utilization. To achieve this, the company applied process mining techniques, focusing on the analysis of digital traces left in their information systems. By leveraging these techniques, the company aimed to reduce production cycle time and improve resource utilization.

Key strategies that were implemented were:

- Identification and reduction of bottlenecks,
- Segmentation and cellular production arrangement,
- Minimization of rework and logistics delays.

Through analyses of the extracted data, it was possible to identify critical bottlenecks such as long handling and process times on specific equipment (e.g., machines 942101 and 999201) as shown in (Fig. 3).



Case ID	Events	Variant	Started	Finished	Duration
A143503-1218326	10	Variant 1	02.10.2022 14:31:00	31.10.2022 19:00:00	29 days, 5 hours
B433453-4066770	11	Variant 2	02.10.2022 08:10:00	10.10.2022 06:36:00	7 days, 22 hours
C402200-7155104	11	Variant 3	03.10.2022 03:44:00	28.10.2022 21:59:00	25 days, 18 hours
A143503-1218325	3	Variant 4	03.10.2022 01:11:00	03.10.2022 13:46:00	12 hours, 35 mins
D376200-4144272	8	Variant 5	04.10.2022 07:02:00	10.10.2022 03:14:00	5 days, 20 hours
A143503-1218327	7	Variant 6	13.10.2022 07:31:00	26.10.2022 19:57:00	13 days, 12 hours
A143503-7202342	10	Variant 7	18.10.2022 03:09:00	31.10.2022 20:25:00	13 days, 18 hours
C402200-7155105	13	Variant 8	19.10.2022 09:15:00	28.10.2022 23:06:00	9 days, 13 hours
D376200-4144273	10	Variant 9	22.10.2022 09:12:00	02.11.2022 12:28:00	11 days, 4 hours
A143503-7202343	7	Variant 10	28.10.2022 02:04:00	11.11.2022 10:25:00	14 days, 9 hours
A143503-7202344	4	Variant 11	04.11.2022 19:26:00	06.11.2022 17:38:00	1 day, 22 hours
A143503-7202345	7	Variant 12	08.11.2022 23:41:00	09.11.2022 23:54:00	1 day, 13 mins

Activity	▲ Frequency	Relative frequency	Median duration	Mean duration	Duration range
999201	19	18.81 %	18 mins	1 hour, 3 mins	10 hours, 27 mins
942101	17	16.83 %	11 mins	2 hours, 25 mins	14 hours, 9 mins
3278105	10	9.9 %	16 mins	19 mins, 54 secs	49 mins
999301	8	7.92 %	6 mins	10 mins, 30 secs	26 mins
2613104	8	7.92 %	10 mins, 30 secs	16 mins, 30 secs	49 mins
941201	8	7.92 %	14 mins, 30 secs	1 hour, 12 mins	8 hours, 14 mins
1385401	7	6.93 %	28 mins	32 mins	1 hour, 45 mins
384301	6	5.94 %	9 mins, 30 secs	13 mins	27 mins
942201	6	5.94 %	17 mins	57 mins, 50 secs	4 hours, 23 mins
382501	3	2.97 %	10 mins	16 mins	20 mins
1622501	2	1.98 %	5 mins	5 mins	10 mins
464101	2	1.98 %	32 mins, 30 secs	32 mins, 30 secs	45 mins
942103	2	1.98 %	16 mins, 30 secs	16 mins, 30 secs	19 mins
333602	2	1.98 %	48 mins, 30 secs	48 mins, 30 secs	1 hour, 31 mins
3278104	1	0.99 %	24 mins	24 mins	0 millis

Fig. 3 Statistical results of mined data from ERP

After addressing and removing bottlenecks, a 15% reduction in production cycle time was achieved.
Through segmentation and cellular production arrangement, machinery was grouped based on operation similarity and frequency, allowing for a more efficient cellular production arrangement.
All these steps taken also led to potential workforce optimization by 10%.

Conclusion

Analyzing industrial production and its processes forms the cornerstone of effective management and optimization within the industry. This analysis is essential as it provides the insights needed to streamline operations, reduce costs, and improve efficiency. However, industrial processes are inherently complex, involving numerous variables and interdependencies. Additionally, these processes often operate in dynamic environments characterized by constant changes in demand, supply chain fluctuations, and evolving technologies. These factors can make it challenging to achieve a thorough understanding and effective management of industrial operations.
In this context, process mining has become a transformative tool for enterprises, extracting knowledge from event logs in modern information systems. By utilizing advanced algorithms and data analysis, process mining allows organizations to visualize actual processes, identify inefficiencies, and uncover opportunities for improvement. It bridges the gap between traditional process modeling and real-world execution, providing a clear, data-driven view of operations.
Through process mining, enterprises can detect bottlenecks, deviations, and redundancies, gaining insights into operation frequencies and durations to optimize scheduling and resource allocation. Additionally, it supports continuous monitoring and improvement, enabling organizations to adapt swiftly and maintain optimal performance.

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IMPROVING THE PRODUCTION PROCESS USING THE SIX SIGMA METHODOLOGY

Dariusz MICHALSKI

Abstract: The article presents the application of the Six Sigma methodology in improving production processes based on the production of a 10 ml bottle with an index of 35091 E, one of the key products of a company specializing in providing modern packaging for the pharmaceutical and cosmetics industry. The Six Sigma method focuses on real situations, leading to continuous improvement in many different segments of the business model [7]. This method uses only statistical techniques to achieve the best results and thus influence greater customer satisfaction. It strives to get rid of waste and build a flawless strategy for the company. Six Sigma uses technical data that is aimed at solving problems related to product deviations, using the data to make corrections. Six Sigma tries to improve processes and become more focused on the product. The primary goal of this method is quality control by reducing production costs and supervising the product [6].
Keywords: Six Sigma methodology, Measurement Systems Analysis, bottle 35091 E, DIP2.

1. The Role and Methodology of Six Sigma in Quality Management

Companies that implement Six Sigma become organizations that are truly focused on customer needs. These companies understand perfectly well that their internal activities affect the environment, and in particular the recipient. Thanks to Six Sigma, entities gain the competence to listen to external stimuli of the environment and analyze them, thanks to which they improve their internal processes. The starting point in Six Sigma is to ensure that the products manufactured in the company meet, to a significant extent, the customer's requirements. For this purpose, it is important to define what part of the process falls within the designated tolerance field, specified by the customer, and what does not. To determine this level, it is crucial to use a measure of variability defined in statistics as standard deviation. In such a deviation, a value is assumed in which one unit is 1σ, and the average is marked with the symbol μ. In the normal distribution, also known as the Gaussian distribution (Fig. 1), the deviation is equal to - 3σ in plus and 3σ in minus - on this basis, it is possible to determine what part of the manufactured products has a chance of being within the tolerance limits. In the normal distribution, 68.27% are within one standard deviation, and between -2σ and 2σ there are already 95.45% of compliant products. In three standard deviations, this value is 99.74% and it may seem like a huge success. However, taking into account mass production, e.g. 1 million pieces, this percentage indicates that the number of DPMO (Defects Per Million Opportunities) - defects per million opportunities - will be about 2700, which is a very undesirable result. [10, 12] The assumption of Six Sigma is that the entire process should be within the tolerance limits, and the number of defects should be close to zero. The aim is to limit the process variability, i.e. to "slim down" the normal distribution so that the tolerance limits are limited by not 3 but 6 standard deviations (Fig. 2).

Tab. 1. Values corresponding to deviations in Six Sigma and the number of DPMO

Standard deviation in Six Sigma (σ)	Percentage of deviation (%)	DPMO - defects per million possibilities
1	30,9	691 462
2	69,1	308 538
3	93,3	66 807

4	99,38	6 210
5	99,977	233
6	99,99966	3,4

In the Six Sigma distribution, the value of products meeting the requirement is able to reach 99.99966%. Then the number of defects per 1 million produced pieces will be only 3.4. Table 1 shows the values corresponding to the deviations in Six Sigma and the amount of DPMO.

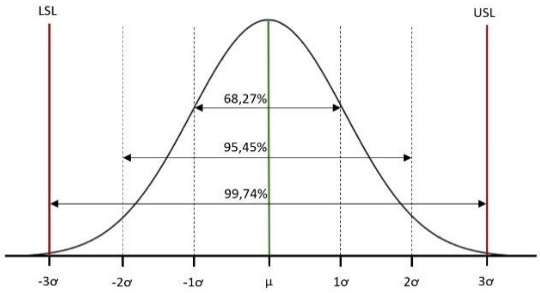

Fig. 1. Standard deviations in the normal distribution [9]

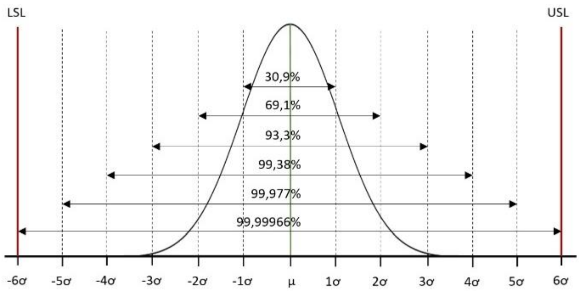

Fig.2. Standard deviations in Six Sigma [12]

2. Application of Six Sigma method in improving the production process

The stages of the Six Sigma methodology in improving the production process of a product for a manufacturer of medical equipment will be presented - using the example of a specific order. The MiniTab program was used to conduct analyses. The customer requested a new mold (E) for product 35091, a 10 ml bottle. The order was accepted by the Sales Department and then forwarded to the R&D Department, the Project Manager. The mold supplier sent the first samples of bottles produced on the new mold. The supplier declares that the samples were made on a Jomar 80 injection machine. Based on the measurement results, the 35091 E mold was accepted and purchased by the company accepting the order, but the first run on the Jomar 40 injection machine did not bring the expected results. A decision was made to introduce the Six Sigma methodology, which aimed to define the problems and improve the production process. A project manager and a team consisting of the best experts in the given process were appointed.

3. Problem Description

Bottle 35091 (new mould "35091E" supplied by the mould manufacturer). The mould 35091E is a 12-fold mould for 10 ml bottles. The first samples were received from the mould supplier. In measurements of three injections, dimensions within tolerance were achieved (Fig. 3), which was the basis for accepting the mould and launching it in the company.

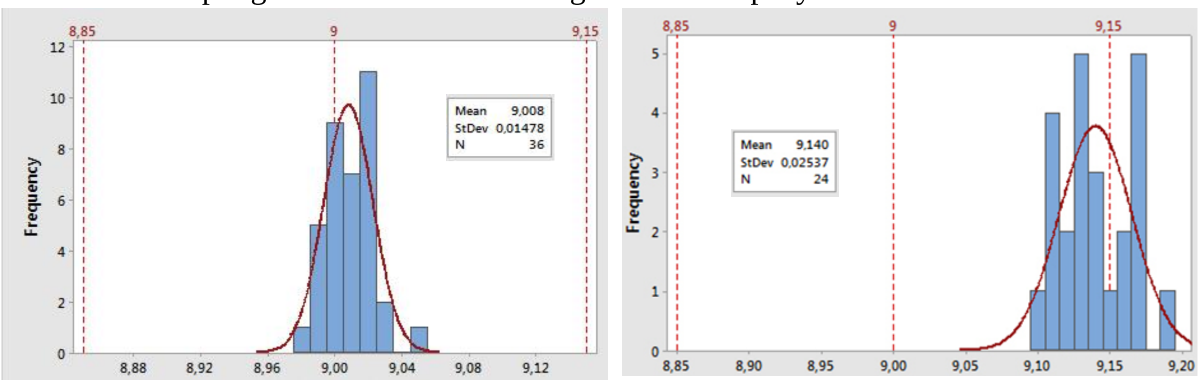

Fig. 3. Histogram of measurements of three injection samples of Bottle 35091 E from the supplier

Fig. 4. Histogram of the measurements of the first launch of Bottle 35091 E in the company

During measurements, after the first launch, based on the "Model parameter card", a dimensional discrepancy was found regarding the DIB2 feature - the lower, internal diameter of the neck (Fig. 4). Exceeding this characteristic is unacceptable to the customer - it indicates this dimension as critical. The DIB2 characteristic affects the tightness between the dropper and the bottle. Finally, a decision was made to temporarily suspend production from the 35091E mould.

4. Project Purpose and Justification

The aim of the project was to identify the cause of the dimensional inconsistency of DIB2, which affects the tightness of the products, obtaining a product in accordance with the customer's requirements. The results obtained in the R&R (Repeatability and Reproducibility) reports, i.e. the repeatability and reproducibility of the measurement system, prove that the measurement system is able to assess the performance of the process according to the specified parameters in terms of repeatability and reproducibility. The final results of the R&R analysis are presented in Table 2.

Tab. 2. R&R analysis results for Bottle 35091 B

Product	Dimension	Process Variability	Tolerance
Bottle 35091 B	Bottle thread diameter (DER)	Total rate = 10.17 % Repeatability = 10.09 % Reproducibility = 1.30 %	Total rate = 3.66 % Repeatability = 3.63 % Reproducibility = 0.47 %
Bottle 35091 B	Bottle neck outside diameter (DEC2)	Total rate = 18.83 % Repeatability = 18.83 % Reproducibility = 0.00 %	Total rate = 8.47 % Repeatability = 8.47% Reproducibility = 0.00 %
Bottle 35091 B	Bottle opening diameter (DIB1)	Total rate = 13.53 % Repeatability = 13.50 % Reproducibility = 0.96 %	Total rate = 6.09 % Repeatability = 6.07 % Reproducibility = 0.43 %

5. Analysis

The first step was to analyze the samples from the supplier to get a full picture of the range of deviation from the expected results. The analysis consisted of a comparative method of bottles from the mold supplier with those produced in the company. The measurement results of the bottle from the supplier (Fig.5) indicate the process capability at the required level of Pp>1.33. It can be stated that they guarantee high process stability and the probability of results occurring outside the specified values is very small. The standard deviation is at the level of 0.15 mm. The percentage of non-compliant products is unlikely.

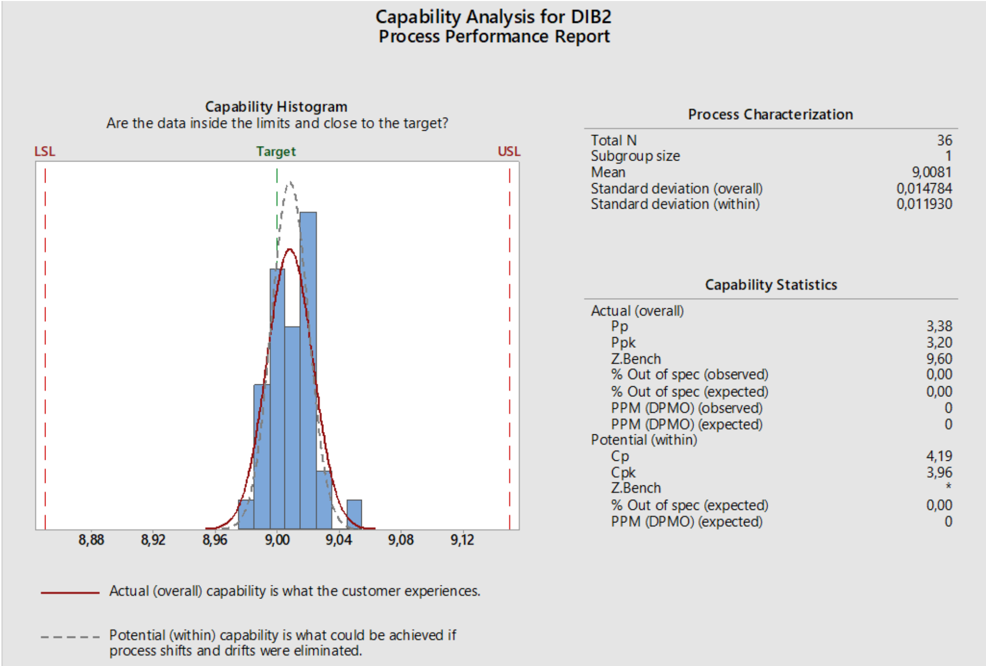

Fig. 5. Histogram of the DIB2 feature measurement of 35091 E bottles received from the supplier

Graph "Probability Plot" (Fig. 6) for all measured mold cavities shows that the distribution is normal, indicated by the P-value > 0.05.

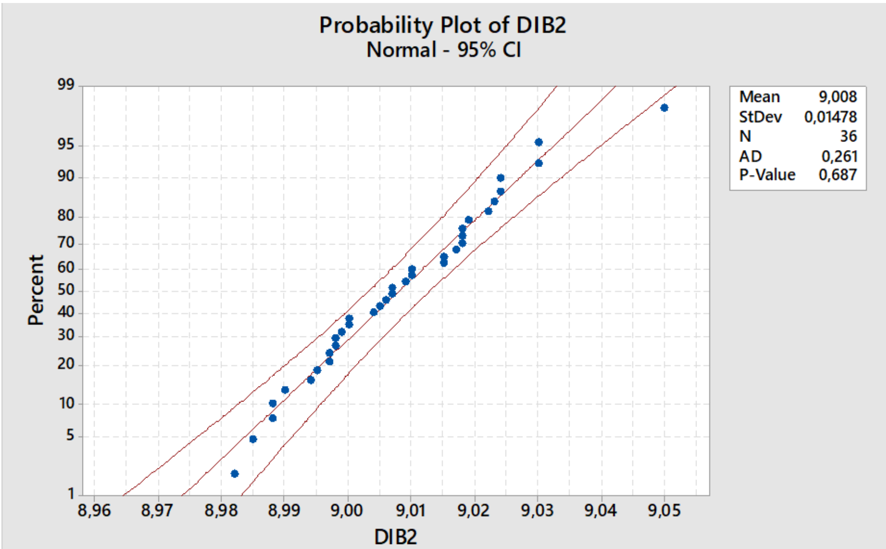

Fig. 6. Probability graph of the DIB2 dimension of the 35091 E bottle from the supplier

The average result obtained from the samples received is 9.0081 mm. The most outlier points (outliers) indicate that something may have happened in the process and should be considered individually. Fig. 7 shows an individual graph of values for individual nests. This type of graph is suitable when the number of samples is less than 50. The largest group of points is located close to the nominal value. The next diagram was a graph for individual bottle nests. It showed that nest 79 takes into account the largest scatter, and 82 the smallest; the higher the number, the lower the result, which indicates unevenness in the execution of the nests. Fig. 8 shows a diagram of the measurement of the DIB2 feature from the supplier for individual nests in the process.

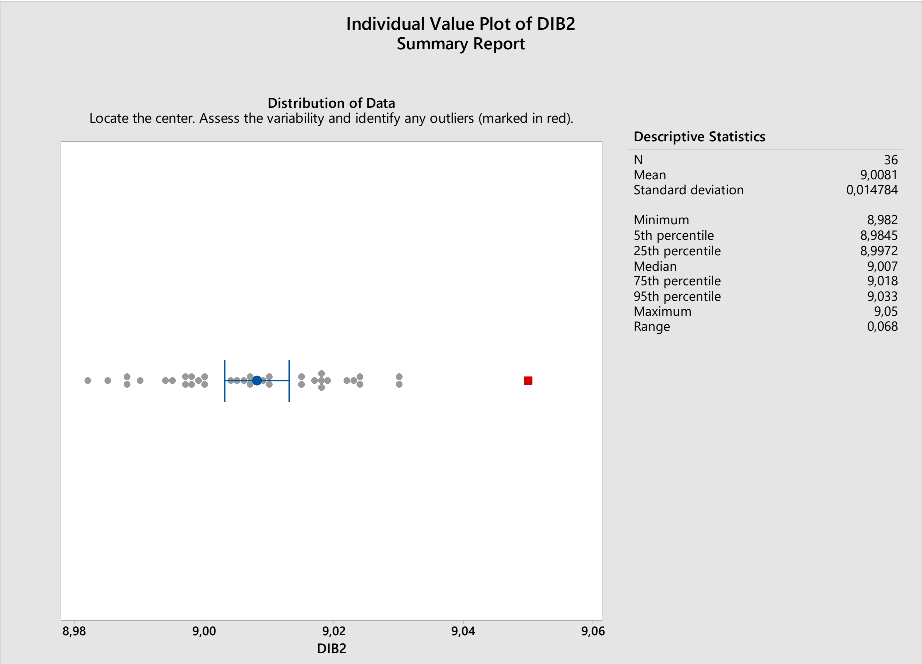

Fig. 7. Individual graph of values for individual sockets of the DIB2 dimension of 35091 E bottles from the supplier

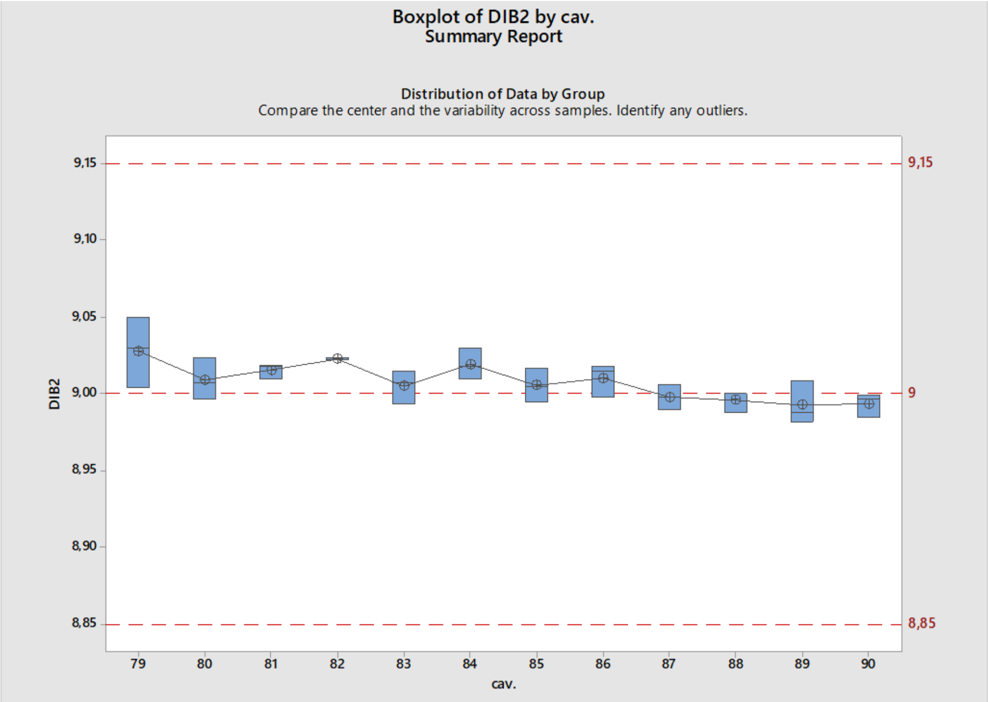

Fig. 8. Diagram of the DIB2 feature measurement from the supplier for individual cells in the process

The last phase of the analysis was to plot the regression line (covariance) for individual injection nests (Fig. 9). Here, we can see a certain relationship between the nests. The relationship is decreasing, which indicates that obtaining smaller values is more likely on the largest nest. Outliers are points that may appear to a lesser extent than the rest.

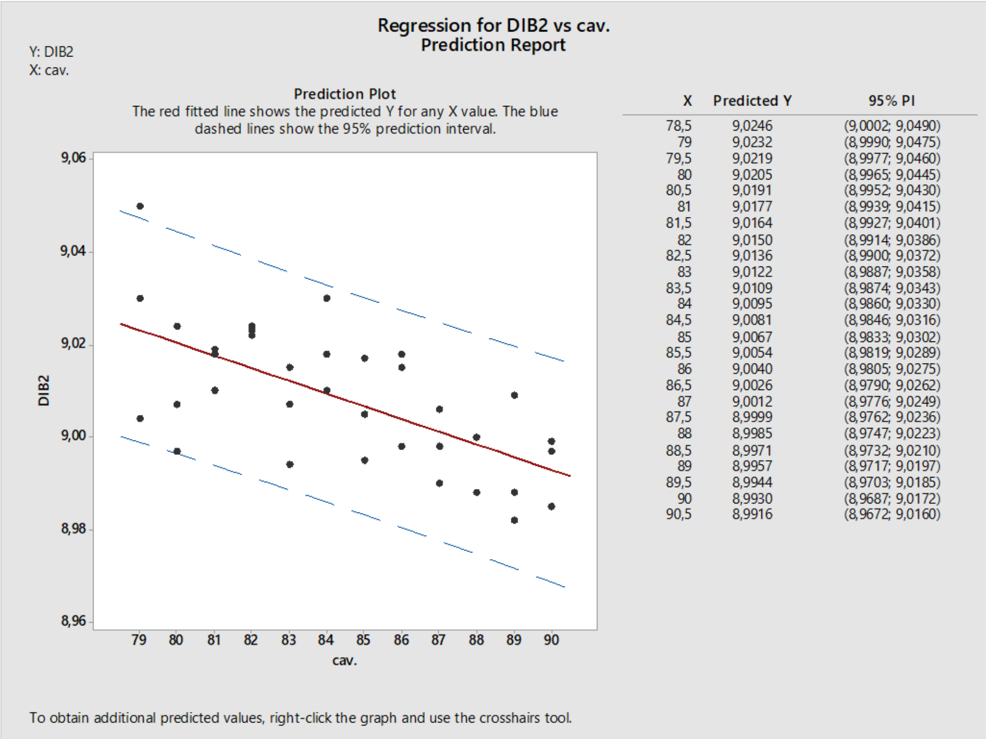

Fig. 9. Regression graph for the DIB2 feature of individual bottle nests 35091 E from the supplier

The next step in the Six Sigma analysis of the given project was to compare the samples of the first run of the 35091E mold and the remaining five samples, in which the variable was the temperature of the water cooling the bottle neck (Fig. 10). From a number of tests performed, it was selected which results gave the best possible result, close to the nominal, i.e. test (5) with a water temperature of 25°C.

