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Optimization of Flat Product Production Costs by Implementing a Robotic Station: Experimental Approach

Mariusz Niekurzak[1]

[1] *AGH University of Krakow, Faculty of Management, al. A. Mickiewicza 30, 30-059 Krakow, Poland*

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Abstract

The aim of this study was to analyse the impact of technological modifications in the production cycle of flat components on reducing production costs. The research involved a detailed analysis of production processes, identification of key areas requiring improvement, and the development of new technological solutions. As part of the study, changes were implemented in the production process, and their effect on production costs was thoroughly evaluated. The technological modification in the manufacturing of the “metal support bracket” was designed to enhance efficiency by reducing unit production time and assessing the effect of this change on overall production performance. The main innovations included the introduction of a machining centre that integrated drilling, chamfering, and threading operations into a single process. This significantly reduced both unit production time and cost while eliminating machine downtime. Additionally, powder coating was replaced with electroplating, which resolved issues related to hole narrowing and ensured the maintenance of precise technical dimensions. The implemented changes resulted in a shorter production cycle, improved product accuracy and quality, and reduced machine downtime. The analysis demonstrated that these modifications positively influenced the enterprise’s competitiveness, generating substantial cost savings. This work provides a practical example of the application of industrial innovation, contributing to cost reduction, shorter production cycle times, and enhanced precision and quality of products.

Keywords
Production cycle, machining centre, laser cutting, powder painting, and threading.

Introduction

In the contemporary context of intensifying competition and rapidly evolving market conditions, manufacturing companies are compelled to continuously enhance their operational processes. The optimisation of production cycles and the implementation of technological innovations are key factors enabling increased efficiency, cost reduction, and shorter processing times. Simultaneously, there is growing pressure to maximise the utilisation of machine potential, minimise material losses, and reduce the amount of waste and rework. Furthermore, enterprises must address challenges related to the mitigation of human error and the elimination of downtime, both of which generate unnecessary costs and adversely affect overall performance.

In the context of flat bar manufacturing, which plays a crucial role across various industrial sectors, even minor improvements in the production process can yield significant technological and economic benefits. In particular, the implementation of advanced technologies, such as Computer Numerical Control (CNC) machines, enables the automation of key production stages, thereby enhancing precision, optimising raw material utilisation, and reducing order processing time (Niekurzak & Kubińska-Jabcoń, 2024). The effective utilisation of machine downtime further contributes to process improvement and the reduction of unproductive working time. However, previous studies on production process optimisation have often overlooked the specific conditions associated with flat bar manufacturing. The existing literature lacks detailed analyses examining how modifications to the production cycle affect economic and temporal efficiency. This study seeks to address this research gap by conducting a comprehensive analysis and evaluation of technological changes within the flat bar production cycle and their influence on reducing production costs.

***Corresponding author**: Mariusz Niekurzak – Gramatyka Street no 10, 30-067 Cracow, Poland, phone: +48 12 617 3990, e-mail: niekurz@agh.edu.pl*

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The primary objective of this study is to analyse technological modifications in the production process of metal brackets to enhance efficiency through the reduction of unit production time. The research adopts a case study approach based on a manufacturing company recognised for its production of furniture and interior design components. Within the scope of the study, key areas for potential improvement were identified, and specific modifications aimed at reducing production costs were proposed. The study also presents a model for improving critical operational areas, accompanied by recommendations to optimise manufacturing expenses.

The remainder of this article is structured as follows. Section 2 presents a review of the relevant literature and prior studies related to the analysed case. Section 3 outlines the research methodology in detail. Section 4 discusses the results of the experimental research and their interpretation. Finally, Section 5 summarises the key findings, highlights the study's limitations, and suggests practical implications and directions for future research.

Literature review

Subject of study

A flat bar is a metal structural element characterised by a rectangular cross-section and is widely utilised in the construction and engineering industries. Its broad range of applications arises from its favourable mechanical properties, including high load-bearing capacity and material durability, which make it indispensable in numerous fields of engineering and construction (Kosmol & Wilk, 2011). The uniform thickness and width of the cross-section make flat bars highly suitable for processing, facilitating operations such as cutting, bending, welding, and drilling (Grandys, 2013). Flat bars are commonly used in load-bearing structures such as machine frames, trusses, and supports, where their bending and tensile strength are of critical importance. As a result, they serve as fundamental structural components in a wide range of load-bearing applications (Łyczko, 2013). The significance of flat bars arises from their excellent mechanical properties, including high resistance to bending and tensile forces, which enable them to effectively transmit both static and dynamic loads. Owing to their precise geometric parameters, such as uniform thickness and width, flat bars are particularly well suited for structures that require high stability, thereby minimising the risk of deformation or structural damage (Kozłowski & Liwowski, 2011).

