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An Integrated Approach to the Development and Implementation of New Technological Solutions

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Abstract

Dynamic technological changes and the variability of market requirements pose significant challenges for modern manufacturing companies in the effective development and implementation of new technological solutions. The aim of the research was to develop an integrated approach covering all key stages of implementation—from formulating technological solutions, through selecting and evaluating variants, to preparing and managing production processes—under the conditions of a medium-sized manufacturing company specializing in the batch production of steel constructions. The analysis was based on an interdisciplinary approach, combining methods of creative design of new technological solutions, including Blue Ocean Strategy, value proposition design, and QFD methodology, with analytical approaches that include multi-criteria evaluation of solution variants, technical preparation of production, as well as the organization and management of production processes in modified organizational conditions. This approach enabled a comprehensive assessment of the developed solutions, taking into account both their operational potential and practical feasibility in realistic implementation conditions, through the use of case studies and simulations to validate the results. The results of the research indicate that integrating methods for creating new solutions with analytical assessment and simulation tools leads to a more precise and data-driven approach to process design, enabling better decision-making based on thorough analysis and predictive modeling. Furthermore, this approach allows for a significant reduction in the risk of implementation failure through early identification of potential problems. The conclusion of the study confirms that a comprehensive and interdisciplinary approach to the implementation of new technologies ensures better alignment with customer demands, reduces production downtime, and enhances product optimization and resource utilization, which are critical factors in building a sustainable competitive advantage for manufacturing companies. The proposed approach enables more deliberate design and organization of manufacturing processes, supporting their flexible adaptation to changing market and technological conditions.

Keywords: industrial implementations; decision support in production; process optimization strategies; comprehensive production preparation; modeling and simulation of manufacturing processes

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Academic Editors: Pier Francesco Orrù, Tsega Yenew Melesse and Mohamed Shameer Peer Mohamed

Received: 7 September 2025
Revised: 17 October 2025
Accepted: 21 October 2025
Published: 23 October 2025

Citation: Plinta, D.; Radwan, K. An Integrated Approach to the Development and Implementation of New Technological Solutions. *Sustainability* **2025**, *17*, 9434. https://doi.org/10.3390/su17219434

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1. Introduction

The modern economy is characterized by rapid technological change, increasing unpredictability of the market environment, and growing pressure on manufacturing companies

to be innovative and flexible [1]. As the importance of sustainable development in the manufacturing sector continues to grow, an increasing number of concepts, technologies, and practical solutions are emerging to improve and assess sustainable manufacturing practices. Sustainability criteria cover environmental, economic, and social aspects. The sustainable production framework proposed by the authors consists of five layers—firstly, collecting data and information from the production process, then analyzing and interpreting this data, and assessing the current state of sustainability. Next, it is proposed to transform the acquired knowledge into concrete actions, develop new theories, frameworks, or models to support decision-making and innovation, and finally achieve the target state of fully sustainable production [2]. Modern stakeholders are increasingly formulating expectations for deep-tech projects, requiring that the value proposition should include a clearly defined aspect of sustainable development [3].

The introduction of new technologies is one of the key factors determining a company's ability to maintain competitiveness and adapt to changing market conditions [4]. Particularly important is the effective implementation of technological solutions that not only address current market needs but also enable companies to anticipate and shape future trends [5]. The literature highlights an insufficient understanding of the mechanisms of new technology implementation by enterprises. There is also a lack of research providing empirical evidence on the actual processes of implementing these technologies in manufacturing companies [6]. Accordingly, there is a need to advance the theoretical and empirical understanding of current implementation practices, to systematize existing knowledge, and to outline directions for future research and development efforts [2].

Previous research indicates that the outcomes of implementing new technologies in industrial enterprises vary considerably, with studies focusing on different stages and aspects of the process. The literature includes research addressing solution design, variant analysis, as well as the improvement of practical practices. These contributions are valuable, as they have identified key factors supporting successful implementation and highlighted organizational, technological, and environmental considerations that need to be taken into account. A considerable number of studies have examined the implementation of sustainable practices and Industry 4.0 technologies in enterprises, providing quantitative insights into their impact on performance and sustainability. Ali et al. [7] surveyed 288 SMEs and showed that sustainable manufacturing practices improve competitive capabilities and overall sustainable performance, particularly under supportive environmental regulations. Jamwal et al. [8] systematically reviewed 127 studies on Industry 4.0 technologies and found that they can enhance production sustainability, though shop-floor implementation remains underexplored. Similarly, Li et al. [9] analyzed 36 enterprises using a FI-RST model and demonstrated that integrating MES, IIoT, and 3D printing significantly improves economic, environmental, and social aspects of sustainability. However, despite significant progress in these areas, the literature reveals a lack of comprehensive approaches that integrate the creative design of solutions with their analytical evaluation and implementation management in real manufacturing environments. This research gap becomes particularly pronounced in the scarcity of empirical studies that validate the effectiveness of such approaches in industrial practice, as well as in the insufficient integration of the proposed methods with the broader challenges of sustainable development. As a consequence of these limitations, manufacturing enterprises frequently experience implementation failures, resulting in resource waste, delays, and even the loss of competitive advantage. Moreover, the lack of integration of environmental and social considerations further constrains the long-term applicability of new technologies under increasing regulatory and market pressures.

Consequently, there is a growing need to develop an integrated approach that supports conscious design and management of technology implementation under produc-

tion conditions. Through this approach, enterprises can foster innovation, facilitate the faster integration of new solutions, and reduce adverse effects on both the environment and society.

The aim of this study was to develop and empirically verify an integrated approach to the implementation of new technological solutions in manufacturing companies. The proposed concept covers all key stages of implementing new solutions—from formulating the concept of solutions, through selecting and evaluating variants, to preparing and managing implementation in a production environment. The conducted analyses enabled a comprehensive assessment of the developed solutions, considering both their potential and their practical feasibility in real implementation environments. Through this integration, the study offers a novel perspective on the current state of knowledge, provides practical guidance for industrial enterprises, and lays a foundation for further research on methods that facilitate technology implementation in accordance with the principles of sustainable development.

The results of the research indicate that such a comprehensive approach not only supports more conscious design of production processes but also reduces the risk of implementation failure by identifying potential technological and organizational barriers at an early stage. The proposed concept may constitute a significant contribution to the development of methods for managing new technological solutions in manufacturing enterprises, supporting their ability to respond flexibly to changing technological and market conditions. Furthermore, this approach may be extended to support sustainable development initiatives, enabling enterprises to integrate technological innovation with environmental and social objectives.

2. Conditions for the Development and Implementation of Technologies in Manufacturing Companies

Continuous transformations in the fields of science, economy, and technology constitute a significant driving force for the development of entrepreneurship and business activities. Competition is a crucial factor that drives economic growth [10]. Enterprises that continuously develop and strengthen their competitive advantage are able to sustain long-term operations in the market [11].

In response to increasing competitiveness in the global market, companies must develop strategies that enable them to compete successfully [12], both by optimizing cost structures and by introducing innovative, differentiated product offerings that address specific market needs [13].

Among the various competencies, particular importance is attributed to innovativeness, which constitutes a key factor differentiating organizations from their competitors and serving as the foundation for establishing competitive advantage [14]. Consequently, companies actively pursue comprehensive analyses and knowledge to augment their innovation capacity [12]. Organizations unable to generate and implement innovations are likely to encounter significant challenges in sustaining their market position [14].

Another challenge driving the development of enterprises is the concept of Industry 4.0, which is becoming not only an opportunity but also a necessity for companies seeking to maintain competitiveness in a rapidly changing economy. Industry 4.0 encompasses technologies from various fields, requiring profound transformations in innovation, production, logistics, and services. It represents a digital revolution aimed at digitizing manufacturing processes with minimal human intervention. The success of this project largely depends on the integration of existing and new technologies with current production processes [15]. The ability of enterprises to effectively implement Industry 4.0 solutions is becoming a new determinant of their competitive advantage.

Industry 5.0 is an extension and complement to the Industry 4.0 paradigm, emphasizing the role of research and innovation in shaping industrial development in a way that considers both social and environmental needs, going beyond economic and technological goals. Within this broader approach, three key aspects can be identified: human-centricity, sustainable development, and industrial resilience [16]. Industry 5.0 promotes collaboration between humans and machines as well as ethical and sustainable practices while facing challenges related to AI integration, workforce adaptation, and balancing social, environmental, and technological objectives [17].

Despite extensive theoretical achievements in the field of business competitiveness analysis, significant research gaps are still evident. In particular, there is insufficient consideration of the practical conditions for implementing strategies aimed at strengthening an organization's market position, especially in the context of the growing complexity and instability of the economic environment. This justifies the need for in-depth empirical research aimed at identifying the real determinants of the effectiveness of strategic actions and mechanisms that support sustainable development.