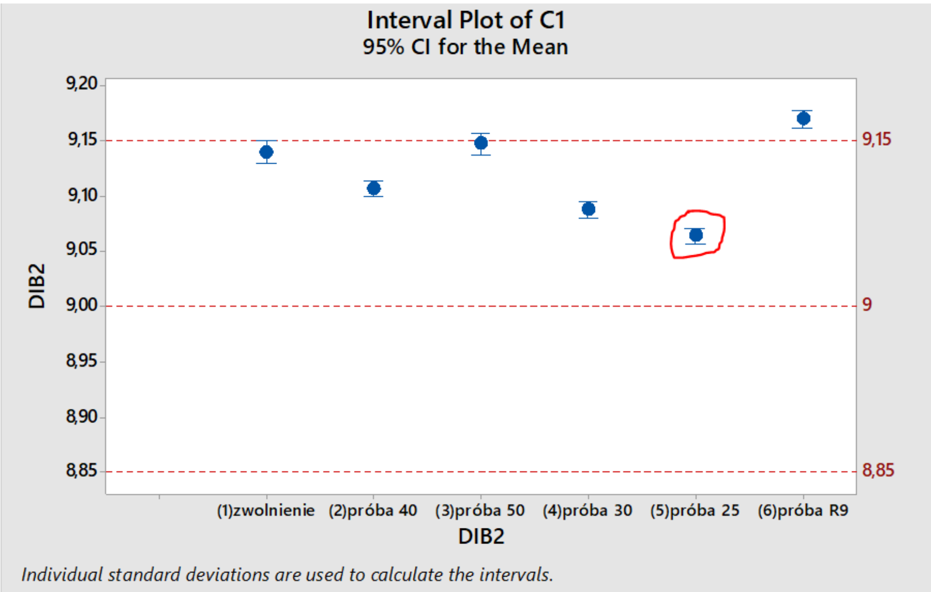

Fig. 10. Comparison chart of the first run of all samples of the 35091E bottle for the DIB2 dimension

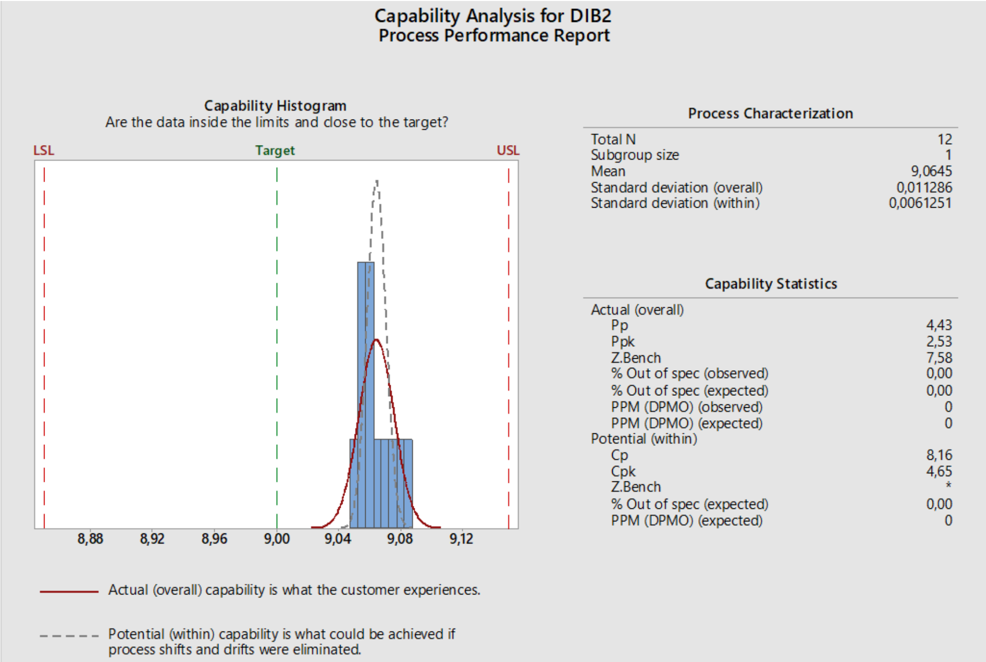

Fig. 11. Histogram of the evaluation results of the DIB2 feature measurement for sample 5 of bottle 35091 E

Despite the small number of bottles (12 pcs.) it was decided to perform the analysis of the process of sample no. 5 (Fig. 11). After the initial results, the forecast is positive, and the process capability at the required level Pp>1.33, as indicated by the value of the indicator of 4.43. P-value>0.05, which indicates the stability and capability of the process (Figure 12). There is one point that deviates from the rest (outlier).

Based on the obtained data, it was decided to start the mould (release), according to the parameters of test no. 5. Based on the presented analyses, the optimal processing window for the process was found.

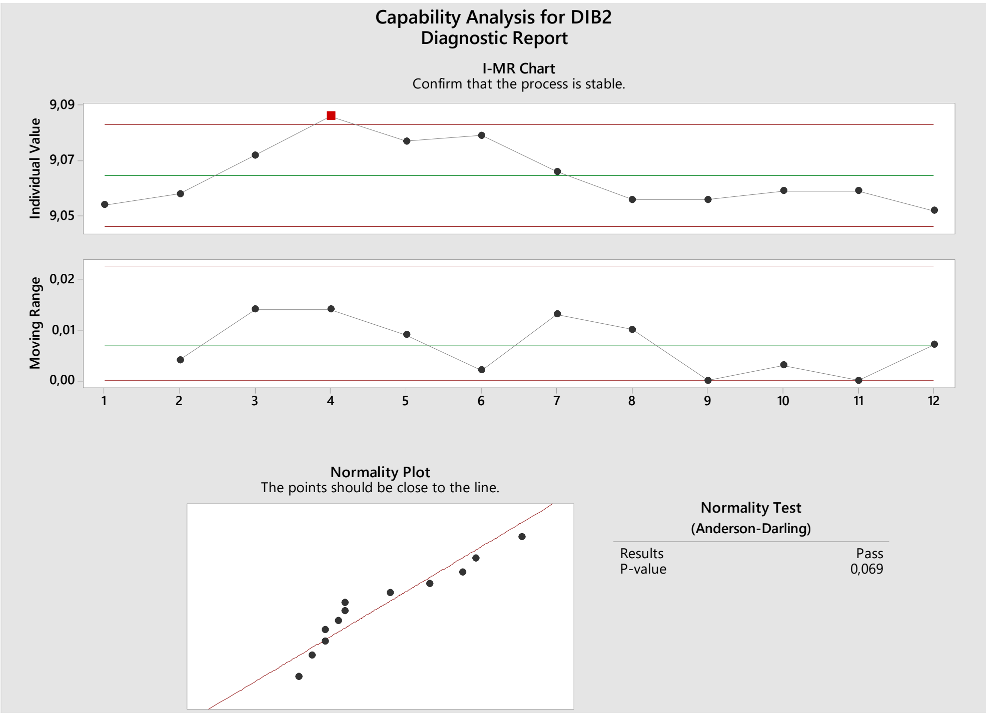

Fig. 12. The diagram shows the process capability level of the DIB2 feature of sample no. 5 of bottle 35091 E

6. Control

At this stage of Six Sigma, the control plan was specified and the effectiveness of the actions taken was checked by conducting a process analysis during the normal production process. The control plan included the following points: dimensional control – level S4 according to ISO 2859-1; measuring instrument for CTQ – Mitutoyo CMM measuring machine; response to non-conformities in accordance with the company's internal procedure – "Procedure for a product not in accordance with the requirements".

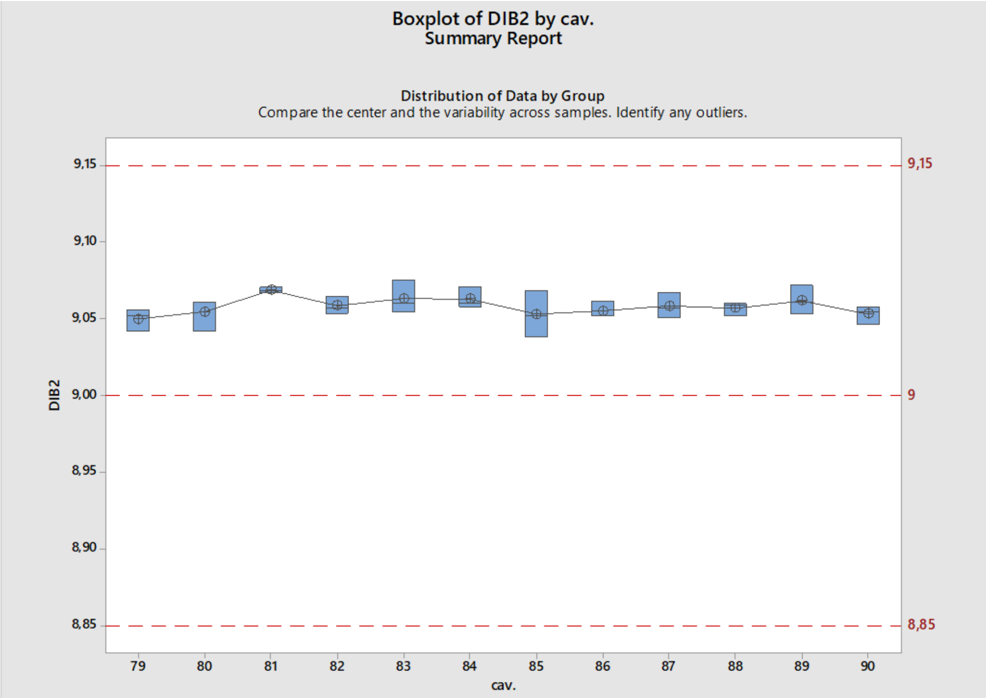

Fig. 13. Diagram of the comparative analysis of individual nests of the representative sample of three series for the DIB2 feature of the 35091E mold

The application of the above-mentioned plan was aimed at verifying the correctness of the actions taken to improve the production process and preventing the shipment of products outside the specification to the customer. The effectiveness of the actions taken was carried out on the basis of a representative sample for three series produced one after the other. A comparative analysis for individual nests in the process confirms the earlier observations about the unevenness of the nests/process. It was possible to see that nest no. 81 has a much smaller dispersion, and no. 85 the largest of all those in the process.

Conclusions

The optimal solution to avoid similar situations in the future, where the parameters declared by the supplier do not match the start-up parameters, would be to use the same type of machines for production. However, from an economic point of view, such a solution is unprofitable due to the fact that large machines, such as Jomar 80, are designed for multi-nest production, with a multiplicity of more than 16 nests. The choice of the Jomar 40 type machine for the production of the 35091 E bottle is fully justified [4, 11]. The team participating in the project proved that through skillful control of the process parameters, the intended, long-term effect can be achieved.

Summation

Six Sigma is a process improvement methodology aimed at reducing errors and improving production methods through data analysis and systematic improvement of operational techniques, which contributes to improving quality management in manufacturing entities [5].

This article proves the improvement of the production process using the Six Sigma methodology. A wide range of tools and their appropriate selection made it possible to obtain optimal results in terms of the technological resources, specialist knowledge and the so-called "mental resources" that are guided by the Six Sigma philosophy [2, 3, 8].

In the course of process improvement using the Six Sigma method, one can see a number of activities focusing on the goal in several of its aspects, i.e.: process quality, process stability, process repeatability.

Comparing the histogram of the DIB2 feature of the 35091 E bottle, the initial course of the process (Fig. 14), to the histogram after introducing changes using the Six Sigma method (Fig. 15), the difference in the obtained results at a very good, high level is clearly visible.

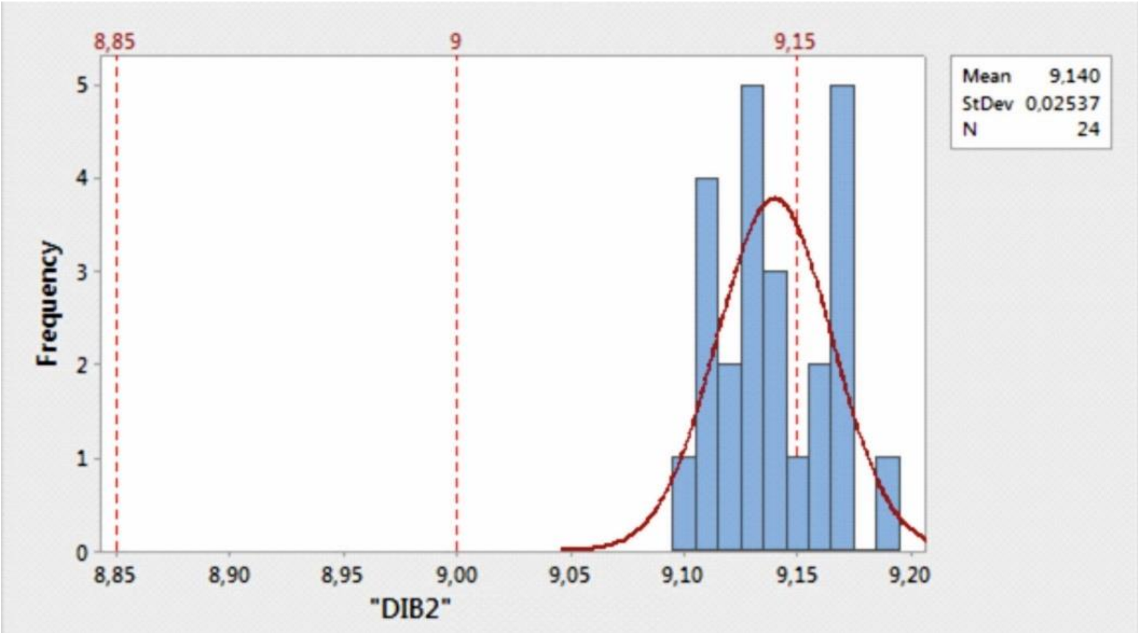

Fig. 14. Histogram of the DIB2 feature of the 35091 E bottle at the initial stage of the process

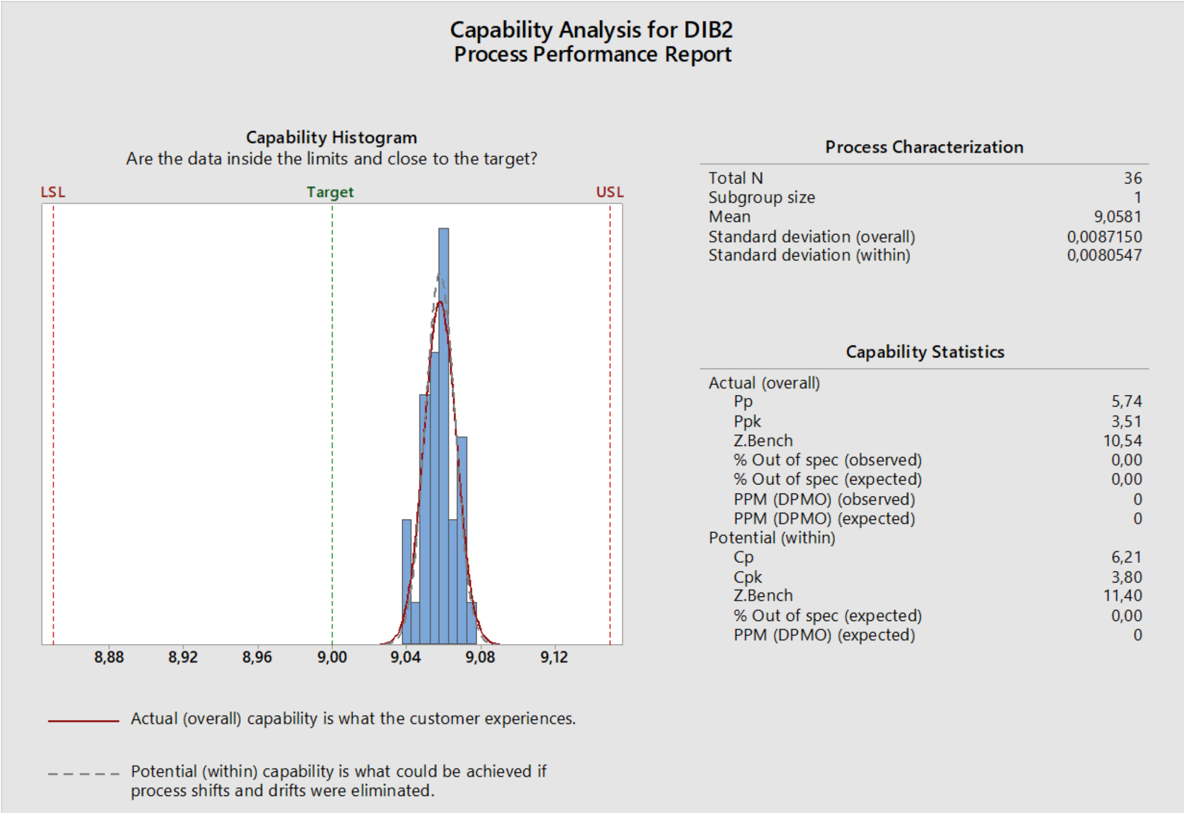

Fig. 15. Histogram of the DIB2 feature of the 35091 E bottle after improving the production process using the Six Sigma method

It is tempting to say that Six Sigma is a cure for the problems of companies of a process nature, requiring the collection of extensive data, which will have to be subjected to statistical analysis in order to affect their variability and, consequently, to improvement. Conducting the Six Sigma method is a difficult task, requiring extensive knowledge, great experience and engaging a team of high-class specialists in various areas of the company's activity. However, this powerful tool, entailing changes in the culture of work, improves communication skills and makes individual units gain confidence in the implementation of production processes.[1]

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ADVANCEMENTS IN INDUSTRY 4.0: INTEGRATING DIGITAL TECHNOLOGIES FOR SMART MANUFACTURING SYSTEMS

Peter MALEGA - Juraj KOVÁČ - Erik VARJÚ - Peter TREBUŇA

Abstract: This paper explores the transformative impact of Industry 4.0 on contemporary manufacturing landscapes. It emphasizes the integration of advanced technologies such as the Internet of Things (IoT), cyber-physical systems, and cloud computing within industrial operations. The evolution from isolated automated units to fully interconnected and intelligent manufacturing environments underscores a significant shift towards optimized production processes. The paper discusses the roles of Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) systems in facilitating real-time data integration and enhancing operational efficiencies. With detailed analyses of the vertical and horizontal integration strategies, the paper illustrates how Industry 4.0 fosters a responsive, agile, and customer-centric manufacturing ecosystem, driving substantial improvements in productivity and competitive capabilities.
Keywords: Industry 4.0, Internet of Things, Cyber-Physical Systems, Manufacturing Execution System, Enterprise Resource Planning

Introduction

In today's world, everything revolves around commerce. However, for people to be able to purchase something, the goods need to be manufactured somewhere. These goods are produced in factories. In order to ensure enough goods for everyone, factories have had to undergo certain changes to improve and enhance their products. However, during these changes, it is crucial for the factory to keep running continuously. This is achieved through a set of measures that are constantly evolving.

We call the industrial revolution in manufacturing "Industry," and we are currently in the midst of its fourth phase. The role of this phase is to digitalize the production system. We believe that this system competes in tomorrow's world, thus helping factories keep up with an era characterized by high demands and an ever-increasing demand for goods. Nowadays, it is said that the level of intelligence offered today is just the beginning of what is to come in the future.

Concept of the 4th Industrial Revolution

The concept of the 4th Industrial Revolution is not straightforward. It is surrounded by many technologies and is used in various contexts. Each concept, when integrated together, creates capabilities that were never possible before.

1. Big Data – is a collection of data from traditional and digital sources both inside and outside the company, which represent a source for ongoing discovery and analysis.
2. Smart Factory – adopts a so-called calm system that is capable of dealing with both the physical and virtual worlds together. It is a seamless connection of individual production steps from the planning phases to practical implementation.

3. Cyber-Physical Systems – are an integration of computing, networking, and physical processes. Computers and networks monitor and control physical processes through feedback loops. The concept focuses on computers and software that are embedded in devices. It is a loop of action and machine learning.
4. Internet of Things (IoT) – connects machines and systems. It allows seamless data transfer across all workplace departments. It opens up opportunities for entirely new business models in manufacturing, computing, and many other industries. This interconnection enables the use of data for production, movement, and reporting.
5. M2M (Machine to Machine) – the main purpose of M2M technology is to penetrate data sensors and transmit them to the network. These M2M applications translate data that can trigger pre-programmed, automated actions. Artificial intelligence and machine learning facilitate communication between systems, allowing them to make their own autonomous decisions.
6. Cloud – management of huge volumes of data in open systems. Real-time communication for production systems.

When the aforementioned elements are combined, what is known as interoperability emerges. It involves the connection of cybernetic systems, people, and smart factories that interact with each other through the Internet of Things. At the same time, it is possible for manufacturing partners to share information with nearly zero errors.

The production itself, according to this concept, takes into account internal factors such as logistics, energy, requirements, plans, or direct customer orders. Furthermore, the concept is linked to systems of mobility, smart homes and buildings, social networks, etc. The concept is also called the internet of things, services, and people. Data, or rather the information that can be obtained from data, also plays an important role in it. The concept will put pressure on global manufacturers to move to a new level of optimization and productivity. Customers will also enjoy personally customized products of a new level, available like never before. Figure 1 shows the technologies of Industry 4.0.

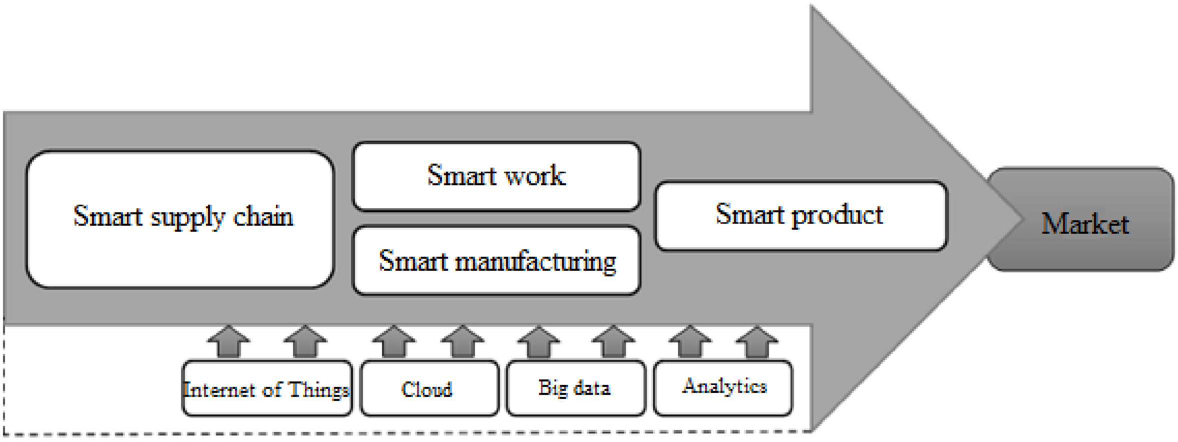

Fig. 1 Technologies of Industry 4.0

Industry 4.0 is transforming manufacturing from isolated automated units into a fully integrated, continuously optimized production environment. New global networks are emerging based on the connectivity of manufacturing equipment into cyber-physical systems (CPS). CPS will be the fundamental building blocks of "smart factories" that will be capable of:

- autonomously exchanging information,
- Initiating necessary actions in response to current conditions, and conducting independent mutual checks.

Sensors, machines, parts, and IT systems will be interconnected within a value chain that extends beyond the boundaries of a single company. These interconnected CPS will react to each other using standard internet-based communication protocols, analyse data to predict potential faults or failures, configure themselves, and adapt in real-time to changing conditions. In these factories, "smart products" will emerge that are uniquely identifiable and locatable, will know their history, current status, and alternative paths that lead to the creation of the final product.
Vertical production processes will be horizontally connected within corporate systems that will flexibly respond in real-time to immediate and changing product demands. They will respond to individual customer requirements and allow efficient production of such customized products. The production process will be continuously optimized and able to respond to unexpected changes caused, for example, by the failure of a manufacturing device.

M2M and IoT

M2M (Machine to Machine) systems utilize communication between machines, sensors, and hardware over mobile or wired networks. The advantages include reduced costs by minimizing maintenance and equipment downtime, enhanced revenue by discovering new business opportunities for field product services, and improved customer service through proactive monitoring and servicing of equipment before it fails or when necessary.

IoT (Internet of Things) systems rely on IP-based networks to transmit data collected from internet-connected devices to gateways, cloud, or middleware platforms. IoT systems take M2M to the next level, synthesizing diverse systems into one large, interconnected ecosystem. Table 1 displays the active differences between M2M and IoT, and Figure 2 illustrates their communication.

Tab. 1 Active differences between M2M and IoT

M2M	IoT
Machines	Sensors
Machines	Software
Vertical applications	Horizontal applications

Machines communicate with machines	Machines communicate with machines, people with machines and machines with people
Does not use IP protocol	Uses IP protocols
Can use the cloud, but is not required	Uses the cloud
Often one-way communication	Feedback
Works through action-based triggered responses	May or may not work on elicited responses
Limited integration options, devices must have additional communication standards	Unlimited integration options, but needs software that manages communication
Structured data	Structured and unstructured data

In the concept of Industry 4.0, deep industrial integration is crucial, which can be divided into two fundamental parts. The first is vertical integration, and the second is horizontal integration. The difference is detailed on the following pa**ges.** In Figure 2 is the communication of M2M and IoT.

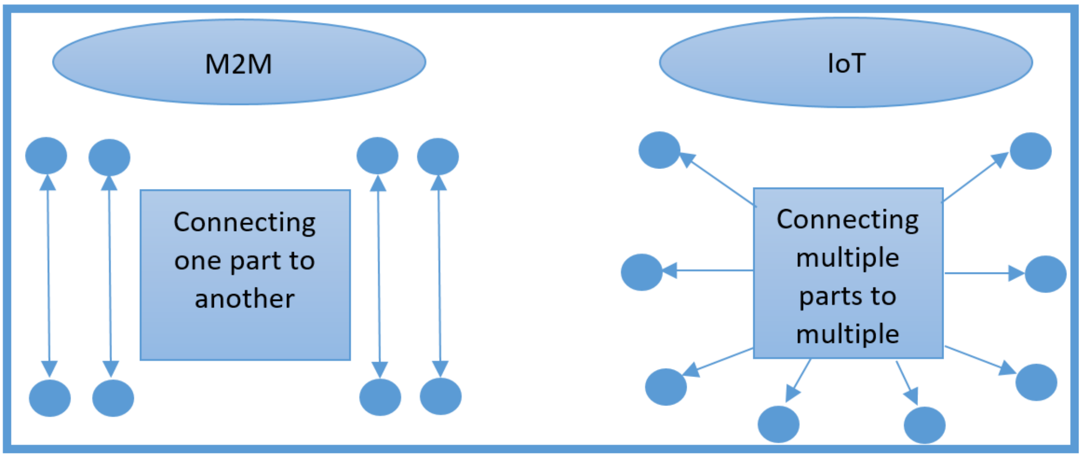

Fig. 2 Communication of M2M and IoT

Horizontal integration of the company

Horizontal integration refers to the integration of IT systems for various manufacturing and business planning processes. It involves the digitization of the entire value and supply chain, with data exchanges and connected information systems becoming the focal point. Among the various processes, there are flows of materials, energy, and information. Furthermore, it relates to internal and external partners (suppliers, customers, and other members of the ecosystem, from logistics to innovation) and stakeholders.

Figure 3 illustrates the integration of information systems and information flows in manufacturing and business planning processes with all involved parties and processes within and outside the value and supply chain: from suppliers of materials and tools to internal processes for distributors and customers.