Furthermore, the ease with which flat bars can be processed through operations such as cutting, welding, and bending renders them highly versatile construction materials, indispensable for the realisation of both simple and complex engineering projects (Niekurzak & Kubińska-Jabcoń, 2021).

The production process of the component consists of several systematically executed stages that employ established methods and tools (Lewandowski, et. al., 2014). Each stage of the process has its own specific significance and directly influences the final quality and characteristics of the finished product (Rusek & Nowak, 2017). The subsequent phases of this process are described in detail below. The production process begins with laser sheet cutting, performed using a modern Adige-Sys LS5 fibre-optic laser cutter (Pasterniak, 2005). This technology is based on the use of a high-power fibre laser, which enables precise and rapid cutting of the material (Musiał, et. al., 2014). As a result, this technology enables the production of components with complex geometries, precisely positioned holes, and smooth edges that do not require additional finishing. Consequently, the lasercutting process ensures high dimensional accuracy and superior surface quality of the manufactured parts (Socha & Weber, 2009). The high precision of laser cutting technology ensures minimal dimensional deviations and guarantees high conformity with the design specifications. The laser cutting process of the component is illustrated in Figure 1.

Fig. 1. Cutting detail with a laser, source: own study.

Following the laser cutting stage, the component undergoes a chamfering (phasing) process, which is performed using a bench drill (Skoczylas, 2011). The purpose of this process is to enhance the quality of the component and to prepare it for the subsequent stages of machining (Adamiec & Tomaszewska, 2016). The removal of sharp edges significantly enhances safety during product handling and assembly by eliminating the risk of mechanical damage or injury. Moreover, it contributes to the improved aesthetics and overall functionality of the product (Patryka, et. al., 2006). After the chamfering process is completed, the component undergoes a key stage, powder coating. This modern surface treatment technology involves the application of electrostatically charged powder particles to the product's Surface (Santarek, et. al., 2017). The powder is applied using specialised electrostatic spray guns and adheres to the metal surface due to the difference in electrical charges, eliminating the need for additional binding agents (Feld, 2018). After the powder coating is applied, the components are transferred to a curing furnace, where they are exposed to elevated temperatures, typically ranging from 160°C to 200°C (Harańczyk, 2017). Under thermal conditions, the powder melts and undergoes polymerisation, forming a durable, uniform, and damage-resistant protective layer. This stage is crucial for achieving the optimal physicochemical properties of the coating, including resistance to corrosion, abrasion, and adverse weather conditions (Rybacki, 2012). After the powder coating process is completed, the component undergoes the threading stage, which constitutes a key element of the technological cycle (Blicharski, 2020). This operation, performed using a handheld tap wrench, consists of precisely cutting internal threads on the surface of the component (Dohnal, et. al., 2011). Threading is a necessary process due to dimensional changes in the holes resulting from the powder coating stage. The paint layer, hardened at high temperature, reduces the hole diameter, which can hinder the proper installation of fasteners such as bolts or screws (Cichosz, et. al., 2017). The reduction in hole diameter results from the uniform powder-coated surface, which not only fills microirregularities but can also partially distort previously machined holes (Sosna, et. al., 2018). To restore the required technical parameters and ensure the full functionality of the connections, it is necessary to recreate precise threaded cuts in accordance with the design specifications. Numerous scientific studies have addressed the issue of improving production efficiency through the use of various tools and optimisation methods. Selected examples are presented below.

Li et al. (2023) observe that, in production processes, random causes occur continuously but generally have minimal impact. These factors are difficult to detect and often necessitate multiple process adjustments. Special causes, in contrast, are easier to identify, allowing for their prompt elimination or reduction. Research conducted by (Lee & Yang, 2023) demonstrates that the Ishikawa diagram, when applied in combination with other quality management methods and tools, significantly enhances process quality within an enterprise. In response to increasing customer demands, manufacturing companies are implementing advanced enterprise improvement systems to enhance operational efficiency and achieve a competitive advantage that is difficult to replicate. An overview of such methods is provided by (Ingle et al., 2023). Weingartshofer et al. (2023) discuss approaches to improving the efficiency of production processes through the application of quality management tools, highlighting gains in production performance and the optimisation of key manufacturing processes. Furthermore (Okuyelu & Adaji, 2024) show that the adoption of Industry 4.0 tools reduces the time required to complete production orders within technological machine chains operating across diverse business profiles.