3. Methods Supporting the Development and Implementation of New Solutions in Manufacturing Companies

3.1. Methods for Developing New Technological Solutions

The complexity of production processes and the growing number of variables make it difficult to choose the optimal solution that will ensure the achievement of the expected results and the company's goals. The key to a company's success is the ability to forecast and respond quickly to a dynamically changing situation [18]. The methodology of the approach to innovation and the process of generating it in companies is undergoing systematic evolution [14].

In the field of innovation research, the most frequently cited and applied theoretical concept remains the Blue Ocean Strategy [19–22], which has gained a dominant position in analyses of this type of case [23]. The Blue Ocean Strategy is based on a set of analytical tools that support the process of discovering new, undeveloped market spaces. One of the key tools used in this methodology is the so-called strategy canvas, which allows for a graphical comparison of a company's offer with those of its competitors in relation to key factors of value for the customer. An example of the use of this tool is shown in Figure 1.

In the strategy canvas, each competitive factor is typically rated on a numerical scale from 1 to 10, reflecting the extent to which a company delivers value from the customer's perspective (1 = minimal value, 10 = maximum value). Key value factors are identified through market analysis, and company ratings are based on market research, customer feedback, benchmarking, and competitor analysis. These ratings are represented in a value curve, illustrating the relative strengths and weaknesses of each company.

Companies should establish dedicated creative management teams within their organizational structures and implement policies that foster an innovation-oriented environment. In this context, managers need to demonstrate creative thinking and problem-solving abilities, which are essential for generating and implementing innovation effectively [14].

A value proposition defines the benefits a company offers to customers by solving their problems. To define this proposition effectively, companies must maintain regular interaction with customers, allowing for a clear understanding of their needs. Based on this insight, appropriate solutions are developed. Customer feedback is collected regularly and used to improve the products or services offered. This is a continuous process that includes identifying needs, validating acquired knowledge, and developing new solutions based on a deeper understanding of customer expectations [24]. Alignment is achieved when the value map corresponds with the customer profile—when the offered products

and services effectively address the customer's key tasks, challenges, and expectations by eliminating problems and delivering relevant benefits. In the context of technological developments in manufacturing, applying the Pigneur and Osterwalder concept enables companies to systematically link customer needs with the design of innovative processes and technologies. This allows companies to precisely define technological requirements, prioritize development activities, and to validate new ideas in practice [25–27].

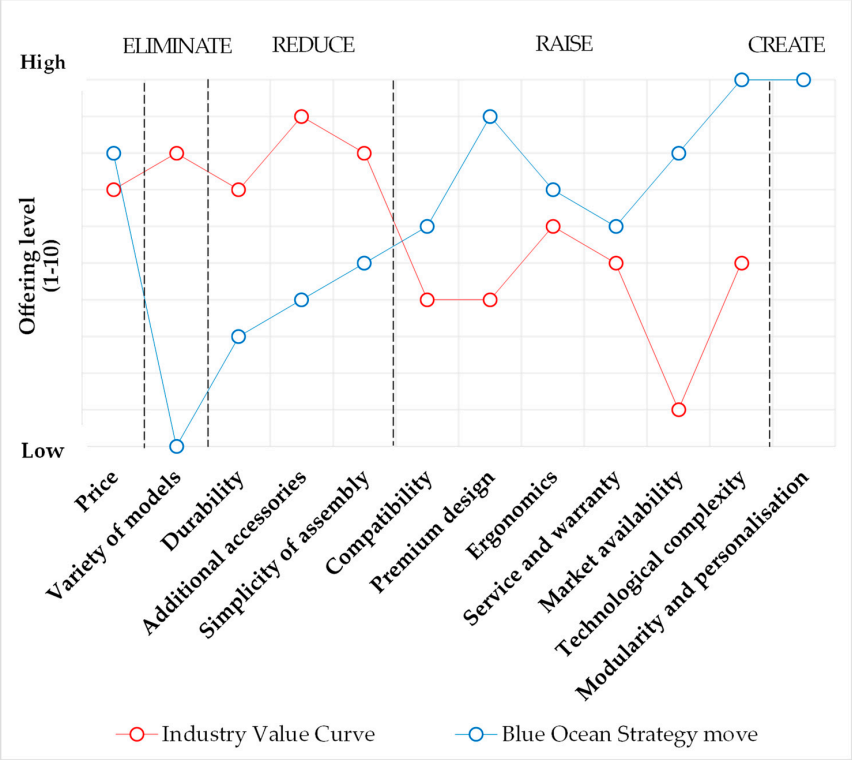


Figure 1. An example of analysis using Blue Ocean Strategy tools.

It is important to note that the innovation literature encompasses a range of influential theoretical and practical frameworks that structure the development and implementation of innovative solutions. Among these, Design Thinking [28] emphasizes user empathy, iterative prototyping, and testing. Another example is TRIZ—the Theory of Inventive Problem Solving [29] which provides a methodical approach to solving technical problems and eliminating contradictions in design projects. The Stage-Gate framework, developed by [30], provides a structured approach for managing the innovation process from concept to implementation, allowing for effective monitoring and control of critical product development stages. Similarly, the Scrum methodology [31] offers a flexible project management approach that facilitates iterative solution development, rapid adaptation to changes, and active customer participation throughout the innovation process. Taking these frameworks into account enables a comprehensive understanding of innovation processes and highlights the importance of integrating strategic, design, and process-oriented approaches to create value effectively for both customers and organizations.

3.2. The Process of Implementing Technological Solutions

In the context of Industry 4.0, multi-criteria decision-making methods are widely applied in the analysis and optimization of sustainable production systems. The growing interest in multi-criteria methods highlights the need for a deeper examination of their role within production systems that support sustainable development [32]. The procedural model for the classical evaluation of solution variants is presented in Figure 2.

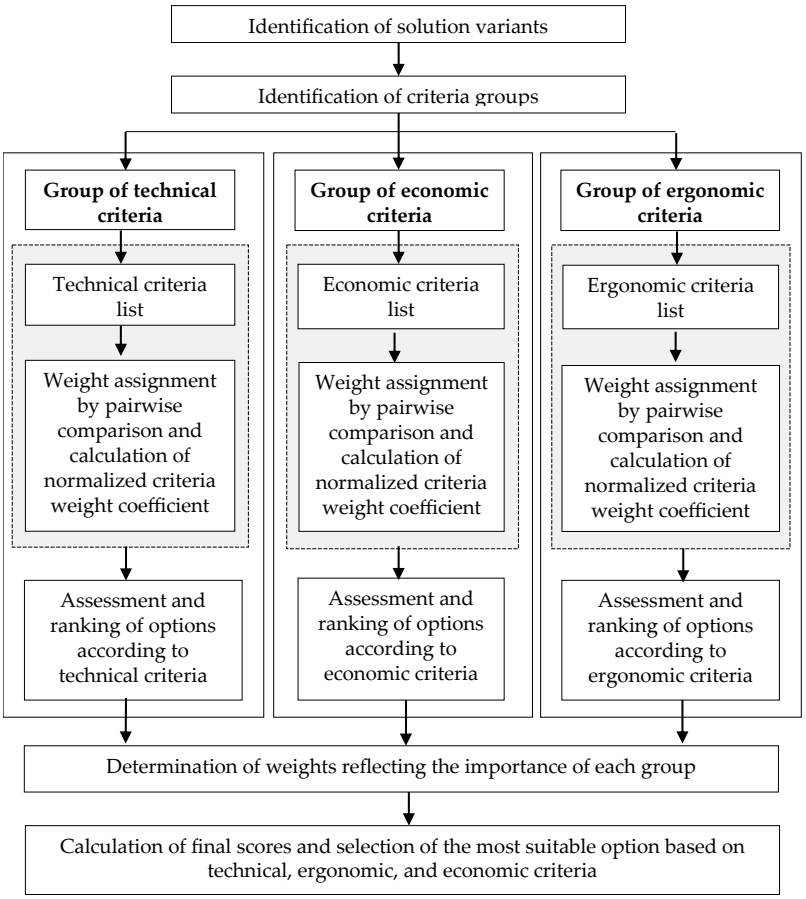


Figure 2. Procedural model for the classical evaluation of solution variants [33].

Production systems should be designed with consideration for the dynamics of their operating environment and the ability to quickly adapt to uncertainty and unexpected changes [34,35]. In response to increasing market demands for product development and innovation, industrial enterprises must address challenges related to the technical preparation of production [36]. The production preparation process serves as a collaborative space where involved parties can jointly make decisions concerning product development and production organization [37], as illustrated in Figure 3. The complexity of individual stages in the technical preparation of production is increasing, while simultaneously the importance of rapidly completing the pre-production phase is growing [36].