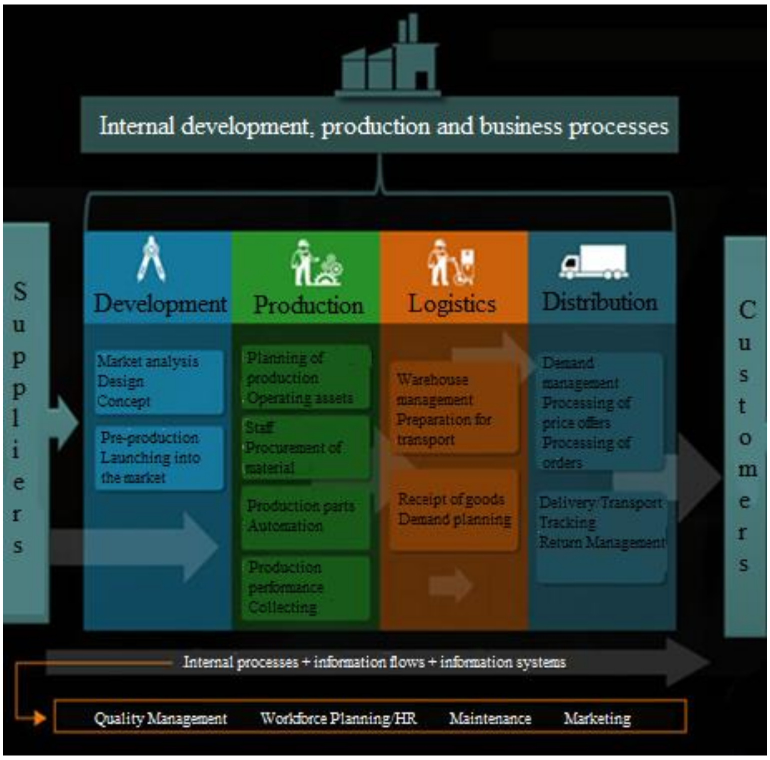

Fig. 3 Horizontal integration

Vertical integration of the company

Vertical integration (Fig. 4) can be described as the integration of IT systems that span different hierarchical levels of production and production stages into one comprehensive solution. The hierarchical levels in vertical integration are as follows:

1. Field level (connection to the production process via sensors and actuators),
2. Control level (regulation of machines and systems),
3. Process line level or the actual production process level (which needs to be monitored and managed),
4. Operations level (production planning, quality management, etc.),
5. Enterprise planning level (management and processing of orders, broader overall production planning, etc.)

Typical solutions and technologies in this vertical integration include:

1. Programmable Logic Controllers (PLCs), which control production processes and are placed at the control level.
2. Supervisory Control and Data Acquisition (SCADA), which enables various levels of production processes and control tasks. It is commonly used in industrial control systems.
3. Manufacturing Execution Systems (MES) for management control.

4. Enterprise Resource Planning (ERP) for the enterprise level, which is the highest level in this hierarchical structure.

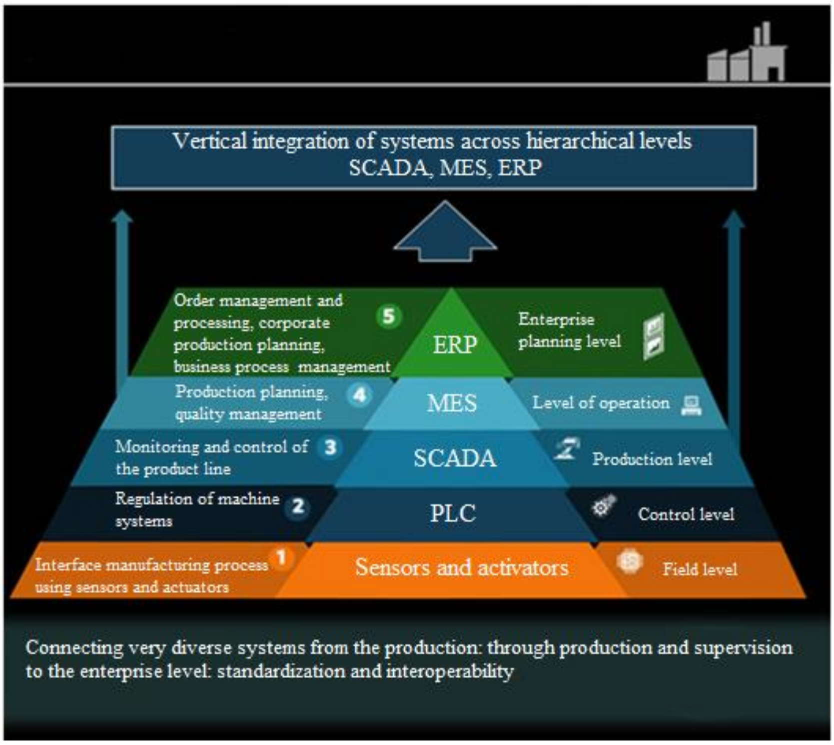

Fig. 4 Vertical integration

ERP systems

ERP, or Enterprise Resource Planning, was developed to coordinate the flow of data and smoothly integrate it across all functional areas within departments. As ERP systems mature, they have become an integral part of manufacturing, which has seen further leaps in production efficiency as well as enterprise-wide operations. They serve as master data and analytical systems for the entire enterprise.

Many ERP systems are beginning to build IoT connectivity for:

- Utilization of data to enable businesses to integrate their data into a single database. Thus, through ERP, the time for implementation, learning, and training curves, as well as process adjustments, are reduced.
- Data interpretation, as most ERP systems are modular and flexible, they can serve as infrastructure on which data from IoT devices can be applied. This is especially true for the Cloud.
- Security to ensure that companies using ERP systems have an established security system.

ERP systems provide higher productivity by consolidating business processes within a single database. They also improve reporting and increase the agility of enterprises across all functional areas. They enable sharper decision-making with better insights into the data they provide while their efforts are easier to manage.

Industry 4.0 naturally merges with ERP systems because it utilizes these elements within the company's infrastructure to reduce deployment time, training, data, and metrics alignment between departments to reduce the need for upfront programming. Or it increases across functional capabilities to higher levels of automation, autonomous decision-making, intuitive, and targeted machine learning.

MES systems

In Industry 4.0, MES (Manufacturing Execution Systems) plays a very crucial role. It is not enough to just record and process data in real time. Instead, MES systems are becoming the central information and data hub for manufacturing and for all other departments of the company. In addition to established ERP systems, MES systems form a bridge to increasingly complex manufacturing processes. With MES, manufacturing companies remain reactive while ensuring they stay competitive in the future.

MES is often integrated with ERP, supply chain management, product lifecycle management, and other key IT systems. The key benefits of using MES include:

- Increased customer satisfaction,
- Improved regulatory compliance,
- Better flexibility and time to market,
- Improved supply chain visibility,
- Reduction in manufacturing process time,
- Elimination of paperwork and manual data entry processes,
- Reduced lead time for orders,
- Lower labour costs,
- Reduced inventory,
- Increased machine utilization.

Figure 5 illustrates the functioning of the MES system.

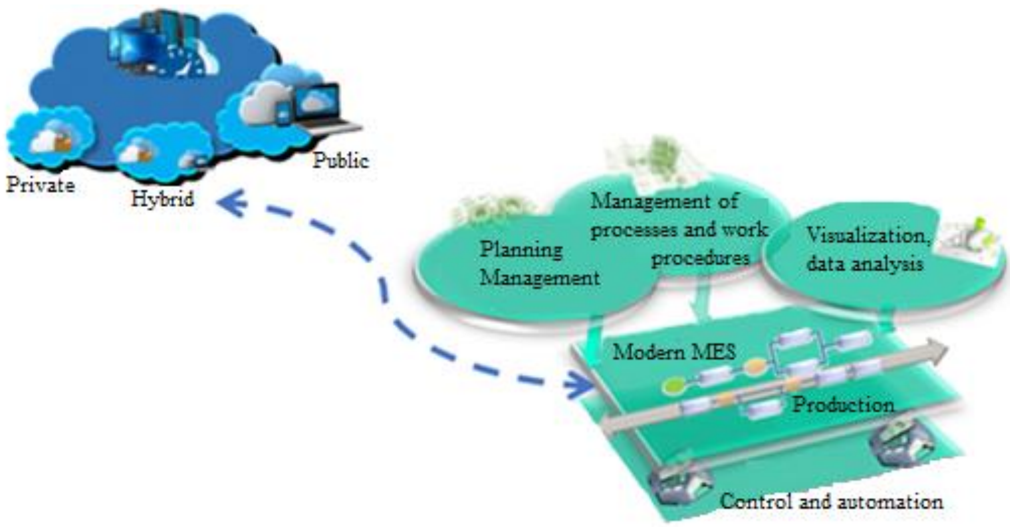

Fig. 5 Operation of the MES system

Conclusion

For users of smart systems, Industry 4.0 enables a multitude of applications that were minimal or not yet utilized due to manual labor. Industry 4.0 continues to change the way we communicate with the world around us, thus creating new challenges. It is important to recognize the essential facts of Industry 4.0 so that businesses and organizations can adopt new thinking, or an understanding of the power of interconnectivity enabled by new technologies.

Since its inception, the industrial revolution has undergone tremendous development. This evolution has brought about many positives as well as negatives. Today, Industry 4.0 opens doors everywhere in advanced factories because its features greatly facilitate production and increase the quality of production, which is in high demand in today's world.

Acknowledgement

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THE OVERALL EQUIPMENT AND ENERGY EFFICIENCY (OEEE) INDEX: A CRUCIAL STEP TOWARDS OPTIMISING ENERGY EFFICIENCY IN MANUFACTURING

Jozef GLOVA – Alena ANDREJOVSKÁ – Dominika FALISOVÁ

Abstract: The study works with the overall equipment and energy efficiency to enhance the traditional overall equipment effectiveness (OEE) metric commonly used in manufacturing. The study proposes the integration of energy efficiency into the existing OEE framework, introducing a new OEEE index. By considering and incorporating energy efficiency as a fourth component, this new metric offers a more comprehensive measure of production effectiveness. In an era where the Internet of Things (IoT) is revolutionizing manufacturing through smart technologies that enable real-time monitoring and optimization, the OEEE index can help manufacturers improve energy efficiency, reduce costs, and achieve sustainability targets, enhancing overall production performance and promoting financial prudence.
Keywords: Energy Optimisation; Internet of Things; Manufacturing; Overall Equipment Effectiveness - OEE; Overall Equipment and Energy Efficiency - EEE.

Introduction

The manufacturing sector, a vital economic driver in Europe, not only accounts for approximately 20% of all employment but also makes a substantial contribution to GDP. However, it has been under pressure due to globalisation, leading to offshoring and subsequent job losses in many European countries (Warwick, 2013). The sector also faces increasing energy costs and environmental regulations, necessitating more sustainable and efficient production processes (EC 2010). In response to these challenges, the integration of advanced Information and Communication Technologies (ICT) has become crucial. The Internet of Things (IoT), a transformative force within ICT, is reshaping the manufacturing sector. By enabling the interconnection of devices, systems, and services, IoT is creating smart manufacturing environments where data-driven decisions can optimise production, reduce energy consumption, and enhance equipment maintenance. The adoption of IoT platforms in manufacturing is pivotal for enabling these optimisations, and the development of business models around IoT capabilities is critical for achieving operational efficiency and sustainability. This article explores the IoT platform, considering OEE and proposed OEEE metrics, with a focus on their practical application within the manufacturing domain.

Literature Review

The concept of smart manufacturing, driven by IoT, has garnered significant attention in recent years. Smart manufacturing refers to the use of interconnected and intelligent systems that enable real-time monitoring, control, and optimisation of production processes (Kusiak, 2018). The integration of IoT into manufacturing is central to this paradigm shift, as it allows for the seamless flow of data between machines, sensors, and analytics platforms, facilitating predictive maintenance, energy management, and quality control (Lee, Bagheri, & Kao, 2015). The Overall Equipment Effectiveness (OEE) metric has traditionally been used to measure manufacturing equipment performance. OEE considers three key factors: availability, performance, and quality (Muchiri & Pintelon, 2008). However, with rising energy costs and increasing emphasis on sustainability, the need for an expanded metric—such as the Overall

Equipment and Energy Efficiency Index (OEEE) - has become apparent. OEEE not only includes the traditional aspects of OEE but also incorporates energy efficiency as a critical factor (Renna & Materi, 2020). This shift reflects the growing importance of energy management in manufacturing, driven by both economic and environmental imperatives.

Remote Service and Maintenance Management, another critical area of IoT application, enables manufacturers to remotely monitor and maintain equipment. This approach leverages IoT-enabled sensors and predictive analytics to detect potential failures before they occur, thereby reducing downtime and extending the lifespan of machinery (Kang et al., 2016). The benefits of such a model include lower maintenance costs, improved equipment reliability, and enhanced operational efficiency (Bokrantz et al., 2020). The growing body of literature on predictive maintenance underscores its importance in the context of Industry 4.0, where interconnected systems and real-time data are key drivers of productivity (Xu, Xu, & Li, 2018).
The concept of Connected Cars, while traditionally associated with the automotive industry, also has significant implications for manufacturing. In the context of manufacturing, Connected Cars can be seen as an extension of IoT, where vehicles are part of a larger network that includes production systems, supply chains, and customer service platforms (Gilchrist, 2016). This connectivity allows for better tracking of products throughout their lifecycle, from production to end-user delivery, enabling manufacturers to optimise logistics, improve product quality, and enhance customer satisfaction (Gupta, 2020).

Energy Consumption in the Automotive Industry

Production machinery, such as the equipment used in BIW lines, is designed on the basis of a certain production capacity, but in practice, the actual output often lags behind the theoretical capacity of the equipment. Efficiency improvements by increasing line production speed often have little or no effect, because more products are being rejected. Other reasons for sub-optimal production are the time it takes to change the production setup and production stops due to lack of robustness to small changes in the working condition.
The Overall Equipment Efficiency (OEE) index is a performance indicator that aggregates the different efficiency losses of a production line into a single index. It is used in most manufacturing companies as a key metric in TPM (Total Productive Maintenance) and LEAN Manufacturing to provide a consistent way of measuring the effectiveness of the production.
OEE breaks the performance of equipment into three separate and measurable components: Availability, Performance and Quality. The diagram in Figure 1 illustrates how the OEE is determined:

- Availability looks at the downtime loss, which is the time the production is stopped, compared to the planned production time. Availability is a function of equipment failures, material shortages, and changeover time.
- The Performance component is also a function of downtime, changeover time and speed loss, i.e., factors that result in the process operating at less than maximum speed due to machine wear, misfeeds, and operator inefficiency.
- The Quality component depends on the amount of produced items that fails to meet quality standards and thus will have to be either rejected or reworked.

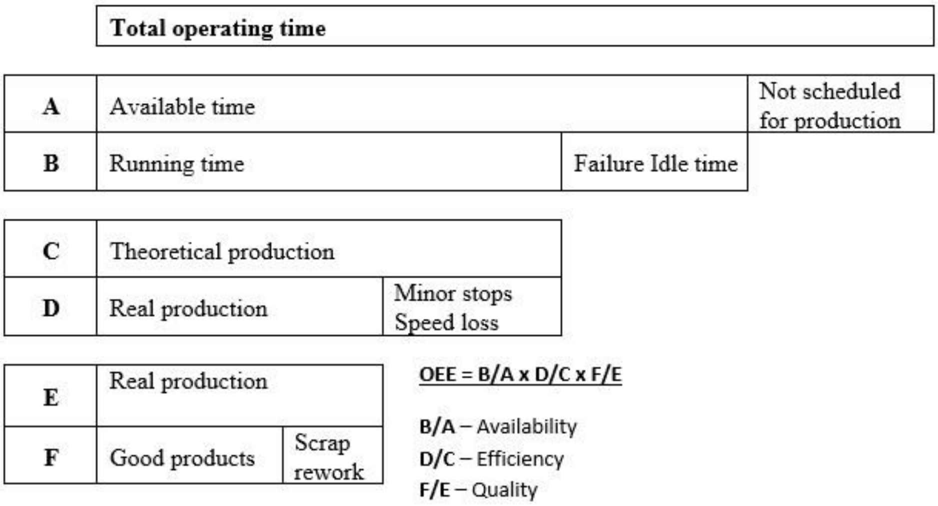

Fig. 1 Calculating OEE index. Source: own elaboration.

Energy optimisation – OEEE Overall Equipment and Energy Efficiency

Presently, pure economic efficiency metrics guide the optimisation of vehicle manufacturing. However, manufacturing is a major consumer of energy.

In order to support sustainability and facilitate interactions between actors in the supply chain, we have defined new, total optimisation metrics by adding energy to the OEE index, thus creating a new key index, the OEEE (Overall Equipment and Energy Efficiency), with the following four components.

The OEEE index breaks the total performance of equipment into four separate and measurable components: Availability, Performance, Quality and Energy Efficiency:

- Availability looks at the downtime loss, which is the time the production is stopped, compared to the planned production time. Availability is a function of equipment failures, material shortages, and changeover time
- The Performance component is also a function of downtime, changeover time and speed loss, i.e., factors that result in the process operating at less than maximum speed due to machine wear, misfeeds, and operator inefficiency
- The Quality component depends on the amount of produced items that fails to meet quality standards and thus will have to be either rejected or reworked
- The Energy component is a function of the actual energy efficiency of the real production process, i.e., how much energy is wasted compared to the most efficient process.

The value of the OEE is an indication of the size of the technical losses (machine malfunctioning and process) as a whole. The gap between the value of the OEE and 100% indicates the share of technical losses compared to the available Loading Time.

How the machine performs in comparison to an ideal machine, i.e., a machine always operating at maximum speed and with a quality rate of 100%, is determined by losses in availability, performance, and quality. The OEE indicates how effectively the machine is being used compared to the ideal machine (OEE = 100%). If the output of quality approved product lags far behind the capacity of the installed machinery the installed machine has a hidden production capacity, i.e., the capacity is not being used for the production of good products.

The OEE methodology provides simple and consolidated formulas to measure the effectiveness of the production system and is used to compare performance across the factory, highlighting

poor line performance. Companies can also use the information to make comparisons across assembly lines to select the line for a specific process. More importantly, companies can use the OEE tool to improve effectiveness or to quantify improvements made and hence, use it as an indicator of process improvement activities (Dal 2000).
When needs for improvements are identified, OEE is used for backtracking (to determine what loss reduces effectiveness) and to identify bottlenecks (such as the machine or line which is slower and less effective). A plant OEE rating can thus reflect improvement steps needed until the target goals and world class manufacturing status are achieved.
In practice, ambitious world-class goals for each component factor can be quite different: availability is typically 90%, performance 95%, and quality 99.9% yielding a world class OEE of 85%. However, most manufacturing industries experience OEE levels around 60% (ProLean 2014).

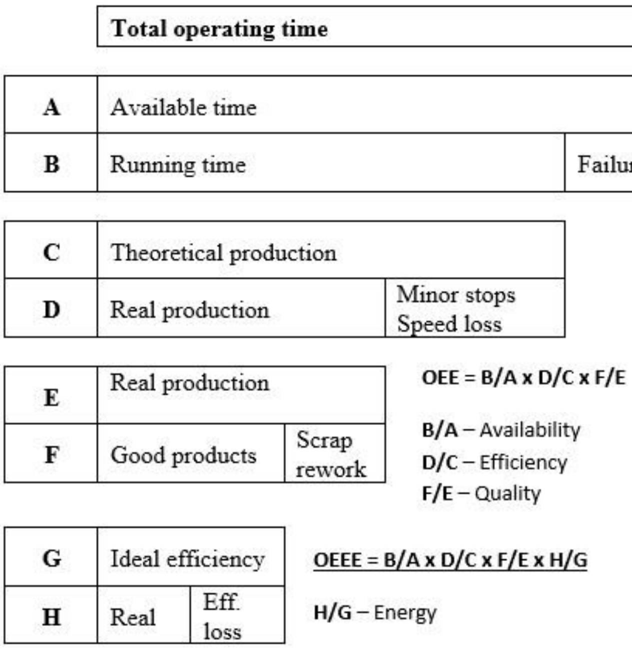

Fig. 2 Calculating OEEE index. Source: own elaboration.

The diagram in Figure 2 illustrates how the new OEEE is determined. The new component in the index (G and H), compared to the OEE index, measures the energy efficiency of the real production in relation to the most efficient or ideal production (100%). In other words, it measures how many cars can be produced for a given amount of energy: “For instance, we can produce 3,906 cars per 1 GWh of energy. However, our goal is to produce 4,300 cars using the same amount of energy”. Hence, in this case, H/G is equal to 93%.
One of the key problems in manufacturing processes is that energy consumption data is rarely available in a usable format for establishing goal-oriented and measurable improvement actions. The OEEE index provides simple and consolidated formulas to measure the energy efficiency of the production system. It can even be used to compare performance across the factory, highlighting poor line performance in terms of energy consumption. The OEEE index will thus allow the European industry to focus not only on production optimisation in economic and resource terms but also on energy optimisation.

Conclusion

The integration of Internet of Things (IoT) platforms into the manufacturing sector is emerging as a transformative force, addressing critical challenges and fostering significant advancements in operational efficiency and sustainability. The development and implementation of the OEEE model exemplify how traditional metrics, such as Overall Equipment Effectiveness (OEE), can be expanded to incorporate energy efficiency. This advancement reflects a growing recognition of the importance of energy management within manufacturing operations. By integrating energy efficiency into performance metrics, the OEEE model facilitates production optimisation and supports sustainability goals, helping manufacturers reduce energy consumption and associated costs.

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The Use of Artificial Intelligence for Predictive Maintenance in Engineering: Improving Efficiency and Reducing Costs in Modern Manufacturing Processes

Sylvia MAŤAŠOVÁ– Martin CHOVANEC

Abstract: Predictive maintenance, based on the analysis of historical and current data, is becoming an essential part of modern manufacturing processes. The use of technologies such as IoT and machine learning enables more accurate predictions of equipment condition and optimization of maintenance activities. The article analyzes technological methods for implementing predictive maintenance, illustrates successful applications in industry, and discusses the benefits and challenges companies face when adopting these innovations. Finally, it focuses on expected trends in AI and predictive maintenance that could influence the future of equipment management in manufacturing.
Keywords: Predictive maintenance, artificial intelligence, machine learning, Internet of Things (IoT), data analytics, manufacturing processes.

Introduction

In today's dynamic industrial environment, predictive maintenance plays a key role in optimizing processes and reducing costs. With the use of artificial intelligence technologies and data analytics, predictive maintenance is becoming a strategic tool that enables companies to predict failures and plan maintenance well in advance. This article addresses various aspects of predictive maintenance, including technological methods, successful case studies, benefits and challenges of implementation, as well as future trends in this field.

Introduction to Predictive Maintenance

Predictive maintenance is becoming a key element in modern manufacturing processes, aimed at optimizing machine operations and minimizing maintenance costs. This approach utilizes the analysis of historical and current data, allowing for the anticipation of potential failures and the planning of maintenance activities in advance. As Carvalho et al. [1] indicate, the use of machine learning in predictive maintenance provides significantly more accurate predictions of equipment status compared to traditional methods.

Currently, technologies such as IoT sensors and advanced analytical tools are essential for the effective implementation of predictive maintenance. According to Elkateb et al. [2], the integration of these technologies allows for the collection and processing of large amounts of data in real-time, which enhances prediction accuracy and contributes to improving overall manufacturing efficiency. In their study, a machine learning-based system achieved an accuracy of up to 92% in classifying various types of machine stoppages in the textile industry, enabling timely maintenance interventions and the prevention of failures.

By implementing predictive maintenance, companies not only avoid costly downtime but also extend the lifespan of their machines. In this way, predictive maintenance is becoming an essential part of the modern approach to managing manufacturing equipment.

Technologies and Methods of Predictive Maintenance

Technological advancements, such as IoT sensors and advanced analytical tools, are crucial for predictive maintenance, especially in the context of Industry 4.0. Soori et al. [3] emphasize that these technologies enable the collection and analysis of vast amounts of data, which are processed in real-time using machine learning. In addition to identifying potential failures, the system also allows for the optimization of operational conditions and the planning of maintenance interventions based on accurate predictions, leading to long-term operational efficiency.

One of the main approaches in predictive maintenance is the use of machine learning. According to Lei et al. [4], machine learning methods, such as classification algorithms and regression models, have proven effective in analyzing historical data and predicting machine performance. These approaches not only enhance the accuracy of predictions but also allow for the customization of models to meet the specific needs and conditions of a given manufacturing environment.

Predictive maintenance technologies are continuously evolving, with newer methods, such as artificial intelligence and big data analytics, offering even more sophisticated solutions. The combination of these technologies contributes to the creation of a robust system capable of effectively responding to changes in equipment conditions and preventing costly failures.

Case Studies from Practice

In recent years, predictive maintenance utilizing artificial intelligence has become the subject of many successful industrial applications. Various case studies demonstrate how companies have implemented AI technologies to improve the efficiency of their maintenance processes. According to Ucar et al. [5], the key components of AI in predictive maintenance are advanced analytical tools that enhance the accuracy of predictions and allow for autonomy and adaptability of systems in dynamic work environments. The authors emphasize the need for trustworthy systems and explore future trends, such as digital twins and blockchain technology, which can further improve the implementation of predictive maintenance.

One notable case involves an automotive manufacturer that implemented a machine learning-based predictive maintenance system to monitor the performance of its assembly lines. This system analyzed historical data and real-time sensor information, enabling predictions of when maintenance would be required, thereby preventing costly downtime (Ucar et al. [5]).

Another example comes from the electronics manufacturing sector, where a company used AI to monitor the condition of its equipment. By employing advanced analytical techniques, they were able to identify anomalies and optimize their maintenance schedule, leading to reduced breakdowns and increased productivity (Ucar et al. [5]).

These cases illustrate how the implementation of AI in predictive maintenance not only improves efficiency but also contributes to strategic decision-making in maintenance, which is essential for maintaining competitiveness in a dynamic industrial environment.

Benefits and Challenges of Implementation

The implementation of predictive maintenance using artificial intelligence offers numerous advantages but also faces several challenges. The main benefits include reduced maintenance costs and increased operational efficiency. According to Meddaoui et al. [6], companies that have implemented predictive maintenance have experienced significant improvements in production efficiency and a reduction in unplanned downtime. These improvements are reflected not only in cost savings but also in enhanced product and service quality.

Despite the advantages of AI in predictive maintenance, significant challenges remain in its implementation. Daoudi et al. [7] identify several key obstacles, including the scarcity of high-quality data, the necessity for specialized training for employees, and the substantial costs associated with acquiring the necessary technology. Furthermore, ensuring that AI systems effectively integrate with existing IT and manufacturing infrastructures poses additional technical difficulties. The transition from traditional maintenance strategies to a predictive approach within the Industry 4.0 framework requires careful consideration of these challenges to achieve successful implementation.

Balancing the benefits and challenges is crucial. Companies that choose to invest in predictive maintenance must carefully plan and assess their capabilities and needs to ensure successful implementation. Overcoming these challenges could be critical to achieving long-term benefits from predictive maintenance.