Following a comprehensive review of both domestic and international literature, the author undertakes an in-depth analysis, using a case study methodology, to investigate opportunities for improving production efficiency through the systematic identification of bottlenecks and the implementation of targeted tools for modifying production processes, with a particular emphasis on reducing production time. The study is characterised by a high degree of innovation, as it integrates theoretical insights with practical application, and aims to demonstrate the tangible potential for optimising, streamlining, and significantly shortening production processes in real manufacturing environments.

Materials & Methods

As part of the research, detailed analyses and systematic descriptions of individual stages of the flat production process were conducted. The characteristics of the finished product were thoroughly discussed, including its dimensions, technical specifications, and application in subsequent processing stages (Gliwa, 2025). Furthermore, a comprehensive description of the original production cycle was provided, encompassing key stages such as laser cutting, phasing, powder coating, and threading, along with detailed descriptions of the applied technologies and equipment. An in-depth analysis of working time across the production cycle was performed, a technological route was developed, and proposed technological modifications were introduced, including the replacement of laser cutting and powder coating operations with modern machining technologies. The final stage of the research involved a comparative assessment of production efficiency and operating costs before and after the implemented modifications, as well as the formulation of recommendations for further technological development and optimisation of the production process. The research was conducted in accordance with the adopted methodological algorithm, as illustrated in Figure 2.

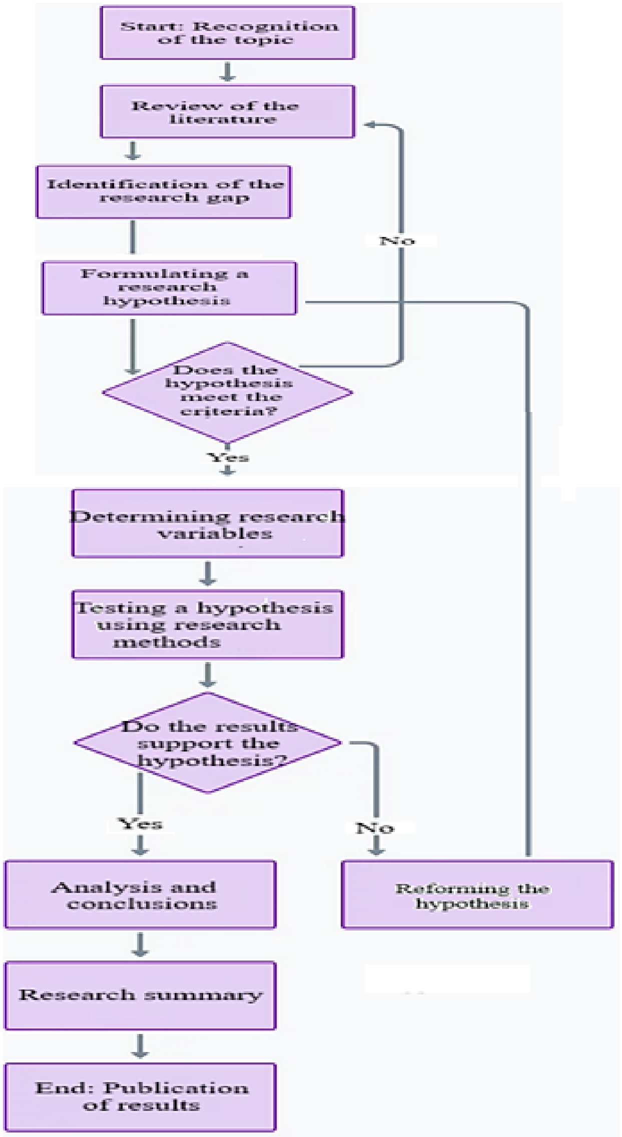

Fig. 2. Flowchart of the research methodology, Source: own study.

The analysed flat bar functions as a metal support bracket and constitutes a critical structural component in furniture constructions such as chairs and armchairs. Its primary function is to ensure the stability and structural integrity of the furniture, particularly within load-bearing zones that are subjected to significant static and dynamic loads during use. Although the component remains concealed within the furniture structure and is not visible to the end user, it plays a decisive role in ensuring product safety and long-term durability. High resistance to mechanical damage, resulting from the appropriate selection of material and the applied manufacturing process, renders the bracket a reliable element supporting the overall load-bearing structure. The flat bar was manufactured from a steel sheet with dimensions of 5.0 × 1250 × 2850 mm, in accordance with the requirements of the PN-EN 10111 (2011) standard, which specifies the properties of hot-rolled steel for general applications. The material selection process included detailed quality control procedures aimed at verifying compliance with both technological and functional requirements. The steel sheet was subjected to mechanical and endurance testing, including the evaluation of plasticity, tensile strength, and resistance to deformation. Additionally, the surface quality was assessed for potential defects such as cracks, non-metallic inclusions, or surface irregularities that could adversely affect the quality and performance of the finished product. The results of the conducted tests confirmed that the material meets all applicable normative and technological requirements, thereby ensuring adequate mechanical properties and durability under long-term operating conditions.