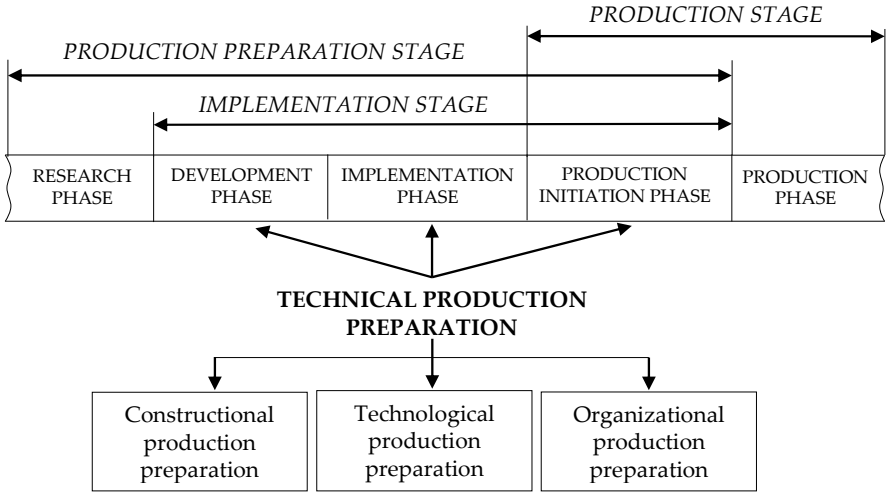


Figure 3. Production preparation in the context of the entire manufacturing process [38].

Such activities are carried out at the early stages of the product life cycle, when it is crucial to plan and organize all aspects related to its manufacturing [39].

Production processes are becoming increasingly complex and difficult to analyze [40]. The complexity of these processes, along with the growing number of variables, makes it challenging to choose the optimal solution that will ensure the achievement of expected results and the fulfillment of the company's objectives. A key element of a company's success is its ability to forecast and respond swiftly to dynamically changing conditions [18]. The integration of production process flows with advanced software not only provides new insights but also equips companies with tools that strengthen their competitive advantage. This line of research aligns well with the prevailing trajectory of digital transformation in the industry, offering tangible solutions aimed at improving production operations in an era of technological progress and dynamic change [41].

Modeling is a theoretical process that enables the study of objects and phenomena through their representations. In this approach, real-world systems are replicated using artificially created models that reflect their structure and behavior. This allows for a deeper understanding of complex processes and phenomena [42]. Simulation methods are divided into deterministic, where random components of the model are omitted and expected values of variables are used, and stochastic, which incorporate random variability using appropriate generators implemented in the software [43]. The choice of method depends on the purpose of the analysis [44].

The construction of simulation models involves certain limitations [45]. The accuracy of simulation outcomes largely depends on the quality of the input data; inaccurate or incomplete data can significantly reduce the reliability of the results obtained. Moreover, effectively resolving problems that arise during the modeling and analysis process remains a significant challenge [46].

Digital process models enable more efficient access to accurate information about underlying mechanisms by providing detailed analysis of the parameters and factors shaping their values and dynamic changes [47]. Simulation-based verification facilitates the identification of interdependencies within production changes and the assessment of operational performance. The developed production system and simulation model can be reused multiple times to test subsequent production plans, allowing for early identification of problems and potential areas for improvement. Simulations make it possible to conduct critical tests that help determine the appropriate course of action prior to the launch of actual production [48].

The software supports both 2D and 3D simulation modes. After each simulation run, a detailed report is generated, allowing for performance optimization, the development of more advanced simulations, and predictive analysis of production process conditions [49]. The simulation model serves as a decision-support tool, offering a variety of implementable solution scenarios. However, simulation alone does not provide a definitive answer to the analyzed issue—it is the management team that makes the final decisions based on the simulation results [46].

Traditional optimization methods often fail to capture the nonlinear dynamics and complex interactions in production systems, which motivates the use of advanced data-driven approaches, including Industry 4.0 technologies such as digitalization, automation, Big Data analytics, and artificial intelligence (AI) [50]. Among these approaches, the application of artificial neural networks in industrial process control enables effective prediction of production process parameters, reducing the number of experimental tests and increasing the precision of quality control [51]. This requires robust protection against industrial espionage, network intrusions, and data breaches [52].

4. Practical Implementation of an Integrated Approach to the Deployment of a New Technological Solution

4.1. Assumptions and Concept of the Study

The implementation of innovative technological solutions in industrial environments is a highly complex process. This process cannot be treated as a one-dimensional activity limited to an isolated design or production phase; rather, it should be understood as a complex, iterative system of integrated actions encompassing needs analysis, concept development, evaluation of alternatives, and effective implementation in a real production environment. The lack of a coherent approach creates the need to develop a comprehensive model supporting all key implementation stages. The objective of the conducted research was to develop and empirically verify a two-phase approach to the implementation of a new technological solution, the structure of which is represented by the model presented in Figure 4.

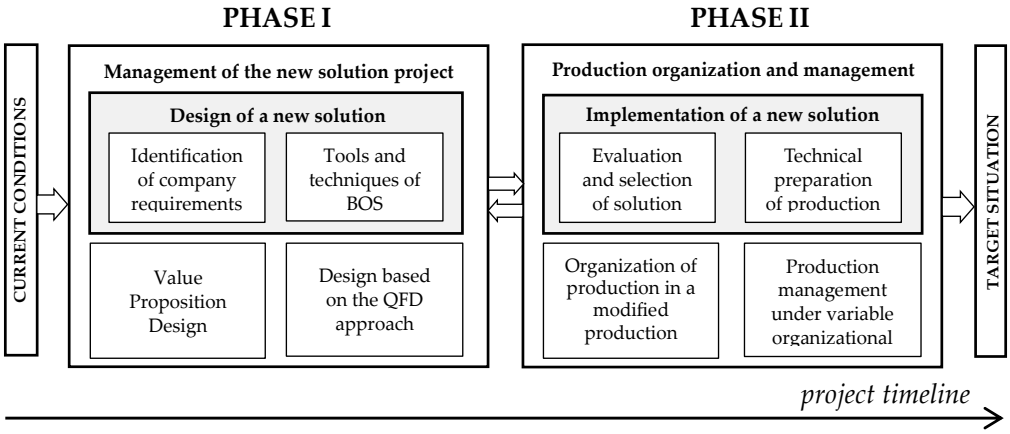


Figure 4. Two-phase model of integrated implementation of a new technological solution.

The first phase, focused on the design and management of the implementation process, included the identification of needs, concept design, analysis of possible solutions, and planning of implementation activities. This part was discussed in detail and published in the article by [48]. The second phase, constituting the primary focus of this study, is dedicated to the practical implementation of the developed solution within industrial environments. This phase involves the identification of critical decision points and the iterative validation of the proposed solutions. Additionally, it encompasses the organization and management of the modified production system.

Based on the identified research gap and the objectives of this study, the following research hypotheses were formulated:

H1. *An integrated, two-phase approach to the implementation of new technologies in a production environment increases the effectiveness of the implementation process compared to traditional approaches.*

H2. *Systematic management of the implementation process, encompassing both the design and implementation phases, enables earlier identification of technological and organizational barriers, thereby reducing the risk of failure.*

H3. *Practical application of a structured implementation model facilitates the repeatability of the process.*

The research was based on a case study that served as a representative example of an industrial environment. The collected data and the results obtained provided a foundation for further considerations on the potential for standardizing implementation processes in the field of mechanical engineering.

4.2. Research Object

The subject of the analysis is the medium-sized manufacturing company specializing in the batch production of steel constructions. The company operates primarily on a make-to-order basis, which results in high project variability, short production series, and frequent changeovers. The company selected for analysis is a representative example of a medium-sized manufacturing company, which allows for a presentation of the characteristic features of its operation and the organization of production processes in this type of company. This characteristic results in a significant share of preparatory and organizational activities. The production system is organized in a manufacturing work cell, which enables flexible adaptation of production flow to current operational requirements. The manufacturing environment comprises both automated workstations and manual operations.

Despite maintaining a stable market position and many years of industry experience, the enterprise encounters numerous challenges associated with reconciling the demand for high operational flexibility with the expected levels of efficiency and timely order fulfillment. The lack of formalized procedures for the implementation of new solutions contributes to delays and elevates the risk of problems during the transition from the design phase to production. Furthermore, the considerable variability in product types imposes significant resources overload, problems with balancing workloads and difficulties in maintaining quality parameters.