Future Trends and Innovations

The future of predictive maintenance is closely linked to the ongoing advancements in artificial intelligence technologies. Ucar et al. [5] indicate that AI is expected to play a more significant role in optimizing maintenance processes and predicting failures. The integration of machine learning with advanced analytical tools will facilitate even more precise modeling of machine behavior and performance forecasting.

The emergence of digital twin technology represents a significant advancement in predictive maintenance. According to Dhar et al. [8], the digital twin paradigm has garnered substantial interest from both academic and practitioner communities, indicating a growing recognition of its potential impact on industrial processes. This technology allows for real-time simulation and evaluation of processes, which can enhance predictive maintenance strategies by providing deeper insights into equipment performance and maintenance needs. By leveraging digital twins, businesses can optimize their maintenance schedules and respond proactively to potential failures.

Additionally, the evolution of IoT technology is anticipated to enhance connectivity and information sharing among various systems and devices. This will foster the creation of more robust ecosystems for predictive maintenance, where real-time data can be exchanged, enabling processes to be optimized based on current information (Ucar et al. [5]).

Given these trends, it is clear that predictive maintenance will become an even more integrated part of industrial operations. Companies that choose to invest in these innovations can expect significant improvements in efficiency and competitiveness.

Conclusion

Predictive maintenance represents a significant step forward in the management of manufacturing equipment. Its ability to reduce costs and prevent failures through accurate predictions makes it invaluable in modern manufacturing processes. Although there are challenges, such as the need for high-quality data and technology integration, the benefits that predictive maintenance offers are substantial. With ongoing technological innovations and the advancement of AI, it is clear that predictive maintenance will become an even more integrated part of industrial operations. Companies that choose to invest in these innovations can expect not only improvements in efficiency and cost savings but also long-term competitiveness in the market.

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DEA METHOD FOR ASSESSING THE EFFECTIVENESS OF MANUFACTURE

Gabriela IŽARÍKOVÁ – Anton HOVANA

Abstract: Monitoring efficiency is, in fact, a critical activity for any company, as it directly impacts competitiveness, profitability and long-term sustainability. In modern society there are several methods for companies to manage their efficiency: Data Envelopment Analysis (DEA), Key Performance Indicators (KPIs), Balanced Scorecard, Lean Manufacturing and Six Sigma, Financial Analysis, Benchmarking. This paper deals with the DEA method. This method belongs to the group of mathematical methods based on linear programming which has wide application.

Keywords: Data Envelopment Analysis, measuring of efficiency, DEA Model Utilization

Introduction

In order to maintain the prosperity and competitiveness of the company, it is important for the management and other interested parties to thoroughly know the economic and financial situation of their company. A prerequisite for a detailed knowledge of the financial situation is paying sufficient attention to the diagnosis of the financial health of the company and timely identification of potential problems threatening its activity. The need for early diagnosis of financial problems of companies has stimulated the creation of various diagnostic models based on financial indicators. The basic and most used methods of measuring the efficiency of production units can be divided into the following three groups: ratio indicators, parametric methods and non-parametric methods.

Data envelopment analysis (DEA) represents a non-parametric method of measuring the technical efficiency of homogeneous units, which belongs to the group of mathematical methods based on linear programming procedures. The origins of the basic idea of technical efficiency assessment date back to the second half of the 20th century, when Farrell (1957) proposed a procedure for analyzing the technical efficiency of units, which made it possible to accept multiple input variables and provided a generally applicable and comprehensive measure of efficiency, see [4]. The approach of Farrell was generalized a few years later for the case of multiple outputs and formulated as a linear programming problem by Charnes et al. in [1]. In order to enable the application of DEA in various areas, the term decision making unit (DMU) was introduced to name the evaluated units, which describes any entity (not only a company) in which the process of converting inputs into outputs takes place. The conceptual apparatus used in DEA is closely connected with the issue of production, as an empirical production function is constructed during the DEA solution. One of the important concepts in DEA is the efficiency frontier (PPF - Production Possibility Frontier), the creation of which is the basic principle of DEA. The PPF is formed by the set of those units that are considered the most efficient within the set of production possibilities (PPS - Production Possibility Set).

Basic methodology of DEA

DEA is a non-parametric method in operations research and economics for the estimation of production frontiers. DEA has wide applications in technical, health care, transportation,

education, agriculture, energy and environment, as well as banking and finance. Each entity (DMU - Decision Making Unit) is evaluated as part of a collection that utilizes similar inputs to produce similar outputs. These evaluations result in a performance score which values lie in a unit interval and represents the "degree of efficiency" obtained by the thus evaluated entity. In arriving at these scores, DEA also identifies the sources and amounts of inefficiency in each input and output for every DMU.
DEA is a performance measurement technique used to assess the relative efficiency of decision-making units (DMUs) such as businesses, public sector agencies, or even individuals. DEA is non-parametric and uses linear programming to evaluate the efficiency of multiple input-output decision-making units. Relative Efficiency: DEA measures the efficiency of each DMU relative to the "best practice" frontier formed by the most efficient DMUs. A DMU is considered efficient if it lies on the frontier and inefficient if it lies below it.
The basic goal of the DEA method is to compare the productivity of companies or organizational units, which we refer to as DMU. Each DMU uses a certain number of inputs for its activity, and the activity results in certain outputs. Inputs are those quantities that are consumed in the given activity, and outputs are the resulting products. In general we prefer smaller input values and larger output values. The effectiveness of the DMU in the simplest case (one input and one output) can be defined by the appropriate proportional indicator:

$$efficiency = \frac{output}{input}.$$

Efficiency is the success with which an organization uses its resources to produce outputs, that is the degree to which the observed use of resources to produce outputs of a given quality matches the optimal use of resources to produce outputs of a given quality. This can be assessed in terms of technical, allocative and dynamic efficiency.
If we evaluate more production units $U_1, U_2, \dots, U_p$ (p – numbers of units) a modification will occur. When monitoring the efficiency of these units, we consider r outputs and m inputs

- $X = \{x_{ik}, i = 1,2, \dots, m, k = 1,2, \dots, p\}$ denotes the matrix of inputs
- $Y = \{y_{jk}, j = 1,2, \dots, n, k = 1,2, \dots, p\}$ denotes the matrix of outputs.

A measure of effectiveness units of U_k can be expressed, in general, by

$$U_k = \frac{weighted\ sum\ of\ output}{weighted\ sum\ of\ input} = \frac{\sum_{j=1}^{n} u_{jk} y_{jk}}{\sum_{i=1}^{m} v_{ik} x_{ik}},$$

- $v = (v_{1k}, v_{2k}, \dots, v_{mk})$ is the input weighted vector,
- $u = (u_{1k}, u_{2k}, \dots, u_{nk})$ is the output weighted vector,

while $u_{ik}, v_{jk} \in (0, 1\rangle$. The efficiency value U_k is maximizing, because we want the most efficient units possible, and therefore the value equal to 1 for efficient units results. Inefficient units have an efficiency value less than 1.
DEA models are based on the fact that for a given problem there is a so-called set of admissible options consisting of all possible (admissible) combinations of inputs and outputs. The set of admissible possibilities is determined by the so-called effective boundary. Production units whose combination of inputs and outputs lie on the efficient frontier are efficient units because it is not assumed that there could realistically be a unit that achieves the same outputs with lower inputs, or higher outputs with lower inputs.

Basic DEA models
DEA models can be divided according to several aspects. Either according to the nature of the returns of scale, or according to the method of achieving efficiency in inefficient units. By

economic definition, returns to scale indicate the relationship between proportional change volume of inputs and changing the output. If we have a production function where $Q = f(K, L)$, where Q denotes the output level and K, L denote the values of individual inputs, and if we multiply both inputs by the same positive constant p, the following possibilities can occur:

- constant returns to scale – if both inputs increase by p percent and output also increases by p percent, $f(pK, pL) = pf(k, L) = pQ$,
- variable returns to scale – a change in inputs does not correspond to a constant change in output (it is either higher or lower)
    - ➢ increasing – if both inputs increase by p percent and output increases by more than p percent, $f(pK, pL) > pf(k, L) = pQ$,
    - ➢ decreasing - both inputs increase by p percent, but output increases by less than p percent, $f(pK, pL) < pf(k, L) = pQ$.

According to this division of returns to scale, DEA models are also divided into models with constant and variable returns to scale. For the second option of dividing models, we distinguish models:

- Input-Oriented – focuses on minimizing inputs while producing a given level of outputs.
- Output-Oriented – focuses on maximizing outputs with a given level of inputs.
- Additive models, Slack-based models – are models that combine both previous types.

The simplest and most frequently used models are two standard DEA models: the CCR DEA (Charnes–Cooper–Rhodes) model of constant returns to scale and the BCC DEA (Banker–Charnes–Cooper) model of variable returns of scale.

Key DEA Models:

- **CCR Model (Charnes, Cooper, and Rhodes)**
- can be input-oriented or output-oriented,
- Constant Returns to Scale (CRS), meaning that increasing inputs by a certain percentage will increase outputs by the same percentage,
    - used when all DMUs are operating at an optimal scale. It compares each DMU against a "virtual DMU" that is a combination of other units.
- **BCC Model (Banker, Charnes, and Cooper)**
- can be input-oriented or output-oriented,
- Variable Returns to Scale (VRS), allowing for increasing, decreasing, or constant returns to scale,
    - **u**seful when DMUs operate under different scales, providing a more flexible evaluation of efficiency.
- **Additive Model**
    - non-oriented (neither input nor output-oriented),
    - can be used with both CRS and VRS assumptions,
    - measures the efficiency by minimizing both inputs and outputs simultaneously.
- **Malmquist Productivity Index**
    - Output-oriented,
    - measures the change in productivity of DMUs over time, considering both technical efficiency change and technological change,
    - commonly used in longitudinal studies to assess productivity changes over multiple periods.
- **Super-Efficiency DEA**
    - can be either input or output-oriented,

- extends traditional DEA models by allowing a DMU to be compared against an efficiency score greater than 1,
- useful for ranking DMUs that are efficient, as traditional DEA only identifies them as efficient without ranking.

- **Network DEA**
  - can be input or output-oriented,
  - considers the internal structure of DMUs, where processes or stages within a DMU are modeled,
  - suitable for complex organizations where internal processes affect overall efficiency, such as supply chains or multi-stage production processes.
- **Stochastic DEA**
  - can be input or output-oriented,
  - incorporates random errors or statistical noise into the analysis,
  - used when data is subject to measurement errors or uncertainty, providing more robust efficiency assessments.
- **Two-Stage DEA**
  - Output-oriented,
  - assesses the efficiency of a DMU in two stages, typically first focusing on production efficiency and then on profitability or other measures,
  - useful in contexts where DMUs have a production stage followed by a service or distribution stage.

DEA Model Utilization - CCR model with one-input and one-output
The CCR model with one input and one output is a simplified version of DEA model. It helps to illustrate the core concepts of DEA without the complexity of multiple inputs and outputs. If we consider only one-input and one-output, the efficiency of the units is only a ratio between the size of outputs and inputs. Thus, efficiency tells us the amount of output per unit of input. It is obvious that for effective se will consider the unit whose output to the unit input will be maximum (we consider constant returns to scale).
Suppose we have five DMUs that each use a certain amount of input (like hours worked) to produce an output (like units produced), Tab.1.

Tab.1 The data for each manufacturing plant for CCR model with one-input and one-output

DMU		A DMU_1	B DMU_2	C DMU_3	D DMU_4	E DMU_5
Input	Hours worked (x)	4	5	10	8	8
Output	Units produced (y)	8	6	15	12	10
$efficiency = \frac{output}{input}$		2	1.2	1.5	1.5	1.25
Relative Rate of Effectiveness:		1	0,6	0.75	0.67	0.63

The ratio proportion y/x expresses the efficiency of the decision-making unit, the higher this value is, the better it is. All DMUs and the efficient frontier are marked in Fig. 1.

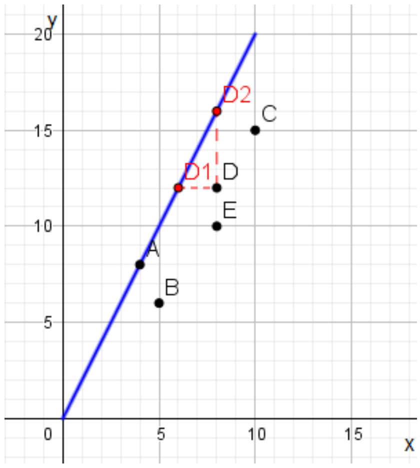

Fig.1 CCR efficient frontier for one input and one output.

It can be seen from Fig. 1 and the data that company A has the greatest efficiency and lies on the border of efficiency. From this we can conclude that company A is efficient and other companies are inefficient. This means that inefficient organizational units must improve, there are three ways to achieve this:

- by increasing the value of output while maintaining the current level of input,
- by reducing the value of the consumed input while maintaining the current level output,
- by combining both previous options.

We will analyze the inefficient organizational unit company D in more detail. Company D can become efficient if we reduce the values of individual inputs (in our case, hours worked) to 6 with unchanged outputs (units produced). Another possibility of moving the unit to the limit of efficiency is to increase the outputs from value 12 to value 16 with unchanged inputs. We can simply interpret it geometrically. It is sufficient if we project this unit onto the efficiency limit and thus obtain an efficient unit, which we will designate as D1 when reducing inputs while maintaining output values and D2 when increasing outputs while maintaining input values.
The efficiency value solved using DEA analysis is bounded from above by 1, therefore, in the case of one input and one output, we transform the shares of inputs and outputs into efficiency values, i.e. so that an efficient firm has an efficiency value of 1 (DMU_1) and inefficient values less than 1. We do this by setting the highest value to 1 and reducing the others proportionally (we divide individual efficiency values by the highest efficiency value). We call these values Relative **Rate of Effectiveness**, the last row of Tab.1.
The CCR model with one input and one output provides a straightforward way to measure and compare the efficiency of different units. It helps identify which units are making the best use of their resources and which ones have room for improvement. This model is particularly useful in simple scenarios where the relationship between input and output is direct and linear.

DEA Model Utilization - CCR model with two inputs and two outputs
Two-inputs, two-outputs DEA models are used to assess the efficiency of decision making units (DMUs) with two inputs and two outputs. CCR model assumes constant returns to scale (CRS) and aims to maximize efficiency based on the ratio of weighted outputs to weighted inputs. The goal is to find the optimal weights that maximize the efficiency of the DMU under evaluation, subject to the condition that no DMU can have an efficiency score greater than 1.
Formulation: for a DMU, lets denote:

- Inputs: x_1, x_2, weights for inputs v_1, v_2
- Outputs: y_1, y_2, weights for outputs u_1, u_2.

The efficiency score is calculated as: $c_q = \frac{u_1 y_1 + u_2 y_2}{v_1 x_1 + v_2 x_2} \rightarrow \quad max$.

Subject to: $\frac{u_1 y_1 + u_2 y_2}{v_1 x_1 + v_2 x_2} \leq 1$, for all $DMUs$, $u_1, u_2, v_1, v_2 \geq 0$.

We will modify the model to be linear so that we maximize the numerator of the objective function on the assumption that the denominator will be equal to 1.
Suppose we want to evaluate the efficiency of five factories (DMUs) that produce the same type of product. Each factory uses two inputs (labor and capital) to produce two outputs (units produced and sales revenue), Tab.2.

Tab.2 The data for each manufacturing plant for CCR model with two inputs and two outputs

DMU		DMU_1	DMU_2	DMU_3	DMU_4	DMU_5
Inputs	Number of workers (x_1)	6	2	8	4	5
	Capital invest. (in 1000€) (x_2)	4	3	1	3	2
Outputs	Units produced (y_1)	6	4	3	2	5
	Sales revenue (in 1000€) (y_2)	2	6	4	5	5

For the Input-Oriented CCR model, the efficiency score for a DMU (let's say DMU_1) is calculated as follows:

$$c_1 = 6u_{11} + 2u_{21} \rightarrow \quad max$$

$$6v_{11} + 4v_{21} = 1$$

$$-6v_{11} - 4v_{21} + 6u_{11} + 2u_{21} \leq 0$$

$$-2v_{11} - 3v_{21} + 4u_{11} + 6u_{21} \leq 0$$

$$-8v_{11} - 1v_{21} + 3u_{11} + 4u_{21} \leq 0$$

$$-4v_{11} - 3v_{21} + 2u_{11} + 5u_{21} \leq 0$$

$$-5v_{11} - 2v_{21} + 5u_{11} + 5u_{21} \leq 0$$

$$u_{11} \geq 0, \quad u_{21} \geq 0, \quad v_{11} \geq 0, \; v_{21} \geq 0.$$

Solution to the problem:

- $c_1 = 0.8049 < 1$,
- $u_{11} = 0.1341$, $u_{21} = 0$, $v_{11} = 0.0854$, $v_{21} = 0.1220$.

Score of 1 indicates the DMU is efficient and lies on the efficiency frontier. Score less than 1 indicates the DMU_1 is inefficient and can improve by either reducing inputs or increasing outputs, therefore, we will build the dual model. While the dual (CCR model) yields the same efficiency score as the primal model, it provides another way at looking at the same problem.

Mathematically the dual may look more complex, but is much faster to solve as it has only as many constraints as there are factors.

Dual model for a DMU_1 is calculated as follows:

$$z_1 \rightarrow \quad min$$

$$6z_1 - 6\lambda_{11} - 2\lambda_{21} - 8\lambda_{31} - 4\lambda_{41} - 5\lambda_{51} \geqq 0$$

$$4z_1 - 4\lambda_{11} - 3\lambda_{21} - 1\lambda_{31} - 3\lambda_{41} - 2\lambda_{51} \geqq 0$$

$$6z_1 - 6\lambda_{11} - 4\lambda_{21} - 3\lambda_{31} - 2\lambda_{41} - 5\lambda_{51} \geqq 0$$

$$2z_1 - 2\lambda_{11} - 6\lambda_{21} - 4\lambda_{31} - 5\lambda_{41} - 5\lambda_{51} \geqq 0$$

$$\lambda_{k1} \geq 0, \qquad k = 1,2 \ldots 5$$

Solving the Problem:

- $z_1 = 0.8049$,
- $\lambda_{11} = 0,\ \lambda_{21} = 0.5854,\ \lambda_{31} = 0,\ \lambda_{41,} = 0,\ \lambda_{51} = 0.7317$

For the entity DMU_1 the sample (peer) entities are DMU_2 and DMU_5, because the variables λ_{21} and λ_{51} are non-zero.

For the first input: $x'_{11} = \lambda_{21}\ x_{12} + \lambda_{51}\ x_{15} = 4.8293$.

For the second input: $x'_{21} = \lambda_{22}\ x_{22} + \lambda_{52}\ x_{25} = 3.2196.$

Tab.3 Results primal and dual of CCR models

	Primal model					Dual model				
	c_k	v_{1i}	v_{2i}	u_{1j}	u_{2j}	λ_{1k}	λ_{2k}	λ_{3k}	λ_{4k}	λ_{5k}
DMU_1	0.8049	0.0854	0.1220	0.1341	0	0	0.5854	0	0	0.7317
DMU_2	1	0.0455	0.3030	0	0.1667	0	1	0	0	0
DMU_3	1	0.0682	0.4545	0	0.2500	0	0	1	0	0
DMU_4	0.7639	0.0417	0.2778	0	0.1528	0	0.6944	0.2083	0	0
DMU_5	1	0.0545	0.3636	0	0.2000	0	0	0	0	1

Entity DMU_1 should reduce the first input, number of employees from 6 to 4.8, cancel one and partially reduce the salary of one. The second input, capital investment, should reduce, from

4 to 3.2 (in 1000€). For the entity DMU_4 the sample (peer) entities are DMU_2 and DMU_3, because the variables λ_{24} and λ_{34} are non-zero. For the first input: $x'_{14} = 3.0552$ and for the second input: $x'_{24} = 2.2915$. Entity DMU_4 should reduce the first input, number of employees from 4 to 3 and the second input, capital investment, should reduce, from 3 to 2.3 (in 1000€).

Conclusion

DEA is a robust tool for efficiency analysis, providing actionable insights for decision-makers. By identifying inefficiencies and setting benchmarks, DEA supports continuous improvement and strategic resource management, guiding organizations towards more effective and efficient operations. The CCR method is a fundamental and widely used model in DEA for evaluating the relative efficiency of decision-making units. It assumes Constant Returns to Scale, meaning that inputs and outputs are proportionally related. By focusing on either minimizing inputs or maximizing outputs, the model helps identify best practices and areas for improvement. Despite its limitations, the CCR model remains a foundational method in the field of efficiency analysis and performance measurement.

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THE IMPACTOF TRUST ON RISK REDUCTION IN RELATIONSHIPS WITH LOGISTICS SERVICE PROVIDERS

Andrzej KOZINA – Tomasz MAŁKUS

Abstract: In an effort to shorten the response time of enterprises to changing conditions in the environment, interest in cooperation with other entities on the market has increased. The intensification of cooperative connections and the variability of conditions in the environment make the issue of risk one of the basic problems of cooperation management. The importance of cooperation with suppliers of logistics service providers, as well as risks associated with such a cooperation, increase the interest in trusting that the partner will work towards cooperation, even if conditions in the environment change and the contract does not include detailed provisions regarding the response to such the change. The objective of the paper is to emphasize the specificity of risk and trust in cooperation with logistics service provider as well as to clarify how trust can reduce risk. The paper takes into account characteristics of risk in the relationship between parties in logistics cooperation, determinants of trust in such a relationship, as well as the role of trust in cooperation with service provider, varied in terms of the subject and scope of cooperation, the period of connection with the partner and the risk occurring in the relationship between cooperators.
Keywords: cooperation, cooperative relationship, risk, trust, risk reduction.

Introduction

In order to shorten the response time of enterprises to changing conditions in the environment, interest in cooperation with specialized service providers of on the market has increased. This cooperation applies in particular to outsourcing auxiliary activities and focusing on one's own core business as well as cooperation with subcontractors, enabling the company to periodically increase its own capabilities to deliver products to recipients. In conditions of intensification of cooperative connections and environmental variability, significant attention is paid to the risk of cooperation.

Considering the contemporary impact of logistics solutions on achieving competitive advantage in the market, the special role of long-term, uninterrupted cooperation with logistics service providers should be emphasized. This relates to developing the ability to reduce the risk of cooperation, which may concern the relationship between partners as well as the impact of external factors on cooperation. Reducing the risk of cooperation can be facilitated by development of trust, that partner will work towards cooperation, even if conditions in the environment change and the contract does not include detailed provisions regarding response to such the change. Due to the actions taken, trust between cooperating units may increase over time. In the event of unfavorable, opportunistic actions, trust can be reduced or even eliminated.

The objective of the paper is to address the specificity of risk and trust in cooperation with providers of specialized logistics services. The paper considers the role trust in the relationship between principal and logistics service provider diversified in terms of the scope of cooperation, the period of relationship with provider and the risk occurring in such relationships. As the introductory part, the characteristics of risk in relationship between cooperating parties, as well as the concept of trust within such a relationship and conditions for its formation are presented.

Methodological approach used in the article

As the main approach for the preparation of this article desk research is used. The application of such a concept is supported by the analysis of studies presented in literature in which generalizations, as well as detailed problems are presented, related to: conditions of cooperation with logistics service providers, risk associated with such type of cooperation, assumptions for the development of trust in cooperation, as well as determinants of the impact of trust on risk reduction in cooperation. Preparation of the content is also supported by authors' individual experience in the area of designing logistics outsourcing management systems, negotiating and preparing the terms of cooperation with logistics service providers as well as preparing and coordinating actions in response to disruptions in cooperation.

In the approach presented in this article, considerations regarding risk in cooperation with logistics service providers are focused primarily on factors occurring within the cooperation, related to shaping the relationship between the principal and the service provider. Due to difficulties related to identification of the entire scope of detailed risk factors occurring in the relationship between principal and service provider, attention has been focused primarily on factors related to theory of transaction costs [1,2], as well as to theory of incomplete contracts [3] and agency theory [4], developed on the basis of transaction cost theory. Such approach presented in this article is also supported by main conditions for shaping trust between partners, which result mostly from the assumptions of the relationship between cooperating parties and resulting transaction costs. It was assumed that a properly functioning relationship between the principal and the provider of logistics service is the basis for joint efforts in responding to external risk factors, including economic, legal, political, technical and technological factors, as well as factors occurring in market competition.

In accordance with the title of the article, the approach used primarily concerns the risk associated with the failure to perform or improper performance of tasks by the logistics service provider and the conditions for developing trust of the principal. This approach results from the specific role of logistics in achieving and maintaining competitive advantage by the principal on the market and the related impact of the logistics service provider's activities on the results of the principal's operations. The importance of logistics service providers in the activities of principals is currently reflected in the offers of service providers on the market. On the one hand, they concern single types of services (transport, storage, loading and unloading) sold individually, on the other hand, there are operators on the market offering comprehensive services to individual principals, as well as entire supply chains.

Literature review on concepts of risk and trust in cooperation with logistics service providers

When considering general conditions of cooperation with service provider, risk is usually perceived negatively, and the main manifestation of its occurrence is non-performance or unsatisfactory performance of tasks assigned to vendor [5-11]. It is worth emphasizing, that such risk is multidimensional. Different types of risk are characterized by different components, between which it is possible to specify factors that can be controlled and other, uncontrollable ones. Also, the way this risk is determined is largely subjective. Since in these circumstances the recognition of risk is primarily of a qualitative nature, and the measurement of cooperation risk is difficult, the following elements of the description and analysis of this risk can be proposed: specification of scenarios that may occur, list of risk factors influencing the occurrence of individual scenarios, the effects of each scenario on principal and service provider, identified ways of reacting to individual risk factors, designed response mechanisms to risk factors [7,11,12].

A holistic approach to the characteristics of risk in cooperation with logistics service provider requires the presentation of typology of such risk. Such issue, generally applied to cooperation with service provider is widely represented in the literature on outsourcing cooperation [8,11,13-15]. From the point of view of the subject discussed in this paper, an approach in which a general division was made according to the period of cooperation in which negative scenarios and the risk factors associated with them occur to be particularly useful. In this approach, following types of risk can be distinguished [8]:

- transaction risk – concerns arrangements for bilateral and unilateral contract termination, including provisions related to the resolution of disputes, mutual obligations, guarantees, transfer of equipment, payment terms, as well as penalties for non-performance or improper performance of the contract (taking into consideration also further consequences of principal related, for example, to incorrect service of principal customers by the service provider),
- operational risk – refers to the impact of cooperation on employees of principal, both those who remain in the company and others who may be transferred to vendor and become its employees, this type of risk is also related to established terms of provider's adaptation to requirements of principal, with the possibility of changes in the regulations of cooperation in the contract, as well as the behavior of the parties in the conditions of ongoing cooperation,
- strategic risk – concerns long-term effects of cooperation, such as: loss of control over relationships with customers of principal served by vendor, loss of principal’s know-how (e.g. in case of transferring activities requiring unique, principal’s knowledge to service provider), changes in quality of service provided, unfavorable for the principal, its suppliers and customers, served by vendor, changes in the characteristics of transport, insufficient adaptation to changing regulations law, e.g. regarding the flow of dangerous materials/goods).