The two-dimensional drawing of the flat plate, presented in Figure 3, was developed in accordance with the PN-EN 22768 (1999) standard, with particular emphasis on the specification of tolerances for dimensions not individually toleranced.

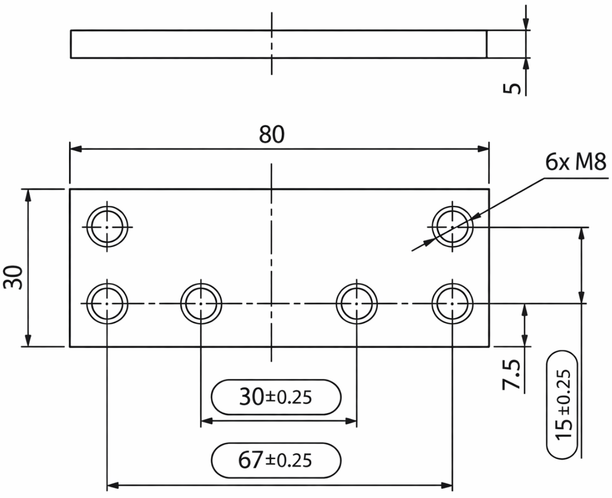

Fig. 3. Detail project in 2D, source: own study.

The standard defines permissible dimensional deviations selected to ensure the required precision of the component while maintaining the efficiency of the manufacturing process. This approach enabled the achievement of dimensional accuracy sufficient for the bracket to perform its intended structural function within the furniture assembly. To illustrate the geometry of the flat plate, a three-dimensional model of the component was developed before the implementation of design modifications, as shown in Figure 4.

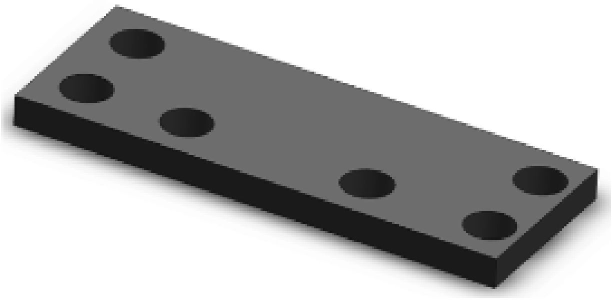

Fig. 4. 3D detail project before the construction change, source: own study.

In addition, the flat bar was subject to the company's Factory Production Control (FPC, ZKP) procedures in accordance with the requirements of the [24] PN-EN 1090-2:2018 (2018) standard. This control encompassed monitoring all stages of the production process, from raw material preparation through rolling and finishing operations to the final quality assessment of the finished component. The standard regulates the execution of steel and aluminium structures and ensures that the manufactured elements meet stringent requirements in terms of safety, dimensional accuracy, and durability.

To enhance the efficiency of the flat bar production cycle in the analysed company, several key modifications were proposed to reduce machine workload, thereby shortening processing time and increasing overall production efficiency. These changes involved the reconfiguration and optimisation of processes performed on existing production equipment, supported by the application of lean manufacturing principles. Additionally, the study proposed the acquisition of a new machining centre, which would significantly contribute to long-term cost reduction and process efficiency. Given the necessity for manufacturing enterprises to remain competitive and deliver high-quality, high-precision products, investments in innovative machining technologies are essential. Consequently, the capital expenditure associated with the purchase of new machinery was excluded from the economic analysis, as it forms part of the company's gradual modernisation strategy. The analysis, therefore, focused exclusively on the efficiency gains achievable through the application of modern manufacturing equipment.

Results

Production cycle before the technological change

Before the implementation of changes in the production process, the manufacture of the metal support bracket comprised three fundamental technological operations carried out at separate production workstations. Each operation was assigned to a dedicated production cell, ensuring specialisation in the execution of specific tasks. A detailed description of the individual process stages is presented in Table 1.

Table 1
Primary technological route

Operation number	Name of the operation	Labour consumption, s	Production socket number
10	Edge pacing over the laser	20	PS16
20	Chamfering of the hole for threading	50	WI09
30	Threading	45	GP10

Source: own study.