As a result of the company diagnosis, based on the systematic collection of data through analysis of technical documentation, direct observations of production processes, time measurements, interviews with engineering and management staff, and examination of current operational procedures, the need to develop a methodology enabling systematic planning, evaluation and implementation of new technological solutions was identified. The integration of engineering activities with technological change management processes was identified as a key area requiring improvement. The analysis also revealed the necessity for a dedicated tool to support the iterative deployment and validation of technological solutions under actual industrial operating conditions. The gathered data were utilized to design and simulate new solutions, plan production flows, schedule tasks, determine material and personnel requirements, and monitor the effectiveness of implemented changes in real industrial conditions.

4.3. Management of the Implementation at the Conceptual Design Phase

4.3.1. The Competitive Profile of the Company as a Basis for a Sustainable Growth Strategy

It is proposed to begin with the development of a competitive profiling framework. The main objectives of competitiveness profiling include understanding the business environment, identifying the strengths and weaknesses of the analyzed company, positioning it on the market, and, as a result, identifying the company's needs and planning its strategy. The competitiveness profiling process consisted of five stages of analysis:

1. Determining a set of competitiveness factors.
2. Conducting a market requirements assessment.
3. Conducting an internal performance assessment.
4. Conducting a competition assessment.
5. Situation analysis.

In the first step—determining competitiveness factors—an approach based on an analysis of the sector's potential, development trends, growth barriers and expansion opportunities was adopted. The analysis incorporated data from industry reports, market research, and macroeconomic studies, enabling the construction of a synthetic and relevant set of factors determining competitiveness within the specific economic environment.

In the next step, as well as in the subsequent stages of analysis, a standardized five-point scale (1–5) was adopted to assess competitiveness factors, where a score of 1 indicates the lowest rating. The final score for each factor was calculated as the average of the partial ratings. To ensure the reliability and objectivity of the results, the quantitative assessment was combined with a qualitative description of each analyzed criterion. This approach is illustrated using the example of market requirements analysis (Table 1).

Table 1. Excerpt from the assessment of market requirements as part of competitiveness profiling.

Factor	Assessment of Competitiveness Factor with Justification					
Price	Competitive pricing remains an important factor in attracting potential buyers. However, the market is increasingly recognizing the added value of products and services, as well as aspects beyond price alone.					
		1	2	3	4	5
	Perceived value relative to price					X
	Price flexibility				X	
	Price competitiveness			X		
	Assessment of the Competitiveness Factor			4		
Technical consulting	Professional technical consulting enables customers to better understand the products or services offered by a company. Well-informed customers are able to compare competing offers more effectively and make more conscious choices, contributing to the company's success in the market.					
		1	2	3	4	5
	Availability of technical support					X
	Quality of technical advice provided					X
	Customer satisfaction with the technical support				X	
	Assessment of the Competitiveness Factor			5		

The collected data was subjected to a detailed comparative analysis aimed at drawing constructive conclusions regarding customer needs, purchasing trends and competitor behavior. The conducted competitiveness profiling enabled the formulation of key insights concerning both the current market position of the analyzed company and its development potential.

Areas for improvement were identified, and the company's strengths were confirmed—these should be maintained and further reinforced. A summary of the competitiveness profiling results is presented in Figure 5.

The results of the analysis served as a starting point for further research and strategic activities. It is recommended that these efforts be undertaken not only as short-term market adaptations, but as part of a long-term strategy for strengthening competitiveness based on responsible and sustainable development. In this context, competitiveness profiling is not merely a diagnostic tool, but rather a foundation for systematically building enterprise value in a dynamic market environment.

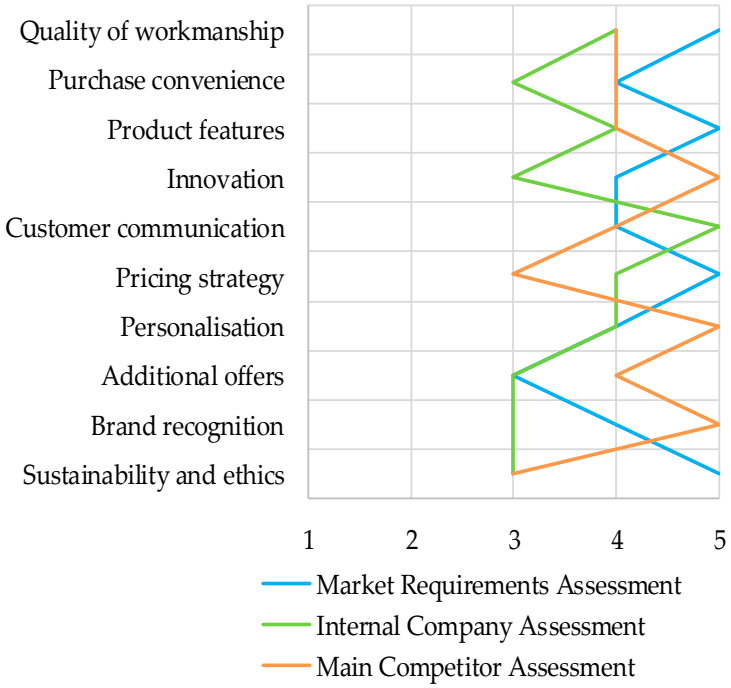


Figure 5. Aggregate chart of competitiveness profiling.

4.3.2. Application of the Blue Ocean Strategy in the Process of Designing New Solution Concepts

In response to the imperative of formulating a novel value proposition and identifying market niches characterized by low competitive saturation, the Blue Ocean Strategy methodology was applied. Its implementation in the analyzed company was based on a set of diagnostic tools and an analytical framework that enabled the creation of new market value. This approach allows the company to move away from competitive rivalry in crowded market segments (referred to as red oceans) and to create an uncontested market space (blue oceans), which addresses current and future customer needs as well as the requirements of sustainable development. The process was structured according to a five-stage model consistent with the foundational principles of Blue Ocean Strategy (Figure 6).

The strategy design process began with a diagnosis of the company's strategic position, the key element of which was the development of a strategy canvas, a comparative analysis tool. For this purpose, a set of competitiveness factors identified in the earlier profiling was used, supplemented with additional determinants resulting from current market conditions and the specific nature of the sector in which the company operates. The chart developed on this basis became the starting point for formulating directions for change in accordance with the Four Actions Framework: elimination, reduction, reinforcement and creation of new elements of the offer. This scheme made it possible to identify which elements of the existing strategy should be modified or completely reformulated in order to increase the attractiveness of the offer.

The subsequent stage pertains to the first principle of Blue Ocean Strategy—the reconstruction of market boundaries—which is implemented through the exploration of six paths to creating new market spaces. The analysis encompassed: (1) alternative industries, (2) strategic groups within the industry, (3) buyer chains, (4) complementary products and services, (5) functional and emotional decision factors, and (6) the dynamics of change over time. Each aspect was developed following a standardized framework that included tabular presentation of evaluations, their visual representation, and derived conclusions, thereby enabling the formulation of accurate recommendations for the designed strategy.

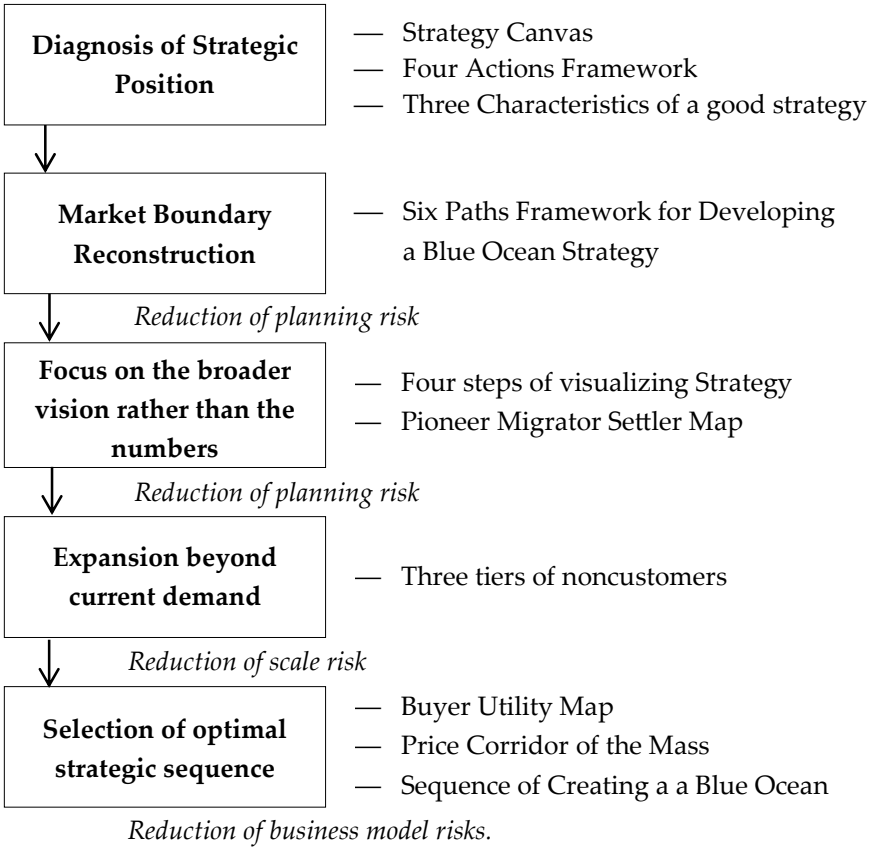


Figure 6. Proposed approach to designing new solution concepts.