The typology presented above may be supplemented by another proposal in which types of risk are distinguished considering the place of its occurrence in the relationship between vendor and principal [15]:

- risk related to behavior of principal – e. g. related to: loss of specific knowledge (principals often do not know the specificity of individual types of service contracted, nor do they know the architecture of their delivery), excessive dependence on service provider that appears during cooperation (in the conditions of servicing clients of principal by the contracted provider, this may result with taking over the relationship with the clients by provider),
- risk associated with behaviour and competence of service provider – concerns mainly: insufficient qualifications of its staff, non-compliance of activities and/or equipment of vendor with terms in contract, as well as the inability of such unit to adapt to new technologies, law regulations e.t.c.,
- general risk of cooperation – particularly regarding the irreversibility of decisions, hidden costs, unclear cost-benefit sharing, insufficient security of information used in cooperation (e.g. about clients and suppliers of principal), also possible employee objections.

As it results from presented typologies, among basic ways of dealing with risk in cooperation, which are available before the beginning of cooperation, appropriate regulations in the contract regarding the principles of cooperation between service provider and the principal are emphasized. Terms of contract specify in particular the features of relationship between cooperating parties, activities, infrastructure, as well as equipment, that should be used in adaptation to conditions of cooperation and during subsequent cooperation [5,16]. Among terms of contract, significant importance is also attached to obligations of parties regarding the implementation of specific activities that involve adapting to changes in external and internal conditions of cooperation. External conditions concern especially factors in the area of law, politics, economy, technology, as well as natural factors affecting activities of parties. Internal determinants of cooperation risk, especially related to the behavior of parties and the relationships between them, can be identified using the theory of transaction costs, especially the sources of these costs [1,2], theory of incomplete contracts [3] and agency theory [4], developed on the basis of transaction cost theory. Treating the sources of transaction costs as sources of risk in cooperation, it can be stated that particularly the specificity of assets may be treated as a factor causing risk, but its occurrence and use is closely related to the tendency to opportunism. The mentioned incompleteness of contracts occurs due to difficulties in obtaining comprehensive information regarding the activities of the parties, their current achievements and the conditions of future cooperation. Using the assumptions of agency theory, it should also be noted that in the agent-principal relationship, an individual who is an agent may act to achieve its own goals and aspirations, and a manifestation of its opportunism is limiting the principal's access to information about the current conditions and effects of the agent's actions. [3,7]. Limited access to information needed to make a decision causes the decision-maker to operate in conditions of bounded rationality.

When beginning consideration of trust concept in the area of cooperation with service provider it should be stated, that in general sense derived from sociology, trust can be treated as a bet on the uncertain future actions of other people [17]. This bet is made in the belief that other members of a given community are characterized by honest and cooperative behavior, based on shared norms [18]. Trust takes into account not only the mentioned belief, but also its expression by taking specific actions. The expectations of a trusting person lead to take certain actions, resulting in at least partially uncertain and uncontrollable consequences. Taking these actions means taking a bet. The fact of acting distinguishes trust from mere belief and from another type of attitude towards risk and uncertainty, which is hope, which means a passive, difficult to explain assumption that future events will occur as expected [17].

Based on the proposed approaches to trust in relationships between principals and service providers presented in the literature, several main features exposed in the definitions can be distinguished [19,20]:

- the belief of one party that its needs will be met in the future by actions taken by the other party,
- conviction that the other party will behave according to partner's needs, regardless of the ability to monitor the other party's actions,
- the belief of one party about the credibility, honesty, reliability and justice of the other party,
- opinion that the other party will avoid opportunistic attitudes and will not take unexpected actions that may result in negative consequences for the partner,
- the expectation of one party that the other party will act in the interest of the relationship.

In addition to the above-mentioned features, emphasis is also placed on the use of trust in joint review and supplementation of the provisions in contract by parties. Due to the regulations regarding the parties' mutual obligations and rights, the contract is usually incomplete and contains deficiencies related to the parties' limited access to information and uncertainty regarding future conditions in the cooperation environment.

When considering the importance and conditions for the development of trust in business activities, it is worth paying attention to several dimensions of the description and analysis of trust in cooperative relationships exposed in the literature. The contractual dimension concerns the belief that the partner will act for mutual benefit, even if some oral agreements are not reflected in the contract. The dimension of trust in competences is related to the expectation that the exchange partner will fulfill the undertaken obligations in accordance with requirements regarding the quality of performance. The third dimension concerns trust in the partner's goodwill [19,21]. The highlighted dimensions create a holistic picture of trust in cooperation with service provider. These can be treated as a reflection of the development of trust, along with the development of the scope of cooperation and the extension of its duration. Therefore, depending on the assumptions regarding objectives of cooperation and expected period of cooperation, the importance of individual dimensions of trust may change. In the conditions of cooperation with logistics service provider that performs short-term simple, supporting tasks for client (such as individual carriage on certain way or storage of specified goods according to generally known principles), the contractual aspect of trust seems to be most important. If principal trusts in competences of provider, it may reduce the need of supervision of such a provider. In conditions of more advanced cooperation, including joint investments for mutual benefits, in addition to the dimensions of trust mentioned so far, the issue of partner's goodwill, taking the initiative, and involvement in the development of cooperation, often going beyond the limits of the contract, will also play an important role.

Emphasizing the importance of trust in the development and maintenance of cooperation, it should be noted that trust is distinguished among the key factors influencing the stability of relationships between parties. Such a stability can be defined as a reflection of a constant, bilateral attitude favorable to the relationship, within the framework of cooperation over a set period of time [21]. It goes beyond a positive assessment of a cooperation partner, based on the current benefits and costs associated with the relationship. It involves considering the mentioned long-term orientation and the willingness of each party to make short-term sacrifices in order to realize long-term, mutual benefits from the relationship [22]. The basis for giving up short-term, one-sided benefits in favor of achieving common long-term effects is shaping the attitude of cooperating parties.

Considering relationship between parties the separate issue is the dependence on the other party. The feeling of dependence may be the result of entering into a relationship with such an entity due to the lack of other opportunities, caused by a small number of units (for example service providers) with specific resources, that are necessary for the principal to run own business and difficult to obtain by this entity [19,23]. A party (provider) with such unique resources has the ability to influence the other party (for example principal), and thus adversely affects the trust between people representing interests of parties. However, a service provider with unique resources can make these resources available without taking advantage of a privileged position vis-à-vis a dependent principal. In these conditions, over time, the involvement of principal may develop and the level of trust of this unit may increase [23].

The feeling of excessive dependence on the cooperating party may also be related to differences in the size of enterprises – parties to cooperation, different scale of operations and the resulting asymmetry of power. Trust develops more easily in conditions of equal influence of the parties on cooperation [24].

Results of research – the way trust can reduce risk of cooperation with logistics service provider

Regardless of how trust is understood in the relationship between parties to cooperation, in each case it is treated as a way to reduce risk, and to a greater extent, uncertainty related to the dependence of one's own activity and its results on the acquired partner. The decision-maker assumes, that acquired party to cooperation will behave in a way that will serve the needs of cooperation and its development, regardless of the possibility of monitoring his activities.

Development of trust in a cooperating party, at the beginning of cooperation is related to ensuring conditions for such a risk and uncertainty reduction mechanism to be introduced. Among these conditions, one can emphasize the importance of the credibility and reputation of the future partner, confirmed by recommendations, certificates and accreditation of independent entities. It is assumed, that the credibility of companies may be related to the culture developed by the company and to control systems promoting behavior demonstrating credibility, or that specific units representing the company may be individually credible [25]. Trust as a risk reduction mechanism replacing or supplementing the requirements of coordination and control of a partner's activities usually develops as more knowledge about the activities and achievements of such a partner is available. The organizational and procedural solutions, as well as adopted methods of behavior towards other enterprises, which are perceived as confirmation of credibility, accelerate the development of trust towards such an entity. They also limit the scope of regulations regarding the coordination and control of the contractor's activities. Reliability may be confirmed by certificates and accreditations issued by independent entities. The reputation mechanism is also related to credibility [26,27]. Information regarding reputation, if it is not possible to check it with a potential contractor, is obtained from other units that have previously cooperated with this contractor. Reputation is reflected in the recommendations issued by the above-mentioned entities and their current opinions.

In general context of the importance of trust in reducing the risk of cooperation, both sociological and economic approaches seem to be useful. From a sociological perspective, it is emphasized that trust reduces the complexity and uncertainty of the behavior of other people with whom the party initiating cooperation enters the relationships. Obtaining the expected results of cooperation in conditions of difficulty in predicting them and frequent randomness requires collecting numerous and expensive information. By accepting legal regulations and social norms as an external risk reduction mechanism, trust enabling the limitation of costly tests, replacing the possession of complete information, is treated as an internal mechanism. If the expected effects of cooperation are achieved, trust is treated as rational. It can be argued that in conditions without the complexity and uncertainty of human behavior, there would be no ethical and sociological basis for creating community and trust. From an economic perspective, it can be said that in the absence of transaction costs, there would be no justification for the operation of a company whose distinguishing feature is the replacement of the price mechanism with a hierarchy [28,29]. Hierarchical relationships, reflected in the form of organizational structure, can also be treated as a mechanism for reducing the risk associated with the implementation of specific activities needed in the company's operations.

By determining the role of trust in reducing the risk of cooperation, an attempt can be made to assign levels of trust to different types of relationships in cooperation, determining the level of risk accompanying each relationship and the importance of trust in reducing it. Such a summary is presented in Table 1.

It is important to add, that sometimes parties to contract take actions that are inconsistent with the trustor's expectations, trust may turn out to be irrational and distrust can be considered as a rational tool to avoid risky situations. In each case, the social system is, to a greater or lesser extent, equipped with external mechanisms in the form of legal and social sanctions in order to enforce general principles according to which expectations towards other people are made in accordance with the law [29].

Considering the impact of trust on risk reduction presented so far, but also the role that distrust may play in reducing the risk and uncertainty associated with starting cooperation, it is worth paying attention to the situation in which trust may be limited or even lost by one of the parties to cooperation. The risk reduction mechanism of trust is ineffective in these conditions. An entity that has lost trust due to the actions taken by the cooperating party may, in extreme cases, strive to terminate the cooperation.

Tab. 1. Trust and risk in different cooperation relationships

Form of trust	Relationship features	Sources of transaction costs and risk
Weak form of trust, based mainly on calculation	• low cost of determining the value of service (transport, packaging) – items of transactions, • costs of interrupting the relationship and changing provider (i.e. carrier, loading/unloading operator) are low, • similar bargaining power of parties (low probability of excessive dependence on other party to cooperation), • the ease of ensuring expected results by increasing costs of supply quality control, • little attention on credibility of parties, • cooperation is not treated by principal as a source of competitive advantage.	• free, wide access of parties to information, influencing cooperation, • no need to invest in specific assets (tools or infrastructure) to cooperate, • low profitability of opportunistic attitudes of parties, • the level of risk of cooperation with the supplier is low, regarding mostly to transactional and, to a small extent, operational dimensions, • the importance of trust to reduce the risk of cooperation is small, related mainly to its contractual and competence dimensions.
Strengthened form of trust, based primarily on knowledge about the partner	• higher susceptibility of the transaction to abuse and interruption of the transaction, • the need to use behavioral monitoring tools to protect partners, • relationship supervision tools make it possible to impose various types of costs on the party to cooperation, that shows an opportunistic attitude, • the existence of relationships with this form of trust may be a source of competitive advantage, but only in conditions of diversification of skills and supervisory abilities.	• limitations in access to information, high costs of obtaining it, • increased need to invest in specific equipment/infrastructure elements to carry out transactions, • the costs of opportunistic behavior may turn out to be high (due to the tools used to influence behavior), • greater importance of the incompleteness of contract, • increasing the role of trust in reducing cooperation risk, especially transaction and operational risk, • the importance of trust, especially in the contractual and competence dimensions, the need to trust the partner's goodwill appears.
Strong form of trust based on identification with the partner	• trust results from the principles of cooperation applied, • lack of emphasis on the use of supervision mechanisms, • parties strive to maintain credibility, regardless of whether transaction carried out within the relationship is susceptible to disruptions- the parties rely on each other, • high level of integration of the parties' activities (they act together as one enterprise), • high level of involvement of the parties, • such cooperation may be the basis for developing a competitive advantage.	• providing each other with all information necessary to establish and implement the terms of cooperation, • agreeing on the terms of division of rights and obligations related to mutual involvement in the creation and development of infrastructure and equipment for cooperation (high specificity of assets in cooperation), • parties avoid opportunistic behavior, • intentional, high level of contract incompleteness, • a strong impact of trust on reduction of cooperation risk, applied especially to operational and strategic risk, and to a small extent also to transaction risk, • the significant importance of trust in the contractual, competence and good will of the partner.

Source: own elaboration based on: [19,21,25,30,31].

However, this is possible primarily in conditions of low specificity of assets used in cooperation, the often-associated lack of integration of the activities of cooperators and a small impact of the change of partner on the results of the activities of the party terminating the cooperation. In the conditions of existing partnership cooperation based on high specificity of infrastructure and equipment used in joint activities, but also in conditions of high level of dependence on the other party, related to the difficulty of obtaining the required resources from another supplier, a quick termination of cooperation may turn out to be too expensive or even impossible. In conditions of a high level of integration of the activities of the parties to cooperation, it is important to quickly initiate and take corrective actions, often related to the solutions adopted in the contract, enabling renegotiation of the terms of the contract, decision by one of the parties to increase the level of supervision of cooperation, as well as temporary or permanent limitation the partner's influence on the activities of the entity that has lost trust in him. It should also be noted that rebuilding trust is usually a process that takes longer than the initial development of trust when starting the relationship.
So far, the relationship between trust and risk has been presented in different stages of cooperation development. Based on the review of a wide range of theoretical studies and empirical research results, it is possible to graphically present the relationship between different stages of cooperation development and trust between partners. In this approach, both the issue of trust development and its reduction are emphasized. For better illustration, symbols used in the decision tree were used, in which squares indicate decision-making and circles indicate states of nature, reflecting the occurrence of different conditions. This is presented in Figure 1. It should be emphasized that in the situation presented in Figure 1, each decision to continue cooperation under the conditions of a prior statement that the provider does not meet expectations included in SLA (Service Level Agreement) should result in an increase in the level of detail of regulations in the contract (of which SLA is a part).
To sum up, it is worth comparing the two key categories (phenomena) related to the cooperation of partners, considered in the paper, i.e. trust and risk. To make such a comparison, two important dimensions characterizing these categories should be taken into account. First of all, it is worth specifying the attitudes (biases, views, imaginations, etc.) of the cooperating partners in relation to both trust and risk. Secondly, it is necessary to characterize the activities (actions, performance, undertakings etc.) taken by partners in the presence of trust or risk in cooperation. Those both dimensions can be described by some features reflecting and concretizing them (see Table 2 and Table 3).

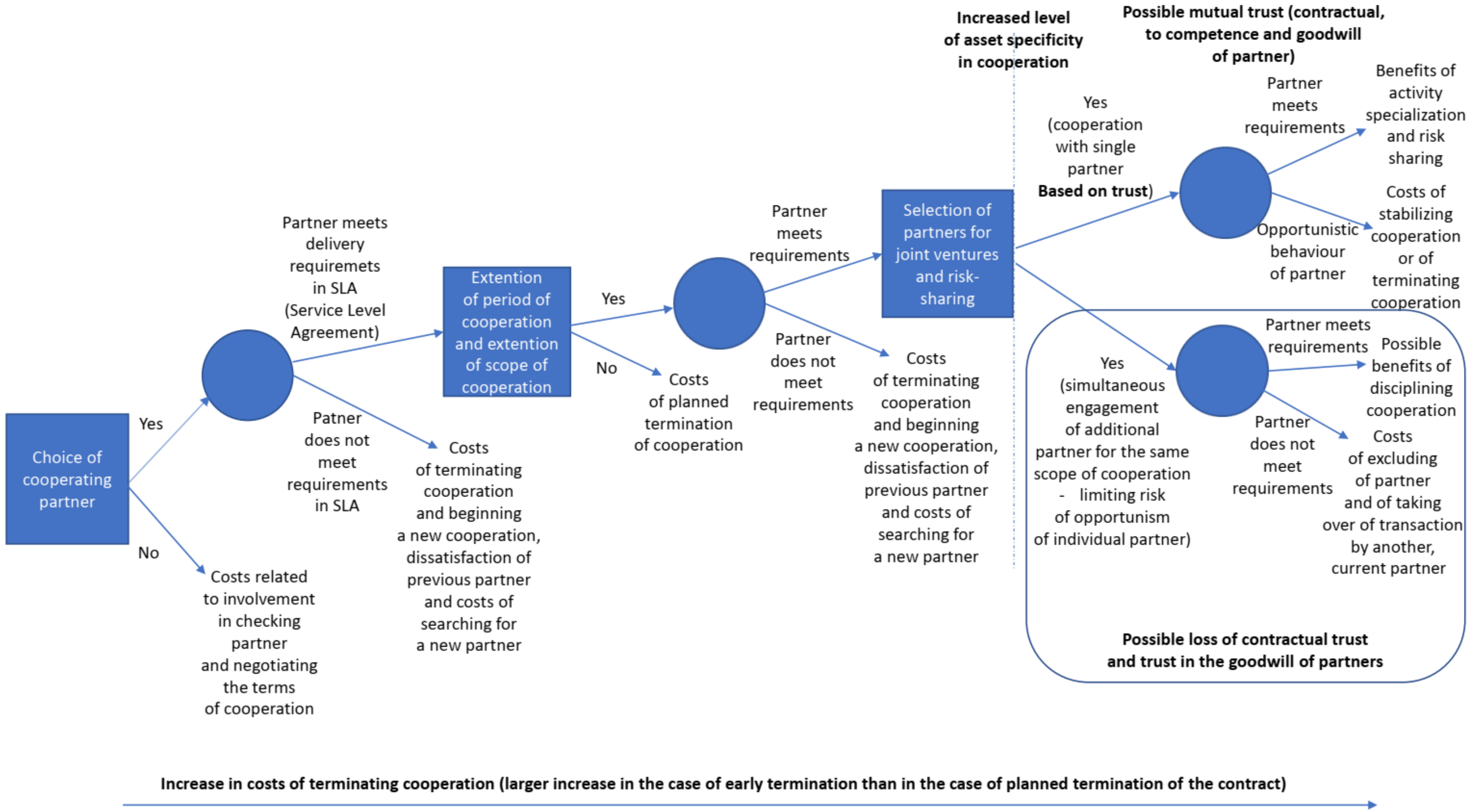

Fig. 1 Development of trust in cooperation with specialized service providers
Source: own elaboration based on: [19,21].

Tab. 2 Attitudes reflected by trust and risk in cooperation

Features	Trust	Risk
Dominant feelings	Contentment, peace, commitment, confidence, comfort, even enthusiasm.	Fear, frustration, discomfort, irritation, discouragement, doubt.
Way of treating cooperation	Desirable as an opportunity to achieve a higher level of effectiveness than with individual action	The focus on risk and counteracting it distorts the image and scope of cooperation.
Idea of partners	Generally positive approach to each other, despite undoubted and understandable differences regarding the goals, values, needs, expectations, etc. of the partners. Ability to discuss and reduce differences.	Risk aversion translates into aversion to the partners. The tendency to take risk stimulates competition within cooperation. Indifference to risk results in a neutral or negative attitude towards the partners.
Perception of cooperation	Treating everyone with understanding as equal partners and coordinated action to achieve common benefits as a kind of synergy effect.	Treating partners with reserve, distrust, emphasizing differences, synergy effect difficult to obtain by separate actions
Focus	Integration and cooperation, not competition, and constant expansion of the scope and enrichment of forms of cooperation.	Disintegration and competition, limited cooperation, selected, random and disturbed by the perception of risk.
Values	Shaping an appropriate level of both mutual trust itself and other co-created values, i.e. reliability, credibility, solidity, etc.	Lack of trust caused by risk, limitations and difficulties in agreeing and shaping common values.
Image creation	Creating and maintaining a positive image of trustworthy mutual partnership.	Overlooking or not noticing image issues, the image is not identified or blurred
Motivation	A strong internal belief in taking the right actions at the right time and place.	A strong sense of powerlessness in the face of threats that are difficult to control.

Source: own elaboration.

Tab. 3 Activities affected by trust and risk in cooperation

Features	Trust	Risk
Process of cooperation	Well-structured, harmonious, smooth, efficiently coordinated and focused on a high level of efficiency, free of unnecessary activities.	Limited, disrupted, focused on risk management rather than cooperation, undesirable, uncoordinated and even accidental actions.
Conflicts resolution	Searching for consensus or compromise when resolving any type of dispute. Comprehensive analysis of nature, causes and effects of conflicts.	Failure to notice or ignore conflicts, high probability of unnecessary conflicts occurring. Poor diagnosis of nature, causes and results of conflicts.
Seeking agreemnt	Striving for full compliance in important matters, i.e. ensuring the desired level of fulfillment of all needs and expectations, efficient management of available resources and implementation of all activities aimed at increasing efficiency.	Objective difficulties in reaching an agreement on important matters, inability to achieve the desired level of meeting needs and expectations, efficient resource management and achieving the expected level of effectiveness.
Mutual dependence	Shaping and maintaining strong and long-lasting positive relationships between cooperation participants, based on shared values.	Neglecting the issue of managing relationships between cooperation participants, they tend to be random and uncontrolled.
Decision making	Joint making of key decisions that determine the achievement of the goals and interests of all participants. Mutual support in ongoing analysis and solving emerging problems. Creativity in finding solutions.	Decisions made by partners independently of each other, lack of mutual support in problems solving, inability to predict the consequences of decisions. Preferring routine in search for solutions.
Communication	Efficient communication guaranteeing the usefulness of the generated and	Selective and impoverished communication limiting the usefulness of the generated and

	transmitted information and the appropriate level of satisfaction of information needs.	transmitted information and obtaining proper satisfaction of information needs.
Exchange	Fully equivalent exchange of tangible and intangible values, based on a solid understanding of the partners' needs and expectations.	Limited, often non-equivalent exchange of tangible and intangible values, of a selective nature, without taking into account the needs and expectations of partners.
Value creation	Co-creation of tangible and intangible values, focused on both achieving current goals and shaping long-term relationships. eliminating activities that reduce efficiency and do not add value	Attempts to appropriate tangible and intangible values, mainly oriented towards achieving current goals, especially material ones. Ignoring activities that reduce efficiency and do not add value

Source: own elaboration.

Conclusions

The concept presented in this chapter was developed primarily on the basis of theoretical considerations presented in the literature and the presented results of empirical research regarding the concept of trust in cooperation and its impact on the reduction of risk and uncertainty in relations between cooperating parties. The authors' own reflections and practical experiences were also used.

The issues included were treated as key to providing a comprehensive picture of the impact of trust on the risk of cooperation, but emphasizing the point of view of principal. In the practice of enterprises, the diversity of problems related to the development of trust and its impact on reducing the risk of cooperation may be much greater. This may be related to a much greater diversity of forms of cooperation compared to those presented in Table 1. Also, the principles of cooperation, mutual obligations and rights taken in response to risk may change, depending on the changing risk factors. It is also worth paying attention to the varied organizational tendency to trust, which is influenced by the attitudes of individual members of the organization responsible for the results of future cooperation. Due to the fact, that the existence of trust between representatives of cooperating parties depends also on the individual characteristics of each person, there may be a significant difficulty in achieving a state in which the joint implementation of agreed activities will be favored by the existence of trust in the affective dimension between cooperators coming from different enterprises. A significant impediment to cooperation may also be the loss of trust, especially as a result of the actions of a partner who, although did not intend to act to the detriment of the other party, but the effects of these actions were interpreted in such a way. It may be impossible to rebuild previous trust. The consequences concern a reduction of the reliance on partner, and in the absence of such possibilities, striving to introduce changes in the contract that will protect the injured party to a greater extent. Typically, these changes consist of disciplining a party to a contract that has behaved in a manner inconsistent with the expectations reflected in the contract. The types and scope of disciplinary actions introduced to the contract depend on the nature of the undesirable behavior of the partner and the related remaining trust, e.g. in his competence.

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CHANGES IN THE LABOUR MARKET CAUSED BY THE APPLICATION OF INDUSTRY x.0 PRINCIPLES

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Abstract: Industry x.0, described as the next phase of the industrial revolution, is bringing fundamental changes to the labour market. This publication analyses the changes, examining the impact of advanced technologies on workplaces and the competencies required of employees. The publication presents the results of available surveys and studies which show that traditional job tasks are gradually being replaced by automation, leading to job losses in some sectors, while new job opportunities requiring higher qualifications and technical skills are emerging in others. This implies the need to adapt education systems to these changes, as well as the roles of governments and enterprises in supporting the retraining of employees. While Industry x.0 brings challenges, it also opens the door to innovation and new opportunities in the labour market.

Keywords: labour market change, Industry x.0, future work force requirements, competencies

Introduction

The labour market has been going through a turbulent period in the last few years. Until recently, the labour market was recovering from the consequences of the Covid-19 pandemic, which saw radical changes in the way work was carried out in a number of sectors. A few months later, the labour market was affected by the conflict in Ukraine in the form of rising inflation. As a result of the rapid changes in the labour market, a certain part of the workforce is becoming vulnerable because it is unable to adapt its skills to the changing situation. This group of people needs to be given early support, otherwise they risk losing their jobs. Artificial intelligence will have the greatest impact on the labour market in the near future.