The total processing time for a single component amounted to 115 seconds and included sequential operations performed at three distinct production stations. This division of labour enabled effective utilisation of available resources and ensured high operational quality. However, the necessity of transporting components between stations introduced inefficiencies that limited overall process performance. These limitations influenced the decision to modify and optimise the technological sequence in subsequent stages of production development. Based on historical data regarding monthly production volumes from the previous year, the approximate working time for each month was estimated. The calculations assumed a unit manufacturing time of 115 seconds per product. The analysis revealed considerable variability in both monthly production volume and working time, with pronounced peaks observed in January, October, and December. In contrast, the lowest production levels occurred in April and August, resulting in reduced working time during these months. The total working time in 2023 amounted to 657,097 hours, indicating a large-scale production process for the metal support bracket.

The previously employed laser cutting process for the production of the flat plate involved cutting the final geometry, including technological holes, within a single production stage. Although this approach enabled the manufacture of finished components, it was associated with significant limitations, such as extended processing time, increased material consumption, and greater technological complexity.

As part of the modernisation of the technological process, a decision was made to simplify and optimise the laser cutting stage. The revised approach involves cutting plates of predefined dimensions without introducing technological holes at this stage of production (Fig. 5). This modification substantially simplified the laser cutting program, thereby reducing machine workload and shortening the duration of cutting operations.

Fig. 5. Detail after laser cutting, source: own study.

In previous production methods, drilling, chamfering, and threading operations were performed at separate workstations using manual tools, such as hand drills. This approach was time-consuming, required intensive operator involvement, and was associated with a high risk of human error, which adversely affected the quality and repeatability of the component (Fig. 6). Furthermore, performing chamfering and threading on separate machines necessitated repeated transportation between workstations, resulting in additional downtime.

A further significant limitation was the powder coating process, which was carried out between these operations. This stage required an average duration of 1.5 hours and substantially extended the overall production lead time.

Fig. 6. Tiles before processing on a lathe, source: own study.

Currently, chamfering, threading, and drilling operations have been integrated into a single process performed at a machining centre. Within one machining cycle, a batch comprising 56 components can be processed. Each machining program has a duration of approximately 51 minutes, resulting in a substantial reduction in processing time compared to the previously used individual operations. The application of a machining centre enables all key operations to be executed within a single technological sequence, thereby eliminating the need for powder coating between chamfering and threading stages. The coating process has been relocated to the final stage of production, which reduces the number of technological interruptions and minimises machine downtime (Fig. 7).

Fig. 7. Phasing with the help of a machining centre, source: own study.

The new process configuration has significantly improved the overall efficiency of the production line. Eliminating the need for inter-station transport reduced time-consuming operations and decreased the number of potential failure points. The centralisation of processes on a single machine enhanced machining accuracy and component repeatability, which translated directly into higher final product quality. Moreover, operating costs were reduced due to a smaller number of machines in use and decreased labour requirements. As a result, the implementation of a machining centre for chamfering and threading operations led to improved production performance, cost reduction, and increased production throughput, thereby directly enhancing the company's market competitiveness.

The previous finishing process involved powder coating. Although this method provided an acceptable aesthetic appearance, it was associated with several significant limitations, including insufficient coating durability, high processing costs, and adverse effects on dimensional accuracy. The relatively thick powder coating layer reduced the effective diameter of technological holes, resulting in deviations from nominal dimensions. To address this issue, the powder coating process was replaced with electrolytic galvanising. This modification provided several advantages, including improved coating durability and enhanced corrosion resistance. Furthermore, the thinner zinc layer eliminated the problem of hole diameter reduction, thereby ensuring the maintenance of precise dimensional tolerances. The galvanising process is performed in

a barrel system, which increases processing efficiency and eliminates the need for a separate drying stage previously required for powder coating. An additional advantage of the new finishing method is the improved surface quality, characterised by a uniform, aesthetic, and durable coating (Fig. 8).

Fig. 8. Galvanically galvanised detail, source: own study.

Powder coating is characterised by the formation of a thick and uniform protective paint layer; however, this characteristic also introduces certain technological limitations. One of the most significant issues is the reduction in the diameter of threaded holes caused by paint deposition within them. The substantial coating thickness leads to difficulties in subsequent operations, such as threading, and necessitates additional corrective measures to restore the required thread dimensions and functionality.