The third phase focused on moving away from quantitative constraints towards formulating a broad and inspiring vision for the company's future (second principle of Blue Ocean Strategy). This principle was implemented through a four-stage strategy visualization process: (1) visual awakening, (2) visual exploration, (3) visual strategy fair, and (4) visual communication. Additionally, the "pioneer–migrator–settler" classification tool was employed to evaluate the company's innovativeness and market position.

The next principle addressed the concept of reaching beyond existing demand boundaries. Three tiers of "non-customers" were analyzed—groups of potential buyers who, for various reasons, do not engage with the company's or the entire industry's offerings. The aim of this stage was to understand the causes of their exclusion from the current market and to identify opportunities for activating these groups as new sources of value and growth.

The final phase of the strategy formulation process involved developing a logical and coherent implementation sequence, taking into account the key factors determining market success. The first step was a comprehensive utility analysis from the buyer's perspective, conducted through six stages of the Buyer Experience Cycle—from purchase to disposal. Each stage was evaluated using six utility levers: productivity, simplicity, convenience, risk, reputation, and environmental impact. Based on this, a Utility Map was created, enabling the identification of barriers that reduce the value of the customer experience (Table 2). This analysis provided essential insights for designing solutions aimed at enhancing utility and eliminating existing obstacles, forming the foundation for further implementation activities within the Blue Ocean Strategy framework.

Table 2. Utility Map for the analyzed company.

		The Six Stages of Buyer Experience Cycle					
		Purchase	**Delivery**	**Use**	**Supplements**	**Maintenance**	**Disposal**
The six utility levers	Productivity	O	X	O			
	Simplicity			X			
	Convenience						
	Risk Reduction					X	
	Reputation	X					
	Environmental impact	X					X

O—Customer pain points; X—Usability blockers.

In the conducted study, within a 36-field matrix, areas exhibiting significant difficulties, so-called pain points, were identified. Utility barriers from the enterprise's perspective (marked with a cross) indicated limitations in generating exceptional value for the customer. Conversely, customer pain points (marked with a circle) reflected systemic barriers characteristic of the entire industry, which may have prompted buyers to opt for alternative solutions. Each marked field was thoroughly justified with a description of the identified issue, alongside proposed corrective or preventive measures. Their identification enabled targeted actions aimed at eliminating the main sources of dissatisfaction and enhancing the utility of the offering.

Subsequently, a price level analysis was conducted using the so-called price corridor of the mass, which takes into account the degree of legal protection and the exclusivity of resources. This analysis enabled the determination of a price point that balances market accessibility with the uniqueness of the offering. The final step in this phase involved a synthetic verification of the strategy against four key criteria: utility, price, cost, and implementation feasibility. This confirmed the alignment of the proposed solution with the principles of the Blue Ocean Strategy.

4.3.3. Management of the New Solution Development Project

The management process for the new solution concept commenced with the development of a Business Model Canvas, serving as a fundamental tool for analyzing the structure of the enterprise's operations. This canvas comprises nine key areas that collectively provide a concise overview of the organization's functioning. Following a preliminary analysis of seven areas, it was decided to conduct a more detailed examination of the customer segment, including an analysis of the Customer Profile. The focus was on identifying the customer's tasks (i.e., the objectives they seek to achieve), expected benefits, and challenges encountered that could act as barriers to using the market offering. Subsequently, the Value Map was developed, encompassing an analysis of the proposed value for the customer, including a list of offered products and services, actions aimed at alleviating difficulties ("pain relievers"), and the benefits resulting from the implementation of the new solution. Similarly to the Customer Profile, these elements were prioritized according to their significance. Ultimately, alignment was achieved between the Customer Profile and the Value Map, enabling the identification of direct links between customer expectations and the value proposition. To translate market requirements into specific technical parameters for the new solution, a Quality Function Deployment (QFD) matrix was employed. The infor-

mation gathered in earlier stages was used to complete the matrix structure, as illustrated in Figure 7.

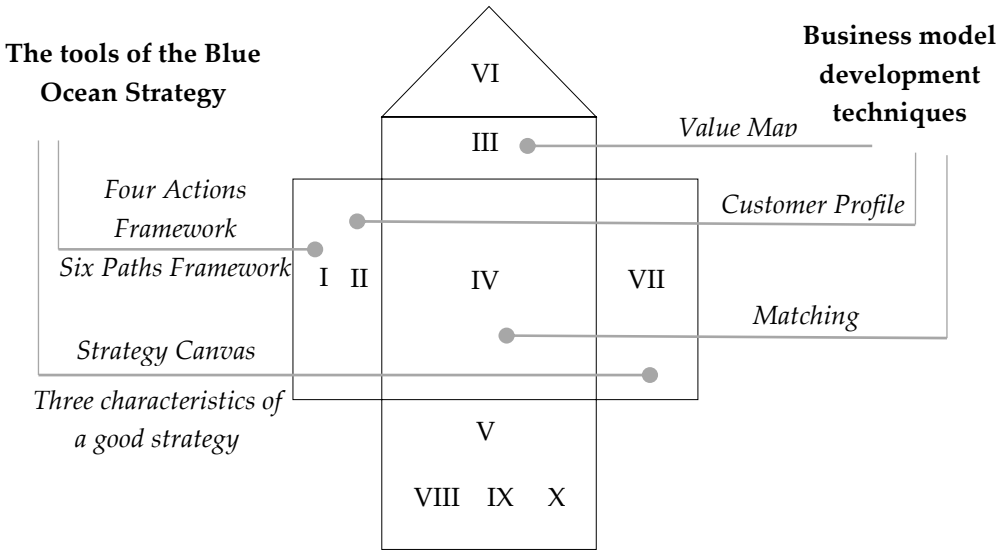


Figure 7. Approach to developing the House of Quality.

The analysis conducted using the QFD matrix enabled not only a systematic mapping of the relationships between market requirements and technology but also identified directions for further improvement of the designed solution.

The integration of Blue Ocean Strategy tools, business modeling, and the QFD matrix enabled the development of a comprehensive approach to designing a new solution. This approach enhances the relevance of the developed concept to actual customer needs and helps reduce implementation risks.

4.4. Organizational and Production Conditions for the Implementation Process of a New Technological Solution

4.4.1. Organizational Aspects of Implementing New Technological Solutions in a Manufacturing Company

Organizational aspects of implementing new technological solutions in a manufacturing company primarily include the evaluation and selection of the optimal technological variant, as well as the technical preparation of the production process.

The process of selecting the optimal technological solution involves a clear distinction between two decision-making stages: an initial analysis of requirements and production capabilities, followed by a detailed evaluation and comparison of the shortlisted options. The first stage, described previously, entails a comprehensive analysis of customer expectations and requirements for the new solution, alongside an assessment of the company's capabilities. Its primary goal is to eliminate options that, for various reasons, should not be realistically implemented. This allows the focus to be placed on a set of solutions that meet both the customer's demands and the company's production capabilities. The second stage involves a multidimensional assessment of the approved options, taking into account a broad range of criteria from the perspectives of both the company and the end customer. The application of the multi-criteria method enables:

- the hierarchy of criteria and the assignment of appropriate weights reflecting the company's strategic goals and market expectations of customers,
- precise comparison of options not only in terms of meeting requirements but also their usability,
- identification of trade-offs between the interests of different stakeholders.

Integrating evaluations from both the company's and the customer's perspectives enables a balanced decision-making process, ensuring transparency and rationality in selecting the technological option. Thanks to detailed multi-criteria analysis, it becomes possible to precisely compare and choose the variant that best fulfills the complex strategic goals of the enterprise while simultaneously addressing the diverse expectations of the market.

The process should begin with a multi-criteria evaluation of solution variants, following the approach proposed by [48]. In this evaluation, the proper selection of criteria plays a key role, as these criteria must comprehensively reflect both the internal conditions of the enterprise and the needs of the market. The set of criteria from the perspectives of the enterprise and the customer is presented in Table 3.

Table 3. Selected criteria within groups from the perspectives of the enterprise and the market.