Changes in the labour market

Changes in the labour market are a continual process that has taken place in the past, in the present and will continue to evolve in the future. A characteristic feature of the current situation, and in the horizon to 2030, is the speed at which the changes in the labour market are taking place, how much pressure is being put on the structure of employment, and how radically the requirements for competences, knowledge and skills of human capital are changing. The rise of technological innovation, automation, digitisation and robotisation, as well as demographic developments, require a rapid response from both the state and sectors to ensure the quality and sufficiency of human resources to remain competitive. Enterprises, in order to maintain their own productivity, are also being forced into higher levels of automation by low birth rates, causing a shortage of working-age labour. [1]

Changes caused by the implementation and application of Industry 4.0 principles and techniques

Technological progress and globalisation bring new opportunities and future challenges in the labour market. Today, the labour market is most affected by digitalisation and automation, changing competency requirements for employees and the creation of new professions. This trend is causing many traditional occupations to disappear, requiring employees to be adaptable, flexible and willing to learn continuously. Flexibility, the ability to learn and to take on new

skills are therefore becoming essential for individuals who want to be successful in the labour market.
Technological progress also brings challenges in the form of retraining employees and updating the skills needed to do the job properly. It is important for enterprises and government to provide support for education and training. Investment in education and skills development is necessary to maintain the competitiveness of the national economy. If the right measures and policies are put in place to support the workforce, technological progress will lead to the creation of higher quality and more productive jobs. [2]
Progress in technology will not cause more jobs to disappear, but it will significantly change the skills requirements of the workforce. The faster the development and innovation of technology progresses, the harder it will be for the workforce to adapt to change. Thanks to the experience of previous revolutions, it is safe to say that the structural change in the workforce brought about by Industry 4.0 is inevitable. However, every previous change brought about by industrial revolutions has resulted in efficiency and productivity gains. [1]

Changes caused by the Covid-19 pandemic

The Covid-19 pandemic has significantly affected the labour market and highlighted the need for changes in employee competencies. Restrictions on movement and health measures introduced worldwide have caused a sudden change in working conditions, with many companies having to switch to remote working. The sudden shift to remote working and the increased use of digital technologies have forced employees to adapt and develop their digital skills. This transition has exposed technology gaps and the need for digital literacy across different sectors.
The most significant changes on the labour market include:

1. **the rise of remote working** – the pandemic has accelerated the adoption of remote working, with many enterprises discovering that they can operate efficiently without having employees physically present in the office;
2. **a reduction in employment in some sectors** – sectors such as tourism, hospitality and retail have been particularly affected, leading to massive layoffs and reduced job opportunities (WEF);
3. **increased demand in other sectors** – sectors such as healthcare, logistics, and information technology have experienced increased demand for labour;
4. **flexibility and instability in employment** – employers have started to use flexible contracts and temporary employment, which has brought more instability for employees.

All these changes have also played an important role in the need to change the competences of the employees, which was necessary and had to be carried out very intensively. In particular, the following areas were affected by the changes in competences: **digital literacy, adaptability and flexibility, communication skills, autonomy and self-management, emotional intelligence and stress management, technical support or security and data protection.**
The global pandemic has accelerated the implementation of Industry 4.0 tools and techniques. Some authors consider it as a kind of catalyst that has helped to accelerate the implementation of tools and techniques in industrial practice that were previously not considered necessary. However, it has fundamentally influenced the necessary competences of employees, not only in the field of digital literacy, but also in other areas, but also other technical skills, analytical skills, collaborative skills, problem thinking and innovation.
The Covid-19 pandemic has accelerated the adoption of Industry 4.0 tools and techniques, increasing the need for new skills and competencies among employees. Digital literacy, technical and analytical skills, the ability to collaborate and solve problems, as well as a constant willingness to learn, have become essential for the successful integration of these

technologies into industrial processes. Enterprises that have been able to react quickly, adapt their workforce and invest in the necessary training have gained a competitive advantage and increased their resilience to future challenges. Employees have had to adapt quickly to new challenges in order to remain productive and competitive.

Current and future needs in the labour market

Education and qualification are essential for a successful career. It is not just about acquiring theoretical knowledge, but first and foremost about developing practical skills and adaptability, which are essential in today's competitive working climate. Enterprises are looking for candidates who are able to learn quickly, adapt to change and apply their knowledge effectively in practice. The dynamics of the labour market require flexibility and the continuous acquisition of new skills that reflect the latest trends and developments in technology. [9]

he Future of Jobs by WEF 2023 report highlights the impact of new technologies on the labour market and the trends, opportunities and challenges facing individuals and enterprises. The report mainly covers topics such as the implementation of automation and artificial intelligence, the skills needed for future jobs, and the potential impact on employment and workforce dynamics. In particular, the report highlights the need to retrain and upskill employees to adapt to the changing labour market. [5, 10]

In 2023, Slovakia experienced record inflation and low unemployment, which were two key aspects of wage increases in all sectors and regions. The biggest wage changes were felt by employees in manufacturing, construction and logistics. In contrast, employees in IT, banking and financial services experienced minimal growth. However, there was still a shortage of employees, especially in manufacturing and logistics, accountants, sales representatives and managers. There was also an increased demand for candidates who speak more than one foreign language, especially a combination of English and German.

As a result of the shortage of people in the labour market, employee turnover also increased, as there were more situations where employees were willing to change jobs if they received a more interesting offer. This brought new challenges for employers, who had to learn to respond more flexibly to changes in the labour market and find ways to retain employees in their businesses [4].

Trexima's study identified ten core skills that are currently considered the most important for employability, including:

- analytical thinking,
- creative thinking,
- resilience,
- flexibility and agility,
- motivation and self-awareness,
- curiosity and life-long learning,
- technological literacy,
- reliability and attention to detail,
- empathy and active listening,
- leadership and social influence, and
- quality control. [7]

Changes in the structure of jobs in the context of Industry x.0

The structural changes currently taking place in the labour market are increasing the demand for skilled labour. The implementation of Industry x.0 principles is fundamentally changing the structure of jobs across different sectors. Automation and robotics are leading to the disappearance of traditional manual jobs, while at the same time creating new job opportunities for experts in the maintenance and programming of automated systems. Technologies such as IoT and AI are increasing the demand for data analysts and cybersecurity specialists. However, a sufficient supply of skilled employees is not immediately available. It is therefore more than necessary to know what competencies will be required of these people in 10 years' time, what

type of education will be suitable for them and what demands will be made of them by employers. Augmented and virtual reality are changing the ways in which employees are educated and prepared for their roles, opening up new positions in the development and implementation of these technologies in practice. [3]
With the advent of automation of production, changes in the nature of work activities and in the structure of jobs are also expected. The shortage of qualified graduates is currently slowing down the development of Industry x.0 in Slovakia. It is necessary for the state to support enterprises in creating new jobs and retraining and developing the skills of the workforce. [11]

Identification of future labour market needs and competences

In the coming years, the ageing population will affect the labour market in Slovakia. Already in 2030 there will be a shortage of 50 000 people. Adapting conditions to older people will be the key to success, so it will be important to keep them in the labour market for as long as possible. Younger workers will be in short supply. The need for new workers will increase in the IT sector, where the supply of jobs will be 50% higher than today. There will be a multidisciplinary fusion of specialists with IT, e.g. accountants will have to link their work with digital technologies. Artificial intelligence will also play a role in several areas.
Studies show that the group at risk is young men who are still boys in primary schools today, and therefore their knowledge and skills need to be directed towards automation. The risk is a 'brain drain', which is linked to the attractiveness of education and the labour market itself. It will be important to develop scientific research cooperation with universities, internships and practical activities in Slovakia.
Based on the study "Skills for the future of a competitive labour market" by Trexima, Dítětová presented the results and forecasts for the development of labour market needs. Environmental literacy already seems to be desirable today, enterprises lack professionals who understand environmental issues or the circular economy and are able to develop the activities necessary in this direction. The need for foreign language skills is also highlighted, as there is still a problem with the use of language in practice, where many people have a certificate but do not know how to apply the knowledge. The skills that everyone should have are mainly digital skills. Digital literacy, understanding of technology and proficiency in working with software will be expected of employees. The European Commission annually monitors the level of development of digital competitiveness, and Slovakia ranks last. Among digital skills, working with information - the ability to search for relevant information and cybersecurity awareness - will be particularly important. One of the big areas within the digital economy will be working with data.
Nowadays, the push is for technological skills. By 2030, mastery of technology is to be a complete essential, just as reading and writing are now. Later, the emphasis is expected to be on soft skills, which are now neglected. Key competencies will be the ability to work effectively in teams, to achieve goals, to motivate oneself intrinsically, as well as mental flexibility and continuous learning. [6]

Conclusion

The changes in the labour market brought about by the implementation of Industry x.0 principles are significant and far-reaching, affecting all sectors of the economy. Technological innovations such as artificial intelligence, the Internet of Things and automation are transforming traditional jobs and creating new opportunities and challenges. Adapting the workforce to new demands requires strengthening digital and technical skills as well as developing critical thinking and adaptability. Close cooperation between educational institutions, government and enterprises is essential to ensure that the workforce is prepared for the future needs of the labour market. Ultimately, Industry x.0 offers the potential to increase productivity and innovation, but the success of this transformation will depend on society's ability to address emerging social and economic inequalities.

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GREEN TECHNOLOGIES IN PRODUCTION AND LOGISTICS

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Abstract: The perspective of green technologies is, on the one hand, to ensure environmentally friendly products and, on the other hand, to ensure that the production process of these products is environmentally friendly. In practice, this means looking for ways to improve logistics performance, export options and resource utilization. Research and development in this area enables a shift in behavioral attitude towards the use of green technologies and the use of green technologies in the production process. This includes choosing a green supplier, prioritizing green engineering in production and green innovation. The main objective of the paper is to present the results of the analysis of the theoretical background and bibliometric analysis, which focused on green technologies (green production and green logistic). The results of the analysis have shown a growing interest of researchers from all the word in the issue of green manufacturing and green logistics.

Keywords: green technologies, industry, logistics, production.

Introduction

The use of green technologies in manufacturing and logistics aims at reducing the negative environmental impacts of the activities mainly of industrial enterprises. Production and logistics are two interdependent areas, so the use of green technologies must respect their specific goals and objectives, in order to mutually support each other and contribute to the sustainability of the carried-out activities.

Green production

Production can be characterized as a creative process whose function is the creation of utility values and which represents the main activity of the enterprise (Majdúchová & Neumannová, 2015). Green manufacturing represents a modern way of production that focuses on the consumption of material resources in the production process and the environmental impact in the production process. Green manufacturing plays an important role in promoting the sustainable development of human society and the development of a circular economy model in the modern manufacturing industry.

The product lifecycle includes product design, product processing and manufacturing, product packaging, product use and waste disposal. Throughout the product life cycle, the goal of green manufacturing is to reduce the negative impact on the environment, improve resource utilization, and increase comprehensive benefits (Liang, 2019). According to Kirik et al. (2021), green manufacturing, which emerges from the deep integration of green technology innovation and manufacturing industry transformation, is becoming an important emerging field in the latest global industrial revolution and technological competition. Both developed countries and emerging economies regard green manufacturing as a key area for gaining an advantage in future industrial competitions and have introduced relevant policies to strengthen implementation measures (Wang et al., 2022). Consumers are influenced by firms' green manufacturing practices in response to pressing environmental issues affecting the current era (D'Angelo et al., 2023). According to Rusink (2007): In addition to consumers, stakeholders are increasingly demanding organizations to make their products and processes more environmentally friendly. Based on the background above, green manufacturing can be seen not only as a tool to optimize production processes, but mainly as a process creating an opportunity to increase the competitiveness of manufacturing organizations.

Green logistics

Enterprises are still facing increasing demands to use resources efficiently and reduce costs through green practices in the supply chain (Umar et al., 2024). Green and sustainable logistics refers to the planning, control, management and implementation of a logistics system using modern environmental logistics technologies (Bask & Rajahonka, 2017). The integration of green initiatives into logistics operations and supply chain management not only provides a competitive advantage but also new market opportunities for a company (Hervani & Helms, 2005; Kumar et al., 2012; Ali et al., 2020). Logistics plays an important role in the economic growth of a country and significantly increases air pollution including greenhouse gases mainly due to the most major activity namely transportation (Khan et al., 2017). Green logistics focuses on reducing greenhouse gas emissions, efficient and sustainable use of natural resources, and returning materials back into circulation at the end of their life cycle (De Souza et al., 2022).
The main objective of green logistics is to reduce the negative environmental impact caused by logistics activities, minimize production costs, and increase product value by reducing packaging, emissions, using alternative energy and fuel sources, or replacing fossil fuels (Lorenz et al., 2011). Green logistics can thus be seen as a combination of traditional logistics and reverse logistics. Traditional logistics involves the flow from raw materials to finished products, while reverse logistics is a relatively new area of research that involves the concept of recycling used products to reduce waste and increase industry performance and subsequent profits (Hung Lau, 2011). Thus, green logistics approaches not only allow for minimizing negative environmental impacts but also reduce energy and raw material costs, while helping to enhance a company's image and its competitiveness in the market.

Materials and Methods

The analysis was focused on a review of the theoretical background and bibliometric analysis, which will provide a space for systems analysis that will help to draw constructive conclusions from the issue of green technologies.
The main aim of the paper is to present the results of the analysis of the theoretical background and bibliometric analysis, which focused on green technologies (green production and green logistic).

Research question 1: Which aspects are important for the implementation of green technologies in production and logistics?
Research question 2: What is the trend of interest in the green technologies implementation in industrial production and logistics based on publications in the world scientific databases Scopus and Web of Sciences?

We used two scientific databases, Web of Science (WoS) and Scopus, to identify relevant literature sources. The search was limited to studies published as All open access. The main keywords included in the analysis were: ["green production"] AND ["green logistics"]. Subsequently, data sets were created by the authors of the paper and processed in the VOS viewer software. VOS viewer is a software for visualization and analysis of bibliometric networks. The software was developed by researchers at the Centre for Science and Technology

Studies (CWTS) at Leiden University in the Netherlands. The tool is particularly useful for analyzing scientific publications, their citations and co-authorships, allowing researchers to better understand relationships and trends in academic research (Eck & Waltman, 2009). The following analyses can be carried out within the software: creation of bibliometric maps (situation maps, citation and co-authorship networks) and data analysis and visualization (clustering and development maps). VOS viewer is a powerful tool that is widely used to analyze scholarly publications, citations and collaborations, helping researchers and other professionals to better understand the dynamics of academic research (Perianes-Rodriguez, Waltman & van Eck, 2016). The results of the analyses performed can be seen in the next section of the paper.

Results

On the basis of already published professional and scientific papers, we analyzed the knowledge on the implementation of green technologies in the field of industrial production and logistics.

Areas influencing the necessity and possibilities of introducing green technologies in production or logistics

The introduction of green technologies is a complex issue that must take into account not only the general societal requirement for environmental protection, but also other important aspects that determine the viability of industrial production. The evaluation of the first research question was carried out on the basis of existing published studies.

Research question 1: Which aspects are important for the implementation of green technologies in production and logistics?
On the basis of the analyzed resources, we can summarize that the main aspects that need to be taken into account in the implementation of green technologies in production and logistics are as follows:

- **Environmental aspects** focus on the expected benefits in the form of significant reductions in emissions, waste production or resource consumption that green technologies offer (Zhang et al., 2015; Islam et al., 2020; Karimi Takalo et al., 2021; Bradu et al., 2022).
- **Economic aspects** include not only the initial investment in green technologies, which often have support in the form of grants, but also the operating costs and the expected savings, e.g. in the form of lower energy consumption. As with other investments, the expected return on investment in new technologies is also an important factor (Yadav, Gaur and Jain, 2021).
- **Social aspects** include stakeholder expectations, such as customer perceptions of the enterprise and increased demand for green products and sustainable practices. However, building an appropriate corporate culture and management support for green initiatives is also important. Information on the benefits of green technologies must be accessible and clearly communicated to all employees. This may require providing the necessary training and raising awareness about effectiveness of new technologies (Karimi Takalo et al., 2021).
- **Technological aspects** of integrating green technologies into existing manufacturing and logistics systems are particularly challenging for industrial engineers who have to choose available green technologies that are reliable and suitable for specific production (Islam et al., 2020; Cvjetko Bubalo et al., 2015; Yu et al., 2022; Bradu et al., 2022).
- **Legislative aspects** represent commitments arising from international agreements. Green technologies must also meet current environmental standards and regulations. Policy

initiatives do not only imply restrictions but also support for green technologies through subsidies, tax reductions or grants (Karimi Takalo et al., 2021; Bradu et al., 2022).

Trends in interest in the application of green technologies in industrial production and logistics

The evaluation of the second research question was processed in MS Excel and VOS viewer.

Research question 2: What is the trend of interest in the green technologies implementation in industrial production and logistics based on publications in the world scientific databases Scopus and Web of Sciences?
The first step was to search for the key phrases ["green production"] AND ["green logistics"] in the scientific world databases Scopus and Web of Sciences. In Scopus database using the search filter 934 results were found, then we used one filter, all open access, the mentioned filter narrowed down the number of publications to 274 records found. The same procedure was chosen for the Web of Sciences scientific database, where 832 entries were retrieved and after applying the All-open access filter, 332 records remained that matched the search. Fig. 1 shows the absolute frequency of occurrence of publications on the selected topic over the last 11 years.

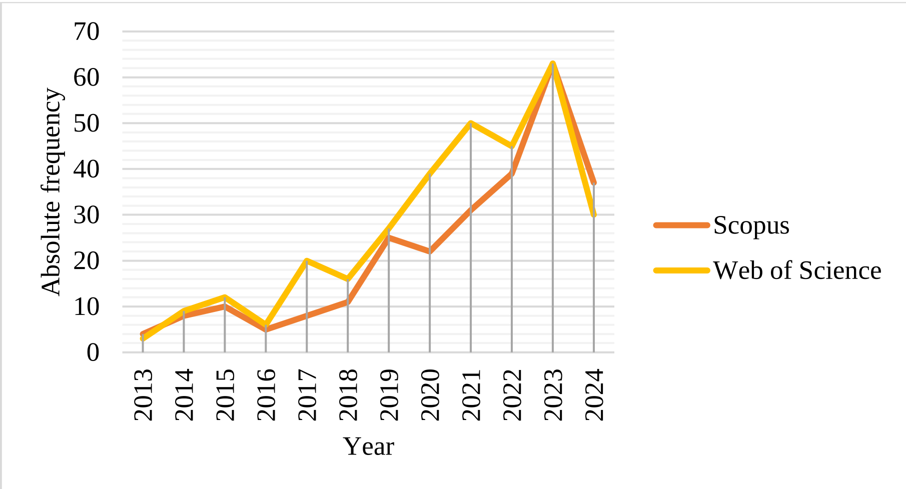

Fig. 1 Occurrence of publications in scientific databases (own elaboration, 2024)

Fig. 1 shows that the analysed issue of green production and green logistics is still relevant with an increasing tendency. There were 11 more publications in the SCOPUS database prior to 2013 and for the Web by Sciences database there were 12 more publications not shown in the graph. The decrease in 2024 is created by the fact that the analysis was performed before the end of the third quarter. Overall, we can assess the above trend of increase is positive and demonstrates the interest of researchers and scientists in the issue of green technologies in production and logistics.
Another analysis that we carried out was a bibliometric analysis in the VOS viewer software, which focused on the occurrence and relationships within the studied issue. For the purposes of the paper, the two datasets were merged to avoid redundancy of items within the analysis. In Fig. 2 we can see the result of the first Bibliographic Coupling analysis focusing on Countries.

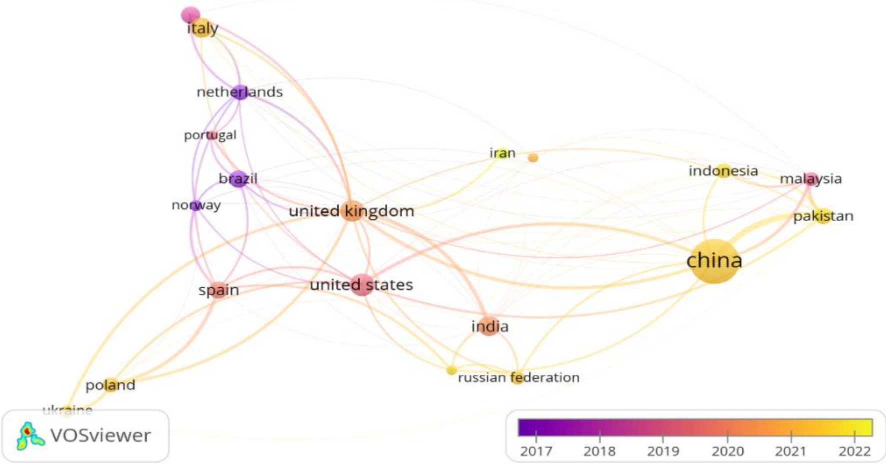

Fig. 2 Type of analysis bibliographic Coupling - Green Technologies (own elaboration, 2024)

Bibliographic Coupling is a method used to measure the similarity between scientific documents. For a deeper analysis, overlay visualization was used by the authors of the paper, which also takes into account time series. Fig. 2 shows that there are 20 items and 5 logical clusters. Among the countries that have addressed the issue of green production and green logistic in the research we rather include Brazil, the Netherlands and Norway. On the other hand, the countries in which researchers have dealt with the above issues in the last three years are Indonesia, Iran and Pakistan. By evaluating the second research question, it was shown, that the issue of green technologies (green production and green logistics) is still growing within scientific databases. Furthermore, countries were identified that have been dealing with the issue earlier, on the contrary, those that have started to deal with it relatively recently.

Conclusions

Adaptability and flexibility are widely regarded as essential attributes for organisations to be able to survive and thrive in changing operating conditions. The introduction of green technologies requires new approaches and solutions, which emphasises the need to support innovative activities in this area. It is important for the management of industrial enterprises to realise that green technologies are an essential prerequisite for a more sustainable future. From the point of view of business management, it is not only by helping to meet legislative requirements and improving the image of enterprises in the field of corporate social responsibility. Green technologies also contribute to the creation of more stable and sustainable industrial and logistics systems, which ultimately also bring economic benefits to businesses.

The main limitation of the presented study is the fact that the analysis was conducted as a theoretical review with quantitative analysis processed in the VOS viewer software and did not progress to a qualitative analysis in the synthesis of the findings. As a further limitation of the research, we note that the last year analysed, 2024, is not completed and therefore the results in that year are biased. Another limitation is the fact that we have only processed results based on two scientific databases (Scopus and Web of Sciences) and papers that have potential but are not indexed are not included in our analyses and findings.

The authors intend to continue further research using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology. The further analysis will include an extension of the PRISMA Checklist and PRISMA Flow Diagram. Further research will focus on defining the theoretical underpinnings that will focus on the development of hypothesis.

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NUMERICAL DIFFERENTIATION METHOD

Gabriela IŽARÍKOVÁ – Anton HOVANA

Abstract: A derivative of a function at some point provides a rate of its change. In the case of point-wise defined function, we approximate its values by continuous function to be the derivative formulas useful. One of the methods to smooth obtained data is numerical differentiation method which involves calculating the derivative of the function f from its values. We provide an overview of its usage. From it follows that an approximation depends on density of a data set.

Keywords: Numerical differentiation, interpolation formula, derivatives of a function,

Introduction

In modern science and technology, derivatives play a crucial role when investigating problems from a mathematical point of view. Classical (analytical) differentiation involves finding the derivative of a function using mathematical rules and formulas. We apply differentiation rules (like the power rule, product rule, quotient rule, etc.) to find an exact formula that represents the derivative of the function, for example, the derivative of the function $sin(x)$ is $cos\ (x)$. Moreover, the derivative of a function at a point represents the slope of the tangent line to the graph of the function at that point. It is a well-known fact that derivative formulas are useless for functions defined on a discrete domain. Thus, numerical differentiation is introduced when approximating point-wise defined functions and data sets. This technique is also used when the results of analytical differentiation yield overly complicated and cumbersome expressions. Numerical differentiation involves approximating the derivative of a function at a particular point using numerical methods. This represents the slope of a secant line through points in the neighborhood of the point of interest. One of the easiest ways to approximate the derivative for a discrete set is to create an interpolation function, which provides an estimated continuous function for the data. Then we can use known derivative formulas.

INTERPOLATION AS A NUMERICAL DIFFERENTIATION METHOD

When differentiating the function numerically, we need to start determining an interpolating polynomial (for example the Lagrange or the Newton interpolation formula) at first to compute the approximate derivative at the given point.

The Lagrange interpolation formula is given by

$$P_n(x) = y_0 l_0(x) + y_1 l_1(x) + y_2 l_2(x) + \cdots . + y_n l_n(x) = \sum_{i=0}^{n} y_i l_i(x) \ ,$$

where $l_i(x)$ are so-called fundamental polynomials defined by

$$l_i(x) = \frac{(x - x_0)(x - x_1) \dots (x - x_{i-1})(x - x_{i+1}) \dots (x - x_n)}{(x_i - x_0)(x_i - x_1) \dots (x_i - x_{i-1})(x_i - x_{i+1}) \dots (x_i - x_n)}.$$

The Newton interpolation formula is given by

$$P_n(x) = a_0 + a_1(x - x_0) + a_2(x - x_0)(x - x_1) + \cdots . + a_n(x - x_0)(x - x_1) \dots (x - x_{n-1}),$$

where the values $a_i = f[x_0, x_1, \dots, x_n]$ are proportional differences,

- zero-order proportional difference at a node x_i , $i = 0,1,2, \dots n$ $f[x_i] = y_i$
- first-order proportional difference in nodes x_i , x_{i+1} , $i = 0,1,2, \dots n-1$

$$f[x_i, x_{i+1}] = \frac{f[\,x_{i+1}] - f[x_i]}{x_{i+1} - x_i}$$

- second-order proportional difference in nodes x_i , x_{i+1}, x_{i+2} , $i = 0,1,2, \dots n-2$

$$f[x_i, x_{i+1}, x_{i+2}] = \frac{f[\,x_{i+1}, x_{i+2}] - f[x_i, x_{i+1}]}{x_{i+2} - x_i}.$$

The resulting interpolation polynomial does not depend on the method used to find it. It is clearly determined by the points through which its graph passes.

NUMERICAL DIFFERENTIATION USING DIFFERENCES

In numerical analysis, numerical differentiation algorithms estimate the derivative of a function using its values and other knowledge from mathematical analysis. Numerical differentiation is a way to estimate the derivative of the function $f(x)$ at the point x without analytical derivation (according to the derivative rules and formulas). It is based solely on the knowledge of the function's values at a finite number of points.

Geometrically, the derivative at the point expresses the slope of the tangent line to the graph of the function. In the numerical differentiation, the tangent line is replaced by the secant line passing through the known points of the graph. The classical derivative expresses an instantaneous rate at which a physical quantity changes while the numerical derivative represents the average rate of change.

Approximating derivatives is a crucial part of any numerical simulation when it is analytically impossible to obtain the derivative value. This prevents detrimental effects on the solution. From mathematical analysis, we know that the derivative of the function $f(x)$ at the point x_0 is defined by

$$f'(x_0) = \lim_{x \to x_0} \frac{f(x) - f(x_0)}{x - x_0}.$$

During numerical derivation, it is necessary to modify this definition by using selected correct mathematical procedures (the difference between two nearby points $h = x_i - x_{i-1}$ must be very small). The method is based on the definition of the derivative:

$$f'(x_0) = \frac{f(x) - f(x_0)}{x - x_0}$$

Differences are the set of tools for estimating the derivative using a set range of x -values. The basic idea is to “move” the points so that they get closer and closer together, making it seem like the tangent line. Exactly how the points are moved (forwards or backwards) gives rise to three common algorithms: backward difference, forward difference and central difference.