In contrast, electrolytic galvanising produces a thinner and more uniformly distributed protective layer. Consequently, this method does not significantly affect the dimensions of threaded holes, making it more suitable for components requiring high geometric precision. To evaluate differences in coating thickness, detailed measurements were performed using a digital calliper, enabling accurate assessment of the impact of both coating methods on component dimensions. The results indicate that powder-coated layers exhibit greater thickness than galvanically galvanised coatings, which is directly attributable to differences in material application technologies (Fig. 9). In the case of electrolytic galvanising, the electrochemically deposited zinc layer forms a thinner coating, as confirmed by an average thickness difference of 0.2 mm, as presented in Table 2.

Fig. 9. Comparison of detail with powder and galvanised painting, source: own study

Table 2
The detailed thickness statement

Powder-painted detail thickness, mm	Galvanised detail thickness, mm	Difference, mm
5.25	5.05	0.20

Source: own study.

Production cycle after technological change

The implemented technological changes significantly affected the production route by reducing the unit processing time from 115 seconds to 55 seconds. The key improvement involved replacing three separate machines with a single modern CNC machining centre, which enables the execution of multiple operations within one machining cycle. As a result, the process became more integrated and efficient, leading to a reduction in the duration of individual production stages. The introduced modifications not only improved the flow of technological operations but also contributed to lower operating and maintenance costs, as well as a reduction in the number of required operator interventions.

Based on historical data concerning monthly production volumes from the previous year, an analysis of working time was conducted following the implementation of the technological changes, which resulted in a reduced unit production time of 55 seconds per component. The calculations accounted for monthly production demand, enabling the estimation of actual working time for each month. The monthly analysis revealed significant variability in production volume and total operating time throughout the year. The highest production levels and corresponding working times were recorded in December, while the lowest values occurred in April and August. The total working time in 2023 amounted to 1,131,350 seconds (314.26 hours), reflecting the scale of production operations. The average monthly production volume was 1,714 units, with an average monthly working time of approximately 94,279 seconds (26.19 hours).

Discussion

This section of the research presents a detailed analysis of the production process performance before and after the implementation of technological changes. A comprehensive comparison of production efficiency and cost structure was conducted for both scenarios. The analysis also included the cost per unit and the total annual production cost, based on historical data from the previous year.

The cycle performance analysis focused on drilling, chamfering, and threading operations, as these processes were replaced by the vertical CNC machining centre. The coating process was excluded because powder coating was substituted with electrolytic galvanising, which significantly reduced the finishing cost to EUR 0.21 per unit. As a result of these changes, the unit production cost decreased to EUR 1.75, leading to a total production cost of EUR 35,878 and an overall improvement in production efficiency of 38%. It should be noted that the two processes differ fundamentally and are not directly substitutable; therefore, a direct comparison of certain operations may be unreliable. The analysis of unit production time for the metal support bracket was performed to evaluate monthly production efficiency in 2023 and to support forecasting for the following year. Before the technological change, the unit production time was 115 seconds, whereas after the implementation of the CNC machining centre, it was reduced to 55 seconds. This reduction provides a clear measure of improved efficiency and the effectiveness of working time utilisation. The primary impact of the technological change is the significant time savings achieved. The difference in total working time before and after the process modification amounted to 342.83 hours, representing a reduction of 52.17% in total production time. The detailed results of this analysis are presented in Table 3.

Table 3
Differences in the work cycle before and after the technological change

No	Name	Working time before the change, h	Working time after the change, h	Difference	Reduction of working time, %
PXXX-YYY	Metal support of the backrest	657.09	314.26	342.83	52.17

Source: own study.

The most significant outcome of the technological change is the increased production performance (Table 4). Reducing the individual cycle time from 115 seconds to 55 seconds led to a substantial improvement in efficiency, enabling a higher number of units to be produced within the same working time.

The technological change in the production process of the metal support bracket has led to a substantial improvement in production efficiency. Reducing the unit production time from 115 seconds to 55 seconds resulted in a reduction of total working time by more than 50%. Consequently, the monthly working time has been significantly decreased, which may contribute to lower operating costs, an increased number of units produced within a given period, and enhanced overall production efficiency. A comparative summary of the total operating time of the machining centre before and after the implementation of the technological changes is presented in Table 5.