Group of Criteria	Enterprise Perspective	Customer Perspective
Technical	Ease of integration with existing processes	Quality of workmanship
	Degree of innovation and uniqueness of the solution	Reliability and durability in use
	Production scalability	Functionality of the solution
Economic	Unit production cost	Purchase price
	Financial risk of implementation	Operating costs
	Storage and logistics costs	Warranty conditions
Ergonomic	Ergonomics of workstations	Ease of use
	Ease of adaptation to changing working conditions	Comfort of use in daily operation
	Training requirements for personnel	Availability of support and user manuals

As a result of the process, following the procedure presented in Figure 2, the total scores for each variant were calculated, and the most optimal option was selected, taking into account technical, ergonomic, and economic criteria.

Once the criteria set K and the possible decision alternatives were defined, the next step was to assign weights to each criterion. This was performed using the pairwise comparison method, which involves:

- if criterion j is considered more important than criterion i, it is assigned a value $u_{ji} > 1$. Consequently, criterion i receives a weight $u_{ij} > \frac{1}{u_{ji}}$,
- when two criteria are assessed as equally important, they are both assigned the value 1,
- the elements on the main diagonal of the comparison matrix are also equal to 1, as each criterion is compared with itself.
- The weights of the criteria K_j in the matrix are calculated by multiplying all values u_{ji} in row j. From the resulting product, the root of the degree equal to the number of criteria considered is then extracted. Subsequently, a normalization process is carried out to rescale the weights so that their sum equals one.
- Partial scores B_{ij} for each variant i with respect to each criterion j are calculated as the product of the point score b_{ij} and the weight w_j according to the formula $B_{ij} = b_{ij}\, w_j$. The total score for each variant was computed separately for the three groups of criteria, which allowed obtaining independent partial evaluations. This can be expressed as:

$B_i = \sum_{j=1}^{m} b_{ij} w_j$. Normalization of the scores was performed independently for each group of criteria, according to the relation: ${}^{norm}B_i = \frac{B_i}{B_{max}}$.

The implementation of new production solutions, particularly under conditions of limited availability of historical data, involves a significant degree of uncertainty and ambiguity. In such circumstances, traditional risk analysis methods may prove insufficient, which justifies the application of an approach based on fuzzy logic. Within the conducted analysis, key risk factors associated with the selected technological solution variant were identified. For each factor, three basic risk assessment parameters were defined: probability of occurrence (P), detectability (D), and consequences (C). These parameters were described using linguistic fuzzy variables, enabling the construction of a rule base grounded in fuzzy inference.

The developed rule base constitutes a matrix that links combinations of the parameters P, D, and C with a defined risk level. This model allows for consideration of interactions between risk factors and identification of the most critical threats. Particular attention should be given to factors characterized by high probability of occurrence, low detectability, and significant consequences, as these pose the greatest potential negative impact on the implementation process. Such an approach aligns with the principles of sustainable development by integrating economic, technical, and organizational aspects, minimizing potential adverse effects, and supporting the continuous growth of the enterprise.

Technical Production Preparation (TPP) constitutes a critical phase in the implementation process of a new product model, acting as an intermediary stage between the design development and the commencement of mass production. This phase involves the integration of design specifications, technological requirements, and organizational considerations, facilitating the conversion of the conceptual design into a stable and reproducible manufacturing process (Figure 8).

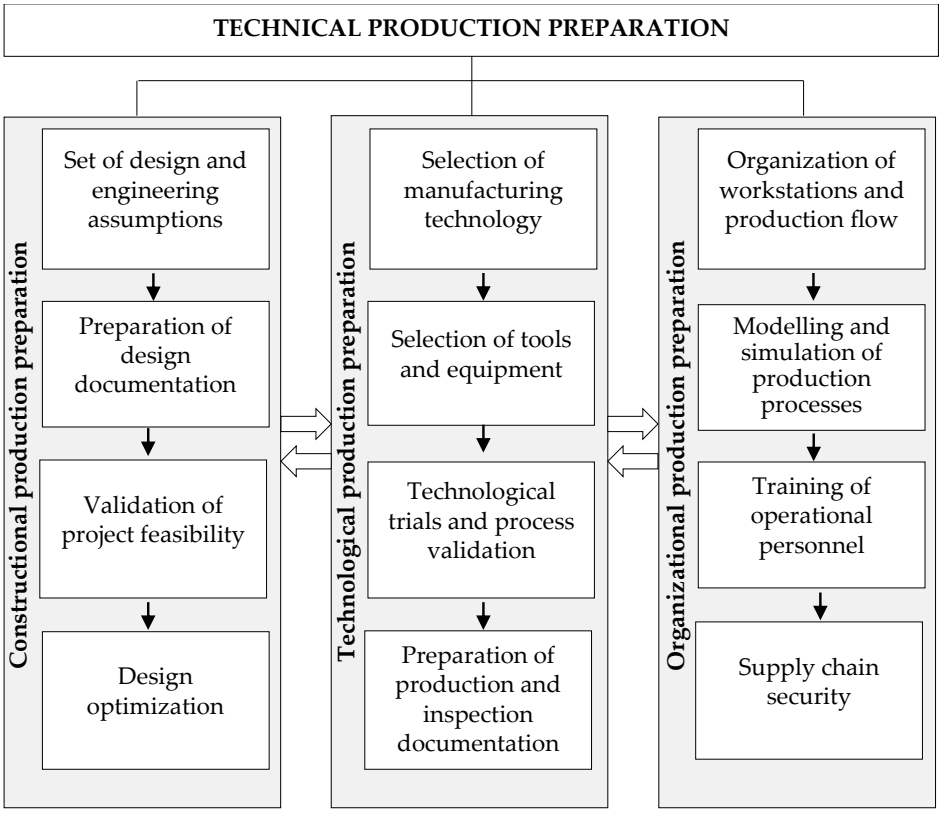


Figure 8. Proposed procedure framework for technical production preparation.

The above model encompasses three fundamental areas of technical production preparation. The primary objective of design preparation is to ensure that the project meets technical requirements and is adapted to available production capabilities. Technological activities focus on developing stable manufacturing processes, taking into account available resources and production constraints. The organizational area covers the planning of necessary infrastructure, human resources, and logistics, ensuring a smooth transition to the operational phase. A comprehensive approach to technical production preparation forms the basis for a rational and controlled implementation process, supporting the achievement of intended technical and economic objectives.

4.4.2. The Use of Simulation Environments to Support Implementation Decisions

Modeling and simulation of production processes play a crucial role in supporting decision-making related to production planning and management, particularly in the context of implementing new technological solutions. In the conducted activities, the Arena Simulation environment was utilized, allowing the creation of digital replicas of real production processes with a high level of detail.

The analysis focused on a new solution, which is a product composed of three segments. Each segment is subsequently assembled into a single subassembly. A simplified process card for the subassembly is presented in Figure 9.

OPERATION SHEET				**Sheet number:**	73/2025
				Order number:	33/07/25
Production start date	**Drawing number**		**Subassembly name**		**Quantity**
03/01/2025	CS-006-001-001-V3		Subassembly type V3		20
No.	**Operation** / **Instruction No.**		**Time**	**Workstation** / **Production department**	
10	Assembly of components of subassembly ICS-001-003-002 / ICS-045-023-001		30	Welding Shop Subassembly Production Depart.	
20	Quality control of the subassembly ICS-003-256-001		15	Quality Control Subassembly Production Depart.	
30	Packaging and securing for transport ICS-005-003-005 / ICS-003-052-001/ICS-200-012-000		30	Packaging Finished Products Warehouse	
Name of subassembly part		**Quantity**	**Unit**	**Acceptance document**	
Segment of subassembly frame		1.00	pcs	DOC-0025/2025	
Frame of subassembly		1.00	pcs	DOC-0032/2025	
Construction of subassembly		1.00	pcs	DOC-0033/2025	
Comments:				**Prepared by**	
				Approved	

Figure 9. Simplified operation sheet for the V3-type subassembly.

A model structure was developed to reflect the main stages of order fulfillment—from the arrival of materials, through successive technological operations, to final assembly and quality control (Figure 10). Each of these stages was mapped using objects from the Basic Process library, which allowed for a detailed mapping of the sequence and course of individual operations in the production process. Due to the complexity of the model, only selected fragments are presented.