Our aim is approximate the slope of a curve f at the point $x = x_0$ in terms of $f(x_0)$ and the value of f at a nearby point where $x = x_0 + h$. Taking the limit of the above function as h tends to 0 is numerically infeasible. Therefore, we use a small h and calculate the value of the derivative. This is called the forward difference scheme provided by the following formula

$$f'(x_0) = \frac{f(x_0 + h) - f(x_0)}{h}.$$

The second idea arises on considering the point on the left-hand side of x_0 rather than on the right-hand side as it is described above. In this case, we obtain the approximation

$$f'(x_0) = \frac{f(x_0) - f(x_0 - h)}{h}$$

This is another one-sided difference, called a backward difference. The backward difference scheme is an alternative method to the forward difference scheme, where we can subtract h from x instead of adding it. It has some advantages, for example when trying to estimate the derivative of the function at the same time as calculating the function itself. It is also a more stable method, even though it has the same accuracy as the forward difference method.
The central difference estimate is a combination of the previous two method mentioned above. We subtract the function value immediately below $f(x)$ from the function value immediately above $f(x)$. It is the most stable and has an order higher accuracy.

$$f'(x_0) = \frac{f(x_0 + h) - f(x_0 - h)}{2h}$$

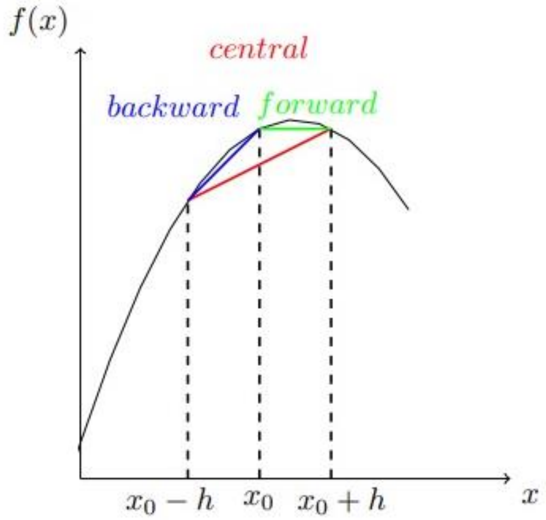

Fig. 1 Illustration of the finite difference approximations (the forward difference estimate – green line, the backward difference estimate - blue line, the central difference estimate – red line)

The forward, the backward and the central difference scheme are often referred to as the finite difference schemes. The figure illustrates how they differ from each other, see Fig. 1.
We describe differences among the forward, the backward and the central difference for the different values of h (0.1, 0.01, 0.001,0.0001), to aproximate the derivative of $\sqrt{x}$, at $x = 3$, Tab.1.

Tab. 15 Example of the forward, backward and central difference

h	backward	central	forward
0.1	0,29112171	0,28871525	0,28630879
0.01	0,28891610	0,28867554	0,28843497
0.001	0,28869919	0,28867514	0,28865108

0.0001	0,28867754	0,28867513	0,28867273

Now, we can compare these approximations with the exact value that is

$$f'(x_0) = \frac{1}{2\sqrt{3}} = 0.28867513$$

For the central difference, each successive approximation has two extra accurate decimal places. In contrast, the second to fourth backward and forward approximations in the example above have one extra accurate decimal place compared to the previous approximation. While the forward and backward methods are easy and involve simple mathematics, they are not very accurate. The central difference method is the most accurate, see Tab.1 and Fig.2.

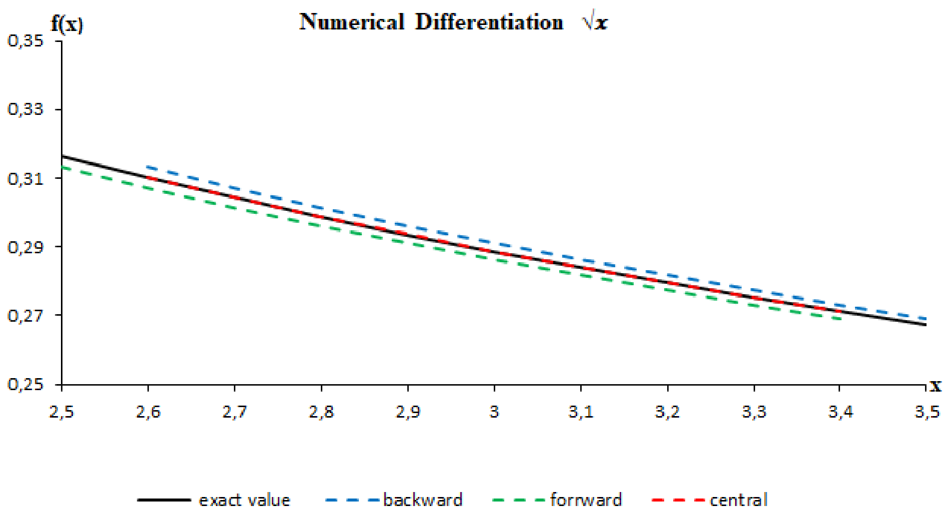

Fig. 2 Illustration of the forward, the backward and the central difference to aproximate the derivative of $\sqrt{x}$, for the value $h = 0.1$ and the interval $(2.5,\ 3.5)$

However, we cannot use the central difference method at the left and right endpoints of the interval because there are no points further to the left or right to calculate an average with. These methods are useful when data is unavailable from before or after certain points. In such cases, we use the forward difference method at the left endpoint and the backward difference method at the right endpoint.

Conclusion

Numerical differentiation is a mathematical tool for estimating the derivative of the function defined on the discrete domain, for example any data set. From practical point of view, it is useful when the analytical expression of the derivative is difficult or impossible to obtain. Numerical differentiation has found its application in numerous fields such as fluid dynamics, structural analysis and control systems, where it is used for approximation of changes of physical quantities.

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CONVERGENCE TESTS OF THE RATIO TYPE

Anton HOVANA – Gabriela IŽARÍKOVÁ

Abstract: Consider infinite number series $\sum_{n=1}^{\infty} a_n$ with positive terms. There are several tests which provide answer to its convergence or divergence. One of them is the ratio test which fails if $\lim_{n\to\infty} \frac{a_n}{a_{n+1}} = 1$. In that case, the ratio $\frac{a_n}{a_{n+1}}$ can be expressed as $\frac{a_n}{a_{n+1}} = 1 + b_n$, where the sequence $\{b_n\}_{n=1}^{\infty}$ vanishes at infinity. We focus on providing criteria of convergence which generalize the ratio one. Our considerations are supported by suitable examples.
Keywords: Infinite series, convergence test, ratio test

Introduction
The first mention of infinite series dates back to antiquity. The question of how the sum of infinitely many positive terms can be a finite number was not only a profound philosophical challenge but also an important milestone in understanding the concept of infinity. The first non-geometric infinite series was calculated by Roger Swineshead (1285–1360) around 1350. The study of convergence criteria for infinite series can already be found in the works of Madhava of Sangamagrama (approximately 1340–1425), who also devised simple convergence tests. In Western culture, mathematicians began to delve deeper into the need for investigating series convergence in the 19th century. From this period stem, the most famous and commonly used criteria taught in the basic courses of mathematical analysis. However, besides these, there are other less-known criteria that are often more useful in investigating the convergence of series, but there are not taught in the standard courses. In our contribution, we focus on convergence tests which require a ratio of two terms of the series.

Preliminaries
Let $\{a_n\}_1^{\infty}$ be a sequence of real numbers. We assign to it the sequence $\{s_n\}_1^{\infty}$as follows:

$$s_1 = a_1,$$
$$s_2 = a_1 + a_2 = s_1 + a_2,$$
$$\vdots$$
$$s_n = a_1 + \cdots + a_n = s_{n-1} + a_n.$$

Expression $\sum_{n=1}^{\infty} a_n = a_1 + a_2 + \cdots + a_i + \cdots$ is called an infinite series. The elements $a_1, a_2, \dots, a_n, \dots$ are called terms of the infinite series and $a_n$is called the *n*-th term of the series $\sum_{n=1}^{\infty} a_n$. The expression s_n is called the *n*-th partial sum of the series and the sequence $\{s_n\}_1^{\infty}$is called the sequence of partial sums of the series $\sum_{n=1}^{\infty} a_n$. The infinite series whose terms are positive numbers is called the infinite series with positive terms. For such series the sequence $\{s_n\}_1^{\infty}$ is increasing. Indeed, for all $n \in \mathbb{N}$ we have $s_{n+1} = s_n + a_{n+1} > s_n$. Moreover, the sequence (and the series as well) should not begin with a_1, we can start with arbitrary term if needed. The sum of the series $\sum_{n=1}^{\infty} a_n$ will be referred to as the limit of the sequence of its partial sums. We denote it as $\sum_{n=1}^{\infty} a_n = \lim_{n\to\infty} s_n = s$. The series is convergent if the sequence of its partial sums converges. The series that does not converge is called divergent. There exist the series whose limit of partial sums is finite number and we are able to determine it, for instance telescoping or geometrical series. In some cases, there is not possible to express this number, we only need to know whether it is finite or not. There exist several criteria, so-called tests, that provide such answer. One of the most often used and taught tests for convergence of series with positive terms is the d´Alembert ratio test which reads as follows.

Theorem (d´Alembert ratio test): *Let $\sum_{n=1}^{\infty} a_n$ be a series with positive terms.*

i) *If for all $n \in \mathbb{N}$ there is $\frac{a_n}{a_{n+1}} \geq q > 1$, then $\sum_{n=1}^{\infty} a_n$ is convergent. If for all $n \in \mathbb{N}$ there is $\frac{a_n}{a_{n+1}} < 1$, then $\sum_{n=1}^{\infty} a_n$ is divergent.*

ii) *If $\lim_{n\to\infty} \frac{a_n}{a_{n+1}} = q$, then $\sum_{n=1}^{\infty} a_n$ is convergent for $q > 1$ and divergent for $q < 1$.*

Applicability of the limit form of the ratio test fails when $\lim_{n\to\infty} \frac{a_n}{a_{n+1}} = 1$. For example, the series $\sum_{n=1}^{\infty} \frac{1}{n}$ is divergent whereas the series $\sum_{n=1}^{\infty} \frac{1}{n^2}$ converges. Although the inequality $\frac{a_n}{a_{n+1}} > 1$ holds for all $n \in \mathbb{N}$, the series should not be convergent, for instance $\sum_{n=1}^{\infty} \frac{1}{n}$. It is obvious that if $\lim_{n\to\infty} \frac{a_n}{a_{n+1}} = 1$, then the ratio $\frac{a_n}{a_{n+1}}$ can be expressed as $\frac{a_n}{a_{n+1}} = 1 + b_n$, where $\{b_n\}_{n=1}^{\infty}$ is the sequence which limit is zero. The expression of the sequence $\{b_n\}_{n=1}^{\infty}$ leads to several improvements that will be discussed in the forthcoming section.

Main result

The first improvement of the ratio test was provided by Joseph Ludwiq Raabe (1801-1859), cf. [3].

Theorem (Raabe test): *Let $\sum_{n=1}^{\infty} a_n$ be a series with positive terms.*

i) *If there exists $q \in \mathbb{R}, q > 1$ and there exists $n_0 \in \mathbb{R}$ such that for all $n \in \mathbb{N}, n > n_0$ we have $n\left(\frac{a_n}{a_{n+1}} - 1\right) \geq q$, then $\sum_{n=1}^{\infty} a_n$ is convergent.*

ii) *If for all $n \in \mathbb{N}$ we have $n\left(\frac{a_n}{a_{n+1}} - 1\right) \leq 1$, then $\sum_{n=1}^{\infty} a_n$ is divergent.*

Similar to the d´Alembert ratio test, we can provide the limit version of the Raabe test.

Theorem (Limit Raabe test): *Let $\sum_{n=1}^{\infty} a_n$ be a series with positive terms. If $\lim_{n\to\infty} n\left(\frac{a_n}{a_{n+1}} - 1\right) = q$, then $\sum_{n=1}^{\infty} a_n$ is convergent for $q > 1$ and divergent for $q < 1$.*

It worth mentioning that the sequence $\{b_n\}_{n=1}^{\infty}$has the expression $b_n = \frac{q}{n}$ for all $n \in \mathbb{N}$.

We determine convergence of the series $1 + \frac{3}{7}x + \frac{3.6}{7.10}x^2 + \frac{3.6.9}{7.10.13}x^3 + \cdots$. It is obvious that the series has positive terms and the n-th term can be expressed by $a_n = \frac{3.6.9.\cdots.(3n)}{7.10.13.\cdots.(3n+4)}x^n$.

Then the ratio $\frac{a_n}{a_{n+1}}$ has the form $\frac{a_n}{a_{n+1}} = \frac{\frac{3.6.9.\cdots.(3n)}{7.10.13.\cdots.(3n+4)}x^n}{\frac{3.6.9.\cdots.(3n)3(n+1)}{7.10.13.\cdots.(3n+4)(3(n+1)+4)}x^{n+1}} = \frac{3n+7}{3n+3}.\frac{1}{x}$, hence $\lim_{n\to\infty} \frac{a_n}{a_{n+1}} = \frac{1}{x}$ and the series $\sum_{n=1}^{\infty} a_n$is convergent for $x < 1$ and divergent for $x > 1$ by the d´Alembert ratio test. For $x = 1$ applying the limit Raabe test, we get $\lim_{n\to\infty} n\left(\frac{a_n}{a_{n+1}} - 1\right) = \lim_{n\to\infty} n\left(\frac{3n+7}{3n+3} - 1\right) = \lim_{n\to\infty} \frac{4n}{3n+3} = \frac{4}{3} > 1$, thus the series $\sum_{n=1}^{\infty} a_n$ is convergent for $x = 1$.

Moreover, the Raabe test is more powerful than the ratio one. Taking the series $\sum_{n=1}^{\infty} \frac{1}{n^2}$ we get $\lim_{n\to\infty} n\left(\frac{a_n}{a_{n+1}} - 1\right) = \lim_{n\to\infty} n\left(\frac{n^2+2n+1}{n^2} - 1\right) = \lim_{n\to\infty} \frac{2n^2+n}{n^2} = 2$ and the series is convergent whereas the ratio test fails. Indeed, $\lim_{n\to\infty}\frac{a_n}{a_{n+1}} = \lim_{n\to\infty}\frac{n^2+2n+1}{n^2} = 1$. Based on this idea we can formulate the following statement.

Theorem (Generalized Raabe test): *Let $\sum_{n=1}^{\infty} a_n$ be a series with positive terms. Assume that there exist bounded sequence of real numbers $\{B_n\}_{n=1}^{\infty}$ such that $\frac{a_n}{a_{n+1}} = 1 + \frac{p}{n} + \frac{B_n}{n^2}$ for all $n \in \mathbb{N}$. Then $\sum_{n=1}^{\infty} a_n$ converges for $p > 1$ and diverges for $p \leq 1$.*

We determine convergence of the series $x + \frac{\alpha^2}{1.\beta}x^2 + \frac{\alpha^2(\alpha+1)^2}{1.2.\beta.(\beta+1)}x^3 + \frac{\alpha^2(\alpha+1)^2(\alpha+2)^2}{1.2.3.\beta.(\beta+1).(\beta+2)}x^4 + \cdots$ while $x, \alpha, \beta > 0$. One can see that the n-th term is $a_n = \frac{\alpha^2(\alpha+1)^2(\alpha+2)^2.\cdots.(\alpha+n-1)^2}{n!.\beta.(\beta+1).(\beta+2).\cdots.(\beta+n-1)}x^{n+1}$. Then for the ratio $\frac{a_n}{a_{n+1}}$ we can write $\frac{a_n}{a_{n+1}} = \frac{\frac{\alpha^2(\alpha+1)^2(\alpha+2)^2.\cdots.(\alpha+n-1)^2}{n!.\beta.(\beta+1).(\beta+2).\cdots.(\beta+n-1)}x^{n+1}}{\frac{\alpha^2(\alpha+1)^2(\alpha+2)^2.\cdots.(\alpha+n)^2}{(n+1)!.\beta.(\beta+1).(\beta+2).\cdots.(\beta+n)}x^{n+2}} = \frac{\beta+(\beta+1)n+n^2}{\alpha^2+2\alpha n+n^2}.\frac{1}{x}$. Applying the limit, we get $\lim_{n\to\infty}\frac{a_n}{a_{n+1}} = \frac{1}{x}$, so the series $\sum_{n=1}^{\infty} a_n$is convergent for $0 < x < 1$ and divergent for $x > 1$ by the d´Alembert ratio test. For $x = 1$ the ratio $\frac{a_n}{a_{n+1}}$ can be expressed in the following way $\frac{a_n}{a_{n+1}} = \frac{\beta+(\beta+1)n+n^2}{\alpha^2+2\alpha n+n^2} = 1 + \frac{\beta+1-2\alpha}{n} + \frac{B_n}{n^2}$. Then the series is convergent when $\beta > 2\alpha$ and divergent when $\beta \leq 2\alpha$.

Some series that cannot be examined using the Raabe test can be analyzed using more refined tests developed by Carl Friedrich Gauss (1777-1855). The following test generalizes the previous theorem, cf. [1].

Theorem (Gauss test): *Let $\sum_{n=1}^{\infty} a_n$ be a series with positive terms. Assume that there exist $p, r \in \mathbb{R}, r > 1$ and bounded sequence of real numbers $\{B_n\}_{n=1}^{\infty}$ such that $\frac{a_n}{a_{n+1}} = 1 + \frac{p}{n} + \frac{B_n}{n^r}$ for all $n \in \mathbb{N}$. Then $\sum_{n=1}^{\infty} a_n$ converges for $p > 1$ and diverges for $p \leq 1$.*

From practical point of view, there is the question of how to construct the sequence $\{B_n\}_{n=1}^{\infty}$. Consider the expression $\frac{a_n}{a_{n+1}} = 1 + \frac{p}{n} + \frac{B_n}{n^r}$. Then $p = \lim_{n\to\infty} n\left(\frac{a_n}{a_{n+1}} - 1\right)$. We introduce helpful sequence $\{A_n\}_{n=1}^{\infty}$, where $A_n = \frac{a_n}{a_{n+1}} - 1 - \frac{p}{n}$. Now, it is enough to take $r \in \mathbb{R}$ such that $r > 1$ and $B_n = A_n.n^r < \infty$ to be the sequence $\{B_n\}_{n=1}^{\infty}$bounded.

We determine convergence of the series $\sum_{n=1}^{\infty}\left(\frac{(2n-1)!!}{(2n)!!}\right)^a$, where $a > 0$. Then for the ratio $\frac{a_n}{a_{n+1}}$ we have $\frac{a_n}{a_{n+1}} = \left(\frac{\frac{(2n-1)!!}{(2n)!!}}{\frac{(2n+1)!!}{(2n+2)!!}}\right)^a = \left(\frac{2n+2}{2n+1}\right)^a$and therefore $n\left(\frac{a_n}{a_{n+1}} - 1\right) = n\left(\left(\frac{2n+2}{2n+1}\right)^a - 1\right) = n\left(\left(\frac{1+\frac{1}{n}}{1+\frac{1}{2n}}\right)^a - 1\right)$. Based on asymptotic behavior of $\left(1+\frac{1}{x}\right)^p$ for $x \to \infty$, i.e., $\left(1+\frac{1}{x}\right)^p = 1 + \frac{p}{x} + O\left(\frac{1}{x}\right)$, we get $n\left(\frac{a_n}{a_{n+1}} - 1\right) = n\left(\frac{1+\frac{a}{n}+O\left(\frac{1}{n}\right)}{1+\frac{a}{2n}+O\left(\frac{1}{n}\right)} - 1\right) = \frac{a}{2} + O(1)$, when $n \to \infty$. Thus by the Raabe test the series is convergent for $a > 2$ and divergent for $a < 2$. In the case of $a = 2$ we use the Gauss test. Firstly, we find p by computing the limit $\lim_{n\to\infty} n\left(\left(\frac{\frac{(2n-1)!!}{(2n)!!}}{\frac{(2n+1)!!}{(2n+2)!!}}\right)^2 - 1\right) =$

$\lim_{n\to\infty} n\left(\left(\frac{2n+2}{2n+1}\right)^2 - 1\right) = \lim_{n\to\infty} \frac{n(4n+3)}{(2n+1)^2} = 1$. Now, we find the sequence $\{A_n\}_{n=1}^{\infty}$by putting $A_n = \frac{a_n}{a_{n+1}} - 1 - \frac{p}{n} = \left(\frac{2n+2}{2n+1}\right)^2 - 1 - \frac{1}{n} = \frac{-n-1}{4n^3+4n^2+n}$. Finally, we need to find $r > 1$ to be the sequence $B_n = A_n . n^r$ bounded. Then $A_n = \frac{-n-1}{4n^3+4n^2+n} = \frac{1}{n^2}\left(\frac{-n^3-n^2}{4n^3+4n^2+n}\right)$ for $r = 2$ we obtain that $B_n = A_n . n^2 = \frac{-n^3-n^2}{4n^3+4n^2+n} < \infty$. Because of $p = 1$ the series $\sum_{n=1}^{\infty}\left(\frac{(2n-1)!!}{(2n)!!}\right)^2$ diverges. To sum up, based on the Gauss and Raabe test, the series $\sum_{n=1}^{\infty}\left(\frac{(2n-1)!!}{(2n)!!}\right)^a$ converges for $a > 2$ and diverges for $a \leq 2$. Because of chronological access in our consideration gathering facts together we are able to formulate the following test.

Theorem (Generalized Gauss test): *Let $\sum_{n=1}^{\infty} a_n$ be a series with positive terms. Assume that there exist $\alpha, p, r \in \mathbb{R}, \alpha > 0, r > 1$ and bounded sequence of real numbers $\{B_n\}_{n=1}^{\infty}$ such that $\frac{a_n}{a_{n+1}} = \alpha + \frac{p}{n} + \frac{B_n}{n^r}$ for all $n \in \mathbb{N}$. Then $\sum_{n=1}^{\infty} a_n$ converges for $\alpha > 1$ or $\alpha = 1$ and $p > 1$ and diverges for $\alpha \leq 1$ or $\alpha = 1$ and $p \leq 1$.*

We determine convergence of the series $\sum_{n=1}^{\infty}\frac{1.4.7.\cdots.(3n-2)}{3.6.9.\cdots(3n)}$. For the ratio $\frac{a_n}{a_{n+1}}$ it holds $\frac{a_n}{a_{n+1}} = \frac{\frac{1.4.7.\cdots.(3n-2)}{3.6.9.\cdots(3n)}}{\frac{1.4.7.\cdots.(3n-2)(3n+1)}{3.6.9.\cdots(3n)(3n+3)}} = \frac{3n+3}{3n+1}$, so the d'Alembert ratio test is useless. Then $\frac{a_n}{a_{n+1}} = \frac{3n+3}{3n+1} = 1 + \frac{2}{3n+1} = 1 + \frac{2}{3n}.\frac{3n}{3n+1} = 1 + \frac{2}{3n}.\left(1 - \frac{1}{3n+1}\right) = 1 + \frac{\frac{2}{3}}{n} - \frac{2}{3n(3n+1)} = 1 + \frac{\frac{2}{3}}{n} - \frac{1}{n^2}.\frac{2n}{9n+3}$. One can observe that the sequence $\{B_n\}_{n=1}^{\infty}$is bounded because for all $n \in \mathbb{N}$ the inequality $\left|-\frac{2n}{9n+3}\right| \leq \frac{2}{9}$ holds. Then $p = \frac{2}{3} < 1$ and the series is divergent.

The next test for convergence of infinite number series with positive terms was provided by Sayel A. Ali, see [2]. His motivation follows from the ratio of not necessarily neighboring terms as it was considered in the previous tests.

Theorem (Second Ali ratio test): *Let $\sum_{n=1}^{\infty} a_n$ be a series with positive terms. Assume that there exist limits $\lim_{n\to\infty}\frac{a_{2n}}{a_n} = L_1$ and $\lim_{n\to\infty}\frac{a_{2n+1}}{a_n} = L_2$. Denote $L = max\{L_1, L_2\}$ and $l = min\{L_1, L_2\}$.*

i) If $L \leq \frac{1}{2}$, then $\sum_{n=1}^{\infty} a_n$is convergent.

ii) If $l \geq \frac{1}{2}$, then $\sum_{n=1}^{\infty} a_n$ is divergent.

If $l \leq \frac{1}{2} \leq L$, then the test does not provide answer about convergence of the considered series. For instance, the series $\sum_{n=1}^{\infty}\frac{1}{n(\ln n)^p}$ is convergent for $p > 1$ and divergent for $p \leq 1$, but $\lim_{n\to\infty}\frac{a_{2n}}{a_n} = \lim_{n\to\infty}\frac{n\,(\ln n)^p}{2n(\ln 2n)^p} = \frac{1}{2}$.

When strengthening assumption on monotonicity of terms, i.e., the sequence of the terms must be decreasing, we get $l \leq \lim_{n\to\infty}\frac{a_{2n+1}}{a_n} \leq \lim_{n\to\infty}\frac{a_{2n}}{a_n} = L$. Therefore we can formulate the following statement.

Corollary: *Let $\sum_{n=1}^{\infty} a_n$ be a series with positive terms and $\{a_n\}_{n=1}^{\infty}$is decreasing sequence. If $\lim_{n\to\infty} \frac{a_{2n}}{a_n} < \frac{1}{2}$, then $\sum_{n=1}^{\infty} a_n$ is convergent. If $\lim_{n\to\infty} \frac{a_{2n+1}}{a_n} > \frac{1}{2}$, then $\sum_{n=1}^{\infty} a_n$ is divergent.*

It is worth mentioning that if the series is convergent determined by the d'Alembert ratio test then the same result is obtained by the second Ali test. The reverse implication is not true. Indeed, taking the Rieman p-series $\sum_{n=1}^{\infty} \frac{1}{n^p}$. Then $\frac{a_{2n}}{a_n} = \frac{n^p}{(2n)^p} = \frac{1}{2^p}$ and $\frac{a_{2n+1}}{a_n} = \frac{n^p}{(2n+1)^p} = \frac{1}{\left(2+\frac{1}{n}\right)^p}$. So, for their limits yield $\lim_{n\to\infty} \frac{a_{2n+1}}{a_n} = \lim_{n\to\infty} \frac{a_{2n}}{a_n} = \frac{1}{2^p}$. Because $\frac{1}{2^p} < \frac{1}{2}$ for $p > 1$ and $\frac{1}{2^p} > \frac{1}{2}$ for $p < 1$ and for $p = 1$ we have the harmonic series which is divergent, then summarizing we get well-known fact that the considered series is convergent for $p > 1$ and divergent for $p \leq 1$. But $\lim_{n\to\infty} \frac{a_n}{a_{n+1}} = \lim_{n\to\infty} \frac{(n+1)^p}{n^p} = 1$ and the classical ratio test is useless.