In the initial phase of the analysed period, the operation of the machine exhibited considerable reserves in terms of utilising its technological potential. The highest utilisation was recorded in the last quarter of the year (October–December), with 80 operating

Table 4
Increasing work efficiency

Index	Months	Working time before the change, h	Working time after the change, h	Increasing work efficiency, %
PXXX-YYY	I.23	56.86	27.19	47.83
PXXX-YYY	II.23	53.92	25.78	
PXXX-YYY	III.23	53.28	25.48	
PXXX-YYY	IV.23	46.63	22.30	
PXXX-YYY	V.23	53.02	25.36	
PXXX-YYY	VI.23	53.34	25.51	
PXXX-YYY	VII.23	53.34	25.51	
PXXX-YYY	VIII.23	46.31	22.15	
PXXX-YYY	IX.23	50.47	24.13	
PXXX-YYY	X.23	58.84	28.14	
PXXX-YYY	XI.23	55.90	26.73	
PXXX-YYY	XII.23	75.13	35.93	

Source: own study.

Table 5
Summary of machining centre operating hours before and after the technological change

Months	Working time before change, h	Working time after the change, h	Increase in performance, %
January	86	113	32
February	98	124	26
March	65	90	39
April	59	81	38
May	80	105	32
June	57	83	45
July	67	93	38
August	79	101	28
September	78	102	31
October	80	108	35
November	58	85	46
December	78	114	46

Source: own study.

hours in October and 78 hours in December. These results indicate that the production schedule was well aligned with the machine's operational requirements and demonstrate a high degree of integration of the device into the plant's production processes. The regular workload of the machine during this period reflects the effective adaptation of both technological and organisational processes, which allowed for the minimisation of downtime and maximisation of operational efficiency.

This part of the research also includes an analysis of the costs associated with producing the component before and after the implementation of process changes (Table 6). The analysis was based on a detailed comparison of unit production costs, as well as the total annual production costs, using historical data from previous years. The evaluation considered the production of 20,570 components in 2023, allowing for an accurate assessment of the impact of the introduced improvements. This comparison provides insight into the extent to which the production process changes contributed to the reduction of unit costs and the overall annual savings, while maintaining the required quality of the final product.

Following the optimisation of the technological process, several significant changes were implemented to simplify production and reduce costs. The base cost of a component without holes remained unchanged at EUR 7 per item. Instead of performing laser drilling, chamfering on a table drill, and manual threading, these operations were consolidated and carried out using a milling machine. This combined process, including drilling on both sides and threading, incurred a cost of EUR 0.83 per item. The finishing process was also modified: powder coating was replaced by electrolytic galvanising, which reduced the finishing cost to EUR 0.21 per item. As a result of these changes, the unit production cost decreased to EUR 1.73, corresponding to a total production cost of EUR 35,586.10 for the full annual output. A comparison of costs before and after the changes demonstrated total savings of EUR 8,228, representing a reduction in total production costs of approximately 18.48%. The reduction in unit costs was achieved by replacing several manual and time-consuming operations, such as hand thread-

Table 6
List of the unit cost of detailed production

Cost estimate of a steel support bracket			
Details – 20,570 pcs (data from production 2023)			
Before the change		After the change	
The unit cost of detail without holes	0.69 EUR	The unit cost of detail without holes	0.69 EUR
Unit cost of burning the holes with the laser	0.05 EUR	Unit processing cost on a milling machine (drilling, bilateral phasing, threading)	0.83 EUR
The unit cost of staining the metal on a table drill	0.49 EUR		
The unit cost of threading the detail on the handbag	0.21 EUR		
Unit cost of painting powder detail	0.69 EUR	The unit cost of painting with zinc galvanic coating	0.21 EUR
Unit production cost [EUR/pcs]			
2.13 EUR		1.73 EUR	
Production cost 20,570 pcs.			
43,814.1 EUR		35,586.1 EUR	
Saving			
8,228 EUR			

Source: own study.

ing and powder coating, with more automated and efficient technological solutions, including milling and galvanisation. Using monthly production data from 2023, a detailed analysis of production costs was performed for the period before the technological changes. The implementation of the new production methods reduced the unit production cost from EUR 2.13 to EUR 1.73. Estimated monthly production costs after the process modification are presented in Table 7.

The analysis indicates that following the implementation of changes in the production process, the total unit cost of manufacturing a metal support bracket decreased from EUR 2.13 to EUR 1.73. For an annual production of 20,570 units, the total production cost was reduced from EUR 43,814.10 to EUR 35,586.10, resulting in savings of EUR 8,228. Higher production volumes would further amplify these cost savings. Figure 10 presents a visualisation of the monthly production costs before and after the technological changes in the studied production cycle.