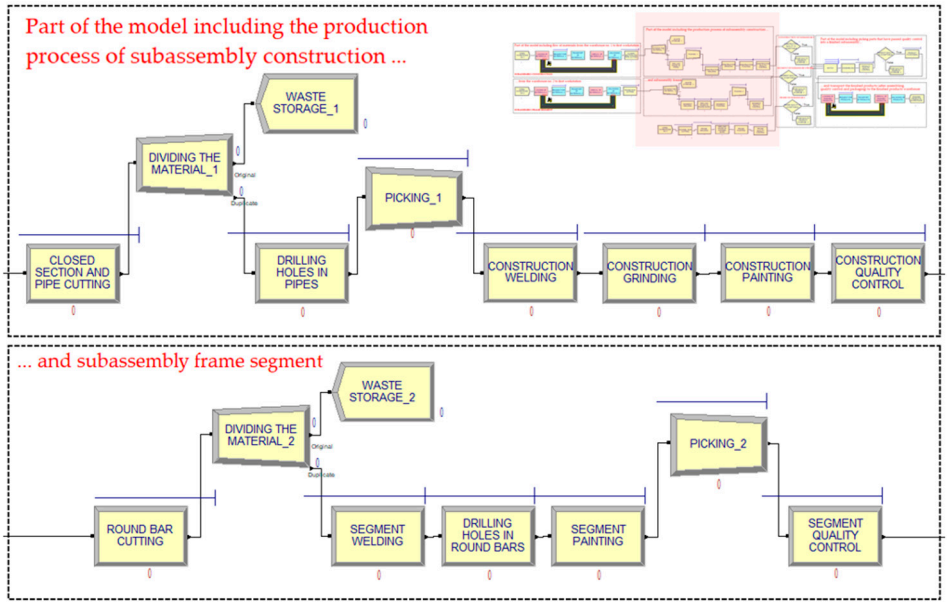


Figure 10. Part of the model of the production process of subassembly type V3 with miniature of the complete system.

The developed model focused not only on specifying the resources necessary for the production process but also incorporated information regarding material transport. The model simulates both the delivery of materials to individual workstations and the movement route of finished products to the final product warehouse. This model structure enables an accurate representation of the actual production process flow and facilitates understanding of the interrelationships between production stages and the resources used. A segment of the material flow route to the production workstation is illustrated in Figure 11. For simulating material transport, objects from the Advanced Transfer library were utilized, allowing the design and analysis of transportation within the model.

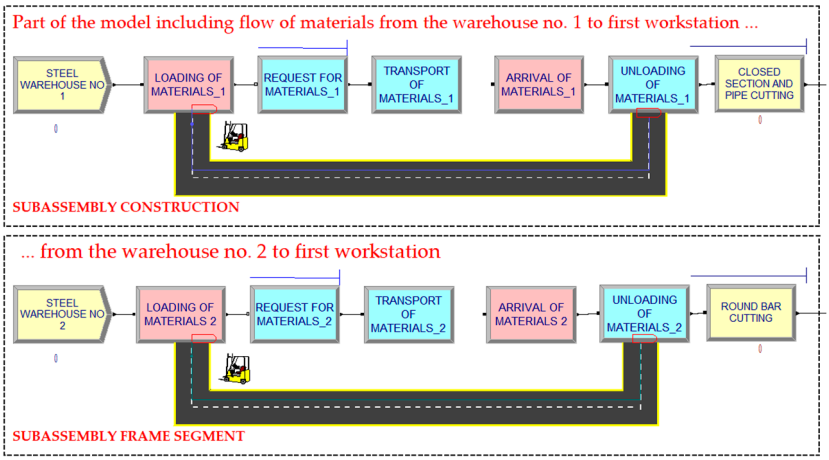


Figure 11. Part of the material flow from steel warehouses to workstations.

According to the designed production process flow, after the completion of machining, the segments are directed to the assembly preparation phase. In the simulation model, this stage was represented using objects from the Advanced Process library available within the Arena Simulation environment. Figure 12 presents a fragment of the simulation model corresponding to the assembly preparation and assembly stage.

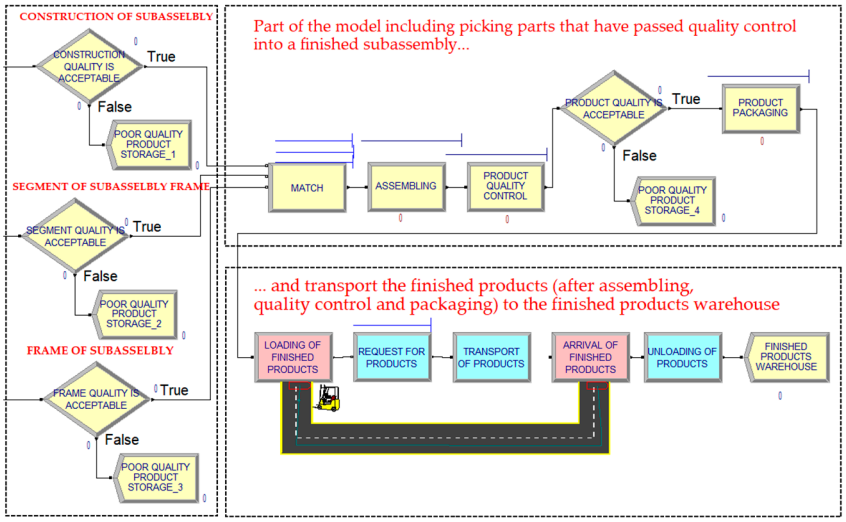


Figure 12. The stage of picking the segments into the subassembly.

To accurately define operation parameters such as processing times, data collection techniques like time study can be employed. These methods enable gathering reliable data that can be used to establish the input parameters for the simulation model. Figure 13 illustrates a fragment of the defined parameters. The Arena software version 16 allows for the definition of various time distributions, enabling the modeling of actual variability in production processes. In the model, a normal distribution was applied, where most values cluster around the mean and the probability decreases with distance from it. The probability density function of the normal distribution describes how the values of a continuous random variable are distributed around the mean. For a continuous variable with mean μ and standard deviation σ, the function is expressed as:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2} \quad (1)$$

where

μ—mean value (average operation duration),
σ—standard deviation,
x—specific operation time value.

	Name	Type	Action	Priority	Resources	Delay Type	Units	Allocation	Minimum	Value	Maximum	Std Dev	Report Statistics
1	CLOSED SECTION AND PIPE CUTTING	Standard	Seize Delay Release	Medium (2)	2 rows	Normal	Minutes	Value Added	0.5	30	1.5	3	☑
2	DRILLING HOLES IN PIPES	Standard	Seize Delay Release	Medium (2)	2 rows	Normal	Minutes	Value Added	0.5	60	1.5	6	☑
3	CONSTRUCTION WELDING	Standard	Seize Delay Release	Medium (2)	2 rows	Normal	Minutes	Value Added	0.5	80	1.5	8	☑
4	CONSTRUCTION GRINDING	Standard	Seize Delay Release	Medium (2)	2 rows	Normal	Minutes	Value Added	0.5	45	1.5	4.5	☑
5	CONSTRUCTION PAINTING	Standard	Seize Delay Release	Medium (2)	2 rows	Normal	Minutes	Value Added	0.5	60	1.5	6	☑
6	CONSTRUCTION QUALITY CONTROL	Standard	Seize Delay Release	Medium (2)	2 rows	Normal	Minutes	Value Added	0.5	50	1.5	5	☑
7	ROUND BAR CUTTING	Standard	Seize Delay Release	Medium (2)	2 rows	Triangular	Minutes	Value Added	27	30	33	0.2	☑
8	SEGMENT WELDING	Standard	Seize Delay Release	Medium (2)	2 rows	Triangular	Minutes	Value Added	45	50	55	0.2	☑
9	DRILLING HOLES IN ROUND BARS	Standard	Seize Delay Release	Medium (2)	2 rows	Triangular	Minutes	Value Added	18	20	22	0.2	☑

Figure 13. Extract of defined model parameters in Arena Simulation.

A triangular distribution was also used, especially when precise data on times is unavailable. This distribution defines the time based on three values: minimum, most

likely, and maximum. The probability density function of the triangular distribution is expressed by the formula:

$$f(x) = \begin{cases} \frac{2(x-a)}{(b-a)(c-a)}, & a \le x \le c \\ \frac{2(b-x)}{(b-a)(b-c)}, & c \le x \le b \end{cases} \quad (2)$$

where

a—minimum value,
b—maximum value,
c—most likely value.

After defining the necessary input data, the simulation was run using the Arena environment. This software enabled the execution of experiments analyzing the behavior of the production process under various scenarios. This allowed for the verification of the model's accuracy as well as the identification of potential bottlenecks and areas requiring optimization before implementing the new solution in the real production environment.

First, the replication parameters for the created model were determined. The duration of a single replication was set to 40 h, corresponding to five full working days with a single shift, assuming an 8 h shift per day. To stabilize the model and eliminate the influence of initial conditions, a warm-up period of 24 h was included. The next step involved providing detailed information about the resources involved in the process, including workstations and personnel, documented in the Resource table. The characteristics of the resources used in the simulation are presented in Table 4.