We determine convergence of the series $\sum_{n=1}^{\infty} \frac{1.3.5.\cdots(2n-1)}{2^n(n+1)!}$. When using the d'Alembert ratio test we get $\lim_{n\to\infty} \frac{a_n}{a_{n+1}} = \lim_{n\to\infty} \frac{2(n+2)}{2n+1} = 1$ and we are not able to decide about its convergence or divergence. It is easy to see that terms of the series form decreasing sequence, i.e., for all $n \in \mathbb{N}$ there is $\frac{a_{2n+1}}{a_n} < \frac{a_{2n}}{a_n}$. Then by the second Ali test we get $\frac{a_{2n}}{a_n} = \frac{(2n+3)(2n+5)\cdots(4n-1)}{2^n(n+2)(n+3)\cdots(2n)} = \frac{1}{2}\left(\frac{2n+3}{2n+4}\right)\left(\frac{2n+5}{2n+6}\right)\cdots\left(\frac{4n-1}{4n}\right) < \frac{1}{2}\left(\frac{4n-1}{4n}\right)^{n-1} = \frac{1}{2}\left(1-\frac{1}{4n}\right)^{n-1}$ and $\lim_{n\to\infty} \frac{a_{2n}}{a_n} \leq \lim_{n\to\infty} \frac{1}{2}\left(1-\frac{1}{4n}\right)^{n-1} = \frac{1}{2}e^{-\frac{1}{4}} < \frac{1}{2}$. So, the considered series is convergent.

Theorem (m-th Ali ratio test): *Let $\sum_{n=1}^{\infty} a_n$ be a series with positive terms and $m \in \mathbb{N}, m > 1$. Denote $L_1 = \lim_{n\to\infty} \frac{a_{mn}}{a_n}$, $L_2 = \lim_{n\to\infty} \frac{a_{mn+1}}{a_n}, \cdots, L_m = \lim_{n\to\infty} \frac{a_{mn+m-1}}{a_n}$ and put $L = max\{L_1, L_{,2}, \dots, L_m\}$ and $l = min\{L_1, L_{,2}, \dots, L_m\}$.*

i) If $L < \frac{1}{m}$, then $\sum_{n=1}^{\infty} a_n$is convergent.

ii) If $l > \frac{1}{m}$, then $\sum_{n=1}^{\infty} a_n$ is divergent. If $l \leq \frac{1}{m} \leq L$, then the test is useless.

Again, when considering the decreasing sequence of terms, we get the following.

Corollary: *Let $\sum_{n=1}^{\infty} a_n$ be a series with positive terms and $\{a_n\}_{n=1}^{\infty}$is decreasing sequence. If $\lim_{n\to\infty} \frac{a_{mn}}{a_n} < \frac{1}{m}$, then $\sum_{n=1}^{\infty} a_n$ is convergent. If $\lim_{n\to\infty} \frac{a_{mn+m-1}}{a_n} > \frac{1}{m}$, then $\sum_{n=1}^{\infty} a_n$ is divergent.*

Conclusion

We have provided an overview how to determine convergence or divergence of infinite number series with positive term when the classical ratio test fails. In that case, the ratio of two neighboring terms of series can be expressed by $\frac{a_n}{a_{n+1}} = 1 + b_n$, where $\{b_n\}_{n=1}^{\infty}$ is the sequence vanishing at infinity. Extensions of the ratio test are based on the expression of that sequence. We have gathered known facts from available literature supported by suitable examples which show that the generalization is more powerful than the original one. Furthermore, the criteria provide only sufficient condition for convergence or divergence of the considered series with positive terms.

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PROPOSAL FOR A SOLUTION TO IMPROVE LOGISTICS PROCESSES IN AN AUTOMOTIVE COMPANY

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Abstract: The article deals with the solution of production capacity, inventory status and production process in an automotive company. The company manufactures head restraints for automobiles in Slovakia. Based on the analysis carried out, insufficient production capacity of one of the necessary components for the production of the headrest was found. The MIN-MAX method was used to identify the bottleneck in production. This bottleneck was eliminated with a suitable solution, thus ensuring safe production and diversifying the risk of machine failure in the future. The introduction of the new foam production line will enable the company to win additional projects from existing or new customers.
Keywords: Logistics, MIN-MAX level system, Production, Capacity, Automotive company.

Introduction

Logistics is not only about systems thinking, but also about a new organisation, with an emphasis on integrating new processes and taking a global view to optimise all related processes. The content of both logistics and management is the organisation, planning, management and control of all physical and information processes.

We could say that: logistics is an interdisciplinary science that deals with the optimal coordination, alignment, interconnection and optimization of the flow of raw materials, materials, semi-finished products, products and services, as well as the flow of information and finance.

Every business has to pay close attention to inventory and record keeping. Inventory management is the methodology of maintaining inventories at the required level and the associated replenishment of the inventory in the enterprise. Inventory records are used for routine and follow-up control, to take timely action to supply shortages, e.g. of materials, and to monitor the cost-effectiveness of storage.

The development of mathematical methods, especially operations research and statistics, in conjunction with the spread of modern computing technology, has also enabled the extremely rapid development of modern inventory management methods, which are gradually being adapted in application to the specific needs of management practice.

The article deals with the decreasing trend of the inventory of produced mechanisms in the enterprise under study, resulting in losses in production. There are risks that if the stock is insufficient and falls below the minimum specified threshold, the enterprise will not have the components to create the final products, thus the production of head restraints will be limited and the customers will not get the required goods. In the case of the automotive sector, this could have fatal consequences. Stopping production at a customer's site is highly penalised and this could put the company in a very difficult financial situation. We have based our analysis on two stated hypotheses:

1. Should customers increase their requirements in the future, the company will not be able to supply the required quantities of bolsters.
2. If the stock values of machinery were below the minimum value, there would be a risk that machinery production would stop if a machine broke down and the firm would not have sufficient stock to cover further demand.

The objectives of logistics will be briefly stated as follows:

- It aims to ensure a continuous supply of materials, goods, services and recycling of waste.
- The handling of materials, goods and services in time and space both inside and outside the enterprise
- To make deliveries to customers appropriate to the market in order to maintain existing relationships or gain new ones.

There are two aspects to these objectives:

1. The executive (technical) objective - the need to prepare the goods in due time at a specific location
2. The economic objective - to satisfy the needs in question at a reasonable level of cost

Among the basic tasks we can include: delivery of materials from the supplier to the company and subsequent production or warehouse, transport of semi-finished goods between production sections or delivery to end customers.

Logistics focuses on satisfying the customer's needs as the end result. It therefore seeks to achieve this with the greatest possible flexibility, precision and economy.

The right choice of the appropriate warehousing method for a company depends on the size of the company, the product range, the quantity of materials or the technical equipment of the warehouse. In this work we have chosen a level system - MIN-MAX. This system is based on tracking the minimum and maximum stock levels. The minimum stock level represents the limit below which the stock must not fall. Otherwise, continuous production would be compromised. The maximum stock represents the limit which the stock must not exceed. It should be large enough to ensure production during the period between two deliveries [14].

Methods and methodology

The lean manufacturing philosophy is based on the idea of reducing time and eliminating waste in the chain between customer and supplier. Waste itself is anything that does not add value to the product and increases its cost of production. In lean manufacturing, profit must be calculated as the difference between price and cost. In lean manufacturing, the most important thing is to reduce the cost of production and the cost of wastage [3]. When trying to eliminate waste from business processes, it is first and foremost essential to identify and measure it. The basic method in lean enterprise is value stream management. The method is an excellent tool for analyzing, visualizing, and measuring waste throughout the value stream [5]. There are many tools and sophisticated methods for designing, analyzing and improving manufacturing and logistics processes.

Our purpose is to analyze a manufacturing company that designs and manufactures customized components for the automotive industry globally. The business, a fully integrated company, is known for providing exceptional design and engineering expertise along with superior product manufacturing. The manufacturing business quickly adapts to market information and develops innovative, cost-effective solutions for their customers, resulting in strong partnerships that have served as the foundation of their success.

The main product of the manufacturing company is the headrest for the automotive industry. Currently it produces more than 10 programs, each of these programs is for a different type of vehicle. The headrest consists of an armature on which the mechanism is foamed and this is covered with a cover, some more complex processing also includes special mechanisms, foam inserts and mechanical parts to move the headrest. The headrest in a car is shown in Fig.1.

Fig. 4. Head restraint in the car

The head restraint in the car is already an integral part of the car for us, but it was-n't always so. In the first cars, the seat was only about shoulder height and there were no seat belts. A lot has changed since then, and today we know that a headrest not only makes a longer or shorter journey in a car more comfortable, but can also save our lives when it's adjusted well. After all, they are developed to protect the head and neck. Even if most drivers don't give a damn about it, it's just as important as the airbag. Because in a crash, our head goes sharply forward and then sharply back, and this is really about inches. Even after a minor accident, we can be left with life-long consequences (dizziness, headaches). In the event of a serious accident, death can result from broken ligaments. If you notice, in a parking lot, most cars have the headrest in the lowest position - the base position, which is not good, because with just that setup, it's as if it's not even there at all. The head restraint should be at the level of the top of your head, by rights. So if someone looks at you from the side, it should be horizontally aligned with your head. If all the head restraints in the car are adjusted correctly, the risk of injury is reduced by up to 5-10%.

Results and Discussion

In automotive production, resources (people, machines, equipment, etc.) are al-ways limited. It is very important for manufacturing companies to produce cost-effective final products in a short period of time, which can be achieved through cost minimization and higher efficiency, and therefore efficiency-enhancing methods are needed. There are many tools and sophisticated methods for designing, analyzing and improving manufacturing and logistics processes.
This is the company's foam line, which is used for the production of the relevant mechanisms. Without these parts, the enterprise would not be able to produce finished products.

Tab. 1. The volume of production and stock levels based on the company's internal materials. (Authors own processing)

Week	Production volume of headrests	Processing mechanisms	Production volume of mech.	Scrap mech.	Estimated scrap mech.	Stock status	MIN	MAX
						45214	30000	90000
CW30	12141	213	30145	0	2474	60744	30000	90000
CW31	10101	380	33124	0	2864	80903	30000	90000
CW32	43237	142	49234	572	4407	82493	30000	90000

CW33	44192	246	46158	604	4312	80147	30000	90000
CW34	45827	152	47514	333	4049	77786	30000	90000
CW35	40422	123	44070	452	3880	77554	30000	90000
CW36	48401	54	50333	527	4356	75130	30000	90000
CW37	46320	140	50088	439	4336	74562	30000	90000
CW38	46295	65	51614	727	4663	75218	30000	90000
CW39	49001	13	50548	258	4062	72703	30000	90000
CW40	43363	39	49975	367	4154	75161	30000	90000
CW41	18855	23	34747	729	3358	87695	30000	90000
CW42	28208	28	29874	446	2715	86646	30000	90000
CW43	27591	16	31475	478	2855	87676	30000	90000
CW44	51154	101	47502	158	3822	80202	30000	90000
CW45	52332	76	57847	261	4676	81041	30000	90000
CW46	50597	261	47571	466	4295	73721	30000	90000
CW47	55598	144	60548	623	5308	73362	30000	90000
CW48	52604	179	61550	243	5038	77270	30000	90000
CW49	57788	71	62327	594	5340	76470	30000	90000
CW50	55408	208	61427	636	5451	77038	30000	90000
CW51	29446	41	25678	198	2165	71105	30000	90000
CW52	28177	90	22549	300	2081	63396	30000	90000
CW01	72314	321	80142	586	6918	64306	30000	90000
CW02	72337	351	79217	1451	7743	63443	30000	90000
CW03	77376	233	78793	588	6730	58129	30000	90000
CW04	77740	140	84235	851	7309	57316	30000	90000
CW05	72389	351	85428	1451	8209	62146	30000	90000
CW06	79840	233	84299	588	7143	59461	30000	90000
CW07	80147	140	87578	851	7559	59333	30000	90000
CW08	80098	351	88828	198	7211	60852	30000	90000
CW09	81464	233	84299	300	6855	56831	30000	90000
CW10	78785	140	84253	586	7045	55254	30000	90000
CW11	84258		90000		6750	54246	30000	90000
CW12	83187		90000		6750	54309	30000	90000
CW13	85575		90000		6750	51984	30000	90000

CW14	87463		90000		6750	47771	30000	90000
CW15	84228		90000		6750	46793	30000	90000
CW16	83412		90000		6750	46631	30000	90000
CW17	87957		90000		6750	41924	30000	90000
CW18	85147		90000		6750	40027	30000	90000
CW19	84241		90000		6750	39036	30000	90000
CW20	87436		90000		6750	34850	30000	90000

Tab.1 was constructed for the observation period from calendar week 30 of 2021 to calendar week 10 of 2022. Since the data table was large, we transposed the data from row to column form using an Excel function. In the first column, we have the volume of FG (Finished Goods) finished supports produced by the firm in that week. The second column presents the scrap mechanisms. Scrap mechanisms is actually a discarded mechanism from production, i.e. this part cannot be used further as a component due to a visual or mechanical defect. The next column is the volume of mechanisms; these are all the mechanisms produced by the foam line in a given week. Right after that is the scrap of mechanisms from that line. Thus, due to the inaccurate declaration of the production of mechanisms and the unreliable documentation of scraps from the foam line, we calculate an overall scrap factor of approximately 7.5% of the total production of mechanisms. Inventory is a numerical quantification of the number of finished supports, the number always presents the figure as of the Monday before the first shift. The last 2 columns are the values for the stock, indicating the minimum required stock and the maximum required stock. The thick blue markings in the table are the data related to the prediction. These data are predictions based on customer orders.
Fig. 2 shows the production of restraints in each week since the observation period. At the beginning in CW30-CW32, a low volume of production can be seen. This was due to customer summer shutdowns. Immediately thereafter, production for over two months was in the range of 40,000pc - 50,000pc. In CW41, production decreased rapidly to 20 000pcs of supports. This happened after the so-called chip crisis. The shortage of semiconductor components resulted in the suspension of production in almost all automotive plants around the world. This also had an impact on production at our plant. After some three weeks the market shook and got back on its feet again, we can notice in the graph that since week 44 production has risen over 50,000 units of the backrests, the numbers were getting below the 60,000 unit mark. CW51 and CW52 are the year-end weeks. The Christmas period and shutdowns have once again dipped the production of rests to just under 30,000pcs/week. Before Christmas the company had announced an increase in customer enquiries. In the very first week, the production of armrests reached the highest so far, 70,000pcs of this 70,000-80,000pcs weekly production. This trend continued until week 10 of 2022. This week, according to the current numbers, we can predict with customer recalls a range of 80,000pcs to 90,000pcs.

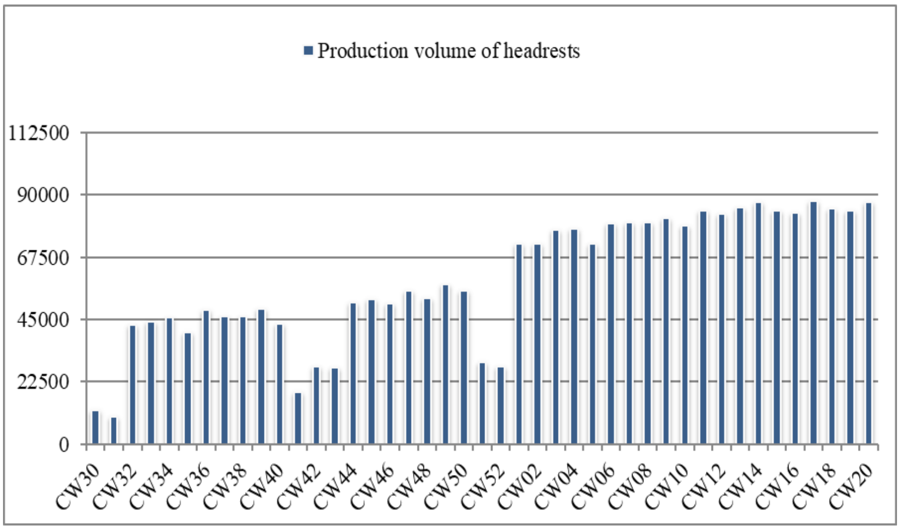

Fig. 2. Graphical presentation of the production volume of headrests

In Fig.3, the stock chart presents the value of the stock of machinery during each week. We obtained these values by summing the inventory stock with the initial value and the production of the mechanisms on the foam line, subtracting the scrap of the mechanisms at product finalization and the estimated scrap. The result is this graph, from it we can see that although the production of supports and mechanisms have a similar shape but this graph has a downward trend. With the increase in demand, the curve has been going down since CW42 last year. The chart also contains data with a forecast up to CW20. We are currently in CW10 with the current data. By forecasting we can observe that in the future the manufacturing company could get below the set minimum value of the stock of machinery. The risk is that the enterprise will therefore not have sufficient stock to produce finished parts and thus will not be able to supply the required quantities to customers.

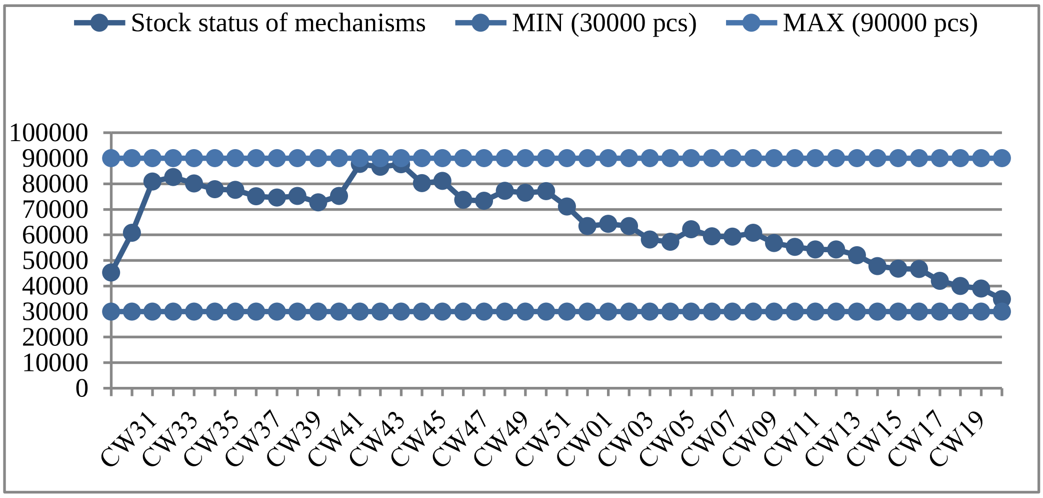

Fig. 3. Graphical presentation of the stock status of mechanisms

Proposal for streamlining logistics activities in production

Based on the elaboration of the analysis and the graphs, it is necessary to address the downward trend in the inventory of produced machinery.

There are risks that if the stock is insufficient and falls below the minimum specified threshold, the company may not have the components to create the final products, so production of headrests will be limited and customers will not receive the goods they want. In the case of the automotive sector, this can have fatal consequences. Stopping production at a customer's site is highly sanctioned and this could put the company in a very difficult financial situation. It would also give the company a bad reputation when looking for new customers and projects.

Should customers increase their appeals in the future, the company will not be able to supply the required quantities of bolsters.

If the stock values of machinery were below the minimum value, there would be a risk of stopping production of machinery if a machine broke down and the firm would not have sufficient stock to meet demand.

Proposals for solutions to ensure the production capacity of the enterprise

Increase in the working fund

Production on the foam line currently runs in a 3-shift operation, from Monday to Friday. Dry ice maintenance takes place on Saturdays, where every single mould and all the components on it need to be cleaned. This task takes 8 hours. If the line were not cleaned there would be a risk of breakdown on the machine and almost immediately defective pieces would appear - scraps.

For a three-shift operation, the foam line produces: production = 5 days * 24 hours = 120 hours

Production therefore takes place during 120 hours a week. The output per hour on the foam line with all 24 active moulds is thus: 24*(60/2,4)=600pcs/hour

From the hourly calculation we can find the weekly production in an ideal state: 600 pcs * 120 h = 72000 pcs/week

The weekly production during a 3-shift operation thus comes out to 72,000 pieces of machinery. As we can see, since the beginning of this year, the production company has been helping itself with extra shifts, so the production has exceeded 72 000k/week.

With the downward trend in stock levels with mechanisms, we need to increase these numbers so that we do not fall below the minimum value of 30,000 units.

If we went to a 4 shift operation, we would be able to get a few extra shifts. So for the numerical calculation we can use: production = 7 days * 24 hours = 168 hours

The difference between the time pool for 4 and 3 shifts is: 168 hours - 120 hours = 48 hours

However, we must not forget the maintenance of the machine, which is 8 hours in 3-shift operation, but when switching to 4-shift operation, this maintenance must be carried out twice a week, which represents a loss of 16 hours. In total we would get: 48 hours - 16 hours = 32 hours

These extra shifts would provide: 32 hours * 600 pcs = 19200 mechanisms

Thus, the total weekly capacity for a 4-shift operation including maintenance could be as high as 91,200 units.

Securing the new foam line

In order to limit the risk and thus ensure a stable inventory level, the company was considering the procurement of an additional foam line. The plant in Mexico does not make full use of one similar foam line, which consists of 16 moulds. It is therefore a smaller foam line compared to the current one at the plant in Slovakia, which consists of 24 moulds. To obtain information on the increase in total production, we have made a calculation.

In total, we will get 2 foam lines, one 16 and one 24 mould line for the plant in Slovakia. These 40 moulds at the same output represents per hour: 40 * (60/2,4) = 1000 pcs/hour
The business was scheduled to go back to standard mode for a 3 shift operation, which is 120 hours of pool time. Capacity per week with 40 moulds: 1000 pcs * 120 hours = 120000 pcs/week
In ideal condition and with all 40 moulds on per week, the production capacity will be up to 120,000 pieces of machinery.
As we can see in Fig.4, after the introduction of the second foam line, we reverse the downward trend of the stock of mechanisms and reach the ideal midpoint, namely approximately 60,000 units. To maintain the ideal state, we have used the planned production output of 97,000pcs of mechanisms. We will not use the full production capacity because we will not necessarily need it at present.
Such securing of another production line represents a diversification of risk for the company, not only in the creation of the stock of machinery but also in the overall production. By having 2 lines and a larger production capacity we will be able to afford to reduce the stock of machinery because we will be able to produce the required quantities in a much quicker time and in the event of a breakdown of one line the company will have another line that will be capable of production. This will give us enough time for the line to be repaired in the event of a breakdown, also the production of the head restraints themselves will not be compromised and so all planned exports will be met. This decision to acquire additional production equipment is also suitable for acquiring a new customer. Should the company be interested in further projects, it can present itself with sufficient production capacity and thus confirm that the company will not be put at risk from the production side.

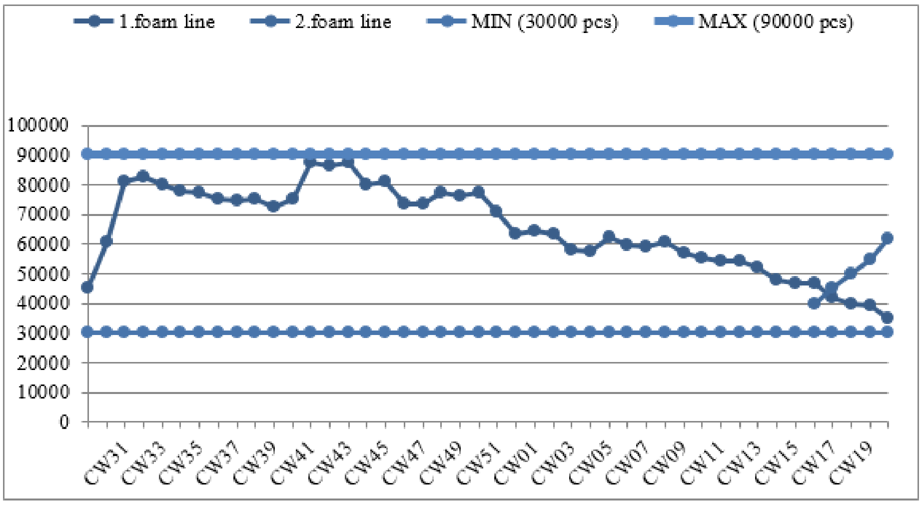

Fig. 4 Graphical presentation of the stock status of mechanisms after the start of the second foam line.

Financial implications of the proposed recommendations

In order to be able to imagine the real benefit of this production line, we have created a simple calculation with a possible financial expression. However, in order to preserve company confidentiality, we will give an approximate average calculation.

Tab.2 Financial comparison of the benefit of new projects

Price of headrests	Full production 120h/w	Actual production 132h/w	Required capacity in the next 10 CW	Capacity 120h/w for both foam lines	Maximum possible production 132h/w
Per piece	72000	91200	100000	120000	132000
6,5 eur	468 000 eur	592 800 eur	650 000 eur	780 000 eur	858 000 eur
Financial difference per week	265 200 eur				
Financial difference per year	12 729 600 eur				

We cannot directly relate the production of mechanisms to the financial indicator because it is only a component, but the production of mechanisms is almost directly proportional to the production of head restraints. In Table 3 we find first of all the indicative price of one headrest. At full production in a three-shift operation, the estimated or average revenue calculated for 72 000 pieces of mechanisms multiplied by the unit price comes out to €468 000 per week. The third column is at the current increased 4-shift production. This is a turnover of approximately €592 800. The required increased capacity of 100,000 with the introduction of the second production line will work out at €650,000. This value will be the most likely for the next period. The full capacity with a 3-shift line is also shown below. If we go to the maximum possible capacity of the production lines then this could increase sales up to 858 000€ per week.
As shown Tab.2, we have compared the actual production with the maximum possible capacity. In a week this represents a contribution of more than 265200€ and per year it could be more than 12 million. This benefit is not very likely in the coming months, years, but the company can achieve higher financial ratios if new projects are implemented or if new customers are acquired.

Conclusion

The paper was prepared for the needs of streamlining the production process and logistics activities in an automotive manufacturing company that produces head restraints for cars. On the basis of a detailed analysis of the company, we found out the current inventory level, the required production capacity of the company and eliminated the identified shortcomings. After conducting analysis and determining the MIN - MAX inventory level system, we further elaborated on the bottlenecks in the manufacturing company. The finding that there was an increasing demand for the products, but the enterprise had only a limited capacity to produce one component, allowed us to focus on developing a design for this solution so that the overall production of the enterprise would not be compromised. The proposed solutions minimised and diversified the risks in the creation of inventory, but also the overall production. The announced demand gradually increased in 2022 and 2023 and the foam line unfortunately did not provide sufficient coverage for the production of headrests. For this reason, we proposed to introduce another foam line into production. In the case of 2 lines, the production capacity will be increased, the company will be able to reduce the stock of machinery and will be able to produce the required quantities in a faster time. In case of failure of one line, the company will have another line that will be capable of production. The additional foam line will allow the company to win additional projects from new or existing customers. These results show that it is possible to optimize the operating costs of the company by proposing the minimization of total purchasing costs as an objective function and analyzing the bottleneck in the company. Financial calculations regarding the amount of investment, production capacity and possible values of saved costs confirm the possibility of further use. The considered information can be used in other important automotive manufacturers, which can be a topic for further research in this area.

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