Table 7
Monthly production costs after technological change

Unit production cost: 1.73 EUR					
Index	Type	Name	Date	Production lot size	Production cost [EU]
PXXX-YYY	Production	Metal support of the backrest	I.23	1780	3079.4 0
			II.23	1688	2920.24
			III.23	1668	2885.64
			IV.23	1460	2525.80
			V.23	1660	2871.80
			VI.23	1670	2889.10
			VII.23	1670	2889.10
			VIII.23	1450	2508.50
			IX.23	1580	2733.40
			X.23	1842	3186.66
			XI.23	1750	3027.50
			XII.23	2352	4055.17
SUM				20 570	35586.10

Source: own study.

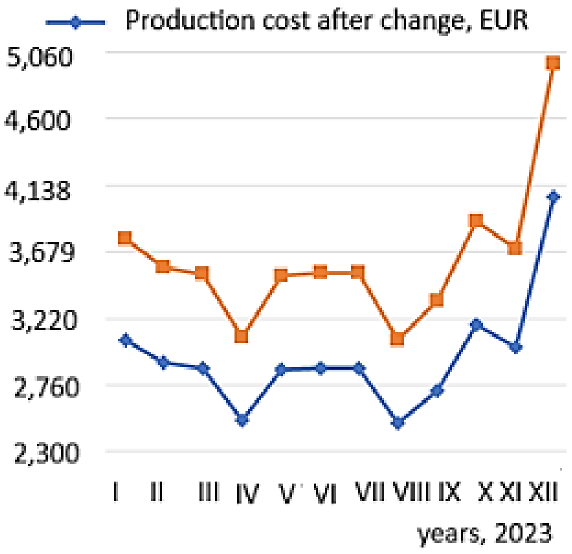

Fig. 10. Monthly statements of costs before and after the introduction of a technological change in the studied production cycle, source: own study.

The analysis of the cost estimate for the metal support bracket before and after the production process changes demonstrated significant savings of 18% (Table 8), contributing to improved financial efficiency for the company.

Table 8
Cost estimate to make a bracket

Date	Production lot size	Production cost before the change, EUR	Production cost after the change, EUR	Cost decrease, %
I.23	1780	3791.40	3079.4 0	18
II.23	1688	3595.44	2920.24	
III.23	1668	3595.44	2885.64	
IV.23	1460	3109.80	2525.80	
V.23	1660	3535.80	2871.80	
VI.23	1670	3557.10	2889.10	
VII.23	1670	3557.10	2889.10	
VIII.23	1450	3088.50	2508.50	
IX.23	1580	3365.40	2733.40	
X.23	1842	3923.46	3186.66	
XI.23	1750	3727.50	3027.50	
XII.23	2352	50009.76	4055.17	
SUM	20 570	43814.10	35586.10	

Source: own study.

The modification of the production process for metal backrest supports resulted in significant savings, both in unit production costs and total production costs. By reducing the number of production stages and optimising the process, the company can achieve substantial cost reductions, thereby enhancing its competitiveness and profitability.

Conclusions

Based on the conducted research, the following conclusions can be drawn:

1. The implementation of advanced technologies, such as laser cutting and CNC machining centres, ensures higher precision and repeatability in production.
2. Zinc galvanisation eliminates issues related to paint deposition in threaded holes, making this method more suitable for components requiring high dimensional accuracy.
3. Optimising the technological sequence minimises inter-operational time and enhances overall production efficiency.
4. Centralisation of processes on a single device reduces the risk of material errors and losses and supports precise control of production.
5. The use of a CNC machining centre significantly reduced the unit production time, from 115 seconds to 55 seconds, resulting in a 47.83% increase in production efficiency.
6. The technological change led to a reduction in the machine's total annual operating time by approximately 343 hours, corresponding to a 52.17% decrease in total working time.
7. The introduction of the machining centre reduced the unit production cost from EUR 2.12 to EUR 1.73, which, for an annual production volume of 20,570 units, resulted in total savings of EUR 8,039.
8. The total production cost decreased from EUR 43,505 to EUR 35,466, representing an 18% reduction in costs.

In summary, the considerations presented regarding the design of an innovative model for reducing machine changeover times to improve production efficiency do not fully address the entire issue. They represent only a fragment of the problem, but at the same time provide an incentive for further research in this area. Future work will focus on defining and identifying the key factors necessary for implementing such an ambitious plan in the furniture industry, where environmental protection and high-efficiency production can coexist. The approach presented, which typically requires significant time investment from company personnel, is sometimes regarded as a limitation. Nevertheless, dedicating time to improvement activities is essential to achieving meaningful results. Therefore, future models should incorporate artificial intelligence methods. The application of AI techniques could enable the development of more effective and efficient production models. A hybrid approach should be considered, combining elements of established management tools with AI-based expert knowledge models, to optimise production processes and maximise operational efficiency.

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