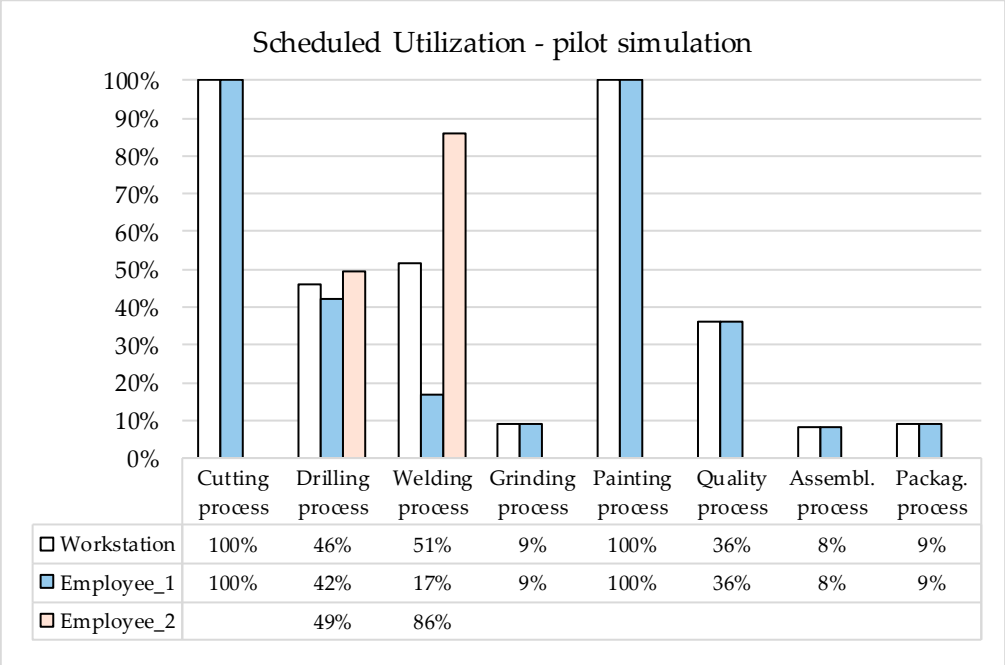
Table 4. Characteristics of resources available in the pilot simulation.

	Name of Resource	Comments
Workstation	Cutting process	One workstation
	Drilling process	Two workstations
	Welding process	Two workstations
	Painting process	One workstation
	Quality control	One workstation
	Grinding process	One workstation
	Assembly process	One workstation
	Packaging process	One workstation
Employee	Cutting process	One employee operates three workstations
	Drilling process	Employee no. 1 operates drilling holes in pipes and round bars
		Employee no. 2 operates drilling holes in channel bars
	Welding process	Employee no. 1 operates construction welding
		Employee no. 2 operates segment and frame welding
	Painting process	One employee operates three workstations
	Quality control	One employee operates four workstations
	Grinding process	One employee operates one workstation
	Assembly process	One employee operates one workstation
	Packaging process	One employee operates one workstation

A pilot simulation of the designed production system was conducted to preliminarily verify its operation under conditions representative of the real environment. The simulation

experiment, carried out with the assumed parameters and constraints of available resources, allowed for the production of only two finished products. The results of this simulation serve as the basis for evaluating the designed system and identifying potential areas requiring improvements.

Analysis of workstation load enabled the identification of areas with the highest resource utilization (Figure 14), indicating potential bottlenecks within the production system. The identified overload points were recognized as critical areas needing further optimization to enhance production flow and reduce the overall manufacturing cycle time.



	Cutting process	Drilling process	Welding process	Grinding process	Painting process	Quality process	Assembl. process	Packag. process
Workstation	100%	46%	51%	9%	100%	36%	8%	9%
Employee_1	100%	42%	17%	9%	100%	36%	8%	9%
Employee_2		49%	86%					

Figure 14. Scheduled Utilization for the pilot simulation.

In response to the identified constraints, a set of improvements was proposed, the implementation of which does not involve significant financial expenditure but may contribute to enhancing the system's efficiency. The initial step involved modifying the material issuance method from the warehouse—from Random (Expo) to Constant—which facilitates the stabilization of material flow and reduces variability in delivery times. Additionally, adjustments were made to the material release schedule for production: the channel bar was scheduled for the second hour of the simulation, while the closed section and pipes were planned for the fourth hour (Figure 15).

	Name	Entity Type	Type	Value	Units	Entities per Arrival	Max Arrivals	First Creation
1	STEEL WAREHOUSE NO 1	CLOSED SECTIONS AND PIPES	Constant	4	Hours	3	Infinite	4
2	STEEL WAREHOUSE NO 2	ROUND BARS	Constant	6	Hours	4	Infinite	0
3	STEEL WAREHOUSE NO 3	CHANNEL BARS	Constant	4	Hours	4	Infinite	2

Figure 15. Changes regarding material warehouse releases.

The implemented changes contributed to reducing queues at workstations and achieving a more balanced distribution of resource load, as confirmed by the results of the subsequent simulation iteration. It was possible to produce three finished products. Consequently, better synchronization of process flow across the entire production system was achieved, marking a significant step towards its further optimization. The obtained results (Figure 16) clearly indicated that in most cases, waiting times significantly exceeded value-

adding times, indicating the presence of substantial downtime and delays, most likely resulting from a lack of coordination and resource availability.

ARENA Simulation Results

Summary for Replication 1 of 1

Project: Subassembly type V3 Run execution date : 7/25/2025
Analyst: Plinta Dariusz, Radwan Katarzyna Model revision date: 7/25/2025

Replication ended at time : 40.0 Hours (Saturday, August 02, 2025, 06:00:00)
Statistics were cleared at time: 24.0 Hours (Thursday, July 31, 2025, 06:00:00)
Statistics accumulated for time: 16.0 Hours
Base Time Units: Hours

TALLY VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Observations
SEGMENT QUALITY CONTROL.TotalTimePerEntity	0.24121	(Insuf)	0.23630	0.24375	3
DRILLING HOLES IN ROUND BARS.VATimePerEnti	0.33901	(Insuf)	0.30441	0.36443	8
DRILLING HOLES IN ROUND BARS.TotalTimePerE	1.1969	(Insuf)	0.33340	2.1949	8
FRAME PAINTING.WaitTimePerEntity	2.5256	(Insuf)	1.4803	3.4873	12
SEGMENT PAINTING.TotalTimePerEntity	2.8821	(Insuf)	1.7840	3.7203	6
DRILLING HOLES IN PIPES.WaitTimePerEntity	0.46750	(Insuf)	0.00000	1.4312	9
DRILLING HOLES IN PIPES.VATimePerEntity	0.99243	(Insuf)	0.86860	1.0769	9
PRODUCT QUALITY CONTROL.VATimePerEntity	0.24750	(Insuf)	0.23239	0.28090	4
CONSTRUCTION WELDING.WaitTimePerEntity	0.00000	(Insuf)	0.00000	0.00000	5
CHANNEL BAR CUTTING.VATimePerEntity	0.79042	(Insuf)	0.69496	0.93661	11
CHANNEL BAR CUTTING.WaitTimePerEntity	9.8062	(Insuf)	6.4641	12.967	11
DRILLING HOLES IN CHANNEL BARS.TotalTimePe	0.58782	(Insuf)	0.48128	0.65941	9
CONSTRUCTION PAINTING.VATimePerEntity	1.0969	(Insuf)	0.94609	1.1519	4
CONSTRUCTION GRINDING.VATimePerEntity	0.77445	(Insuf)	0.68000	0.83991	4
CONSTRUCTION WELDING.TotalTimePerEntity	1.2624	(Insuf)	1.0345	1.3945	5
ASSEMBLING.VATimePerEntity	0.53987	(Insuf)	0.45391	0.62433	4
SEGMENT QUALITY CONTROL.VATimePerEntity	0.24121	(Insuf)	0.23630	0.24375	3

Figure 16. Excerpt from the report following modifications implemented in the materials warehouse.

Particularly disturbing results were recorded for cutting operations. The proportion of value-added time in the total process time was only 7.46% for channel bar cutting, 5.54% for closed section and pipe cutting, and only 4.85% for round bar cutting.

Subsequent decisions on improvement directions were made based on data obtained from reports generated during the simulation. These reports provided a valuable source of information, enabling the identification of critical bottlenecks and the assessment of system performance. Quantitative data contained within the reports, such as resource utilization levels, queue lengths, and waiting times, allowed for the formulation of well-founded and objective conclusions. Thus, these reports formed the foundation for making rational optimization decisions and designing improvement scenarios, the effectiveness of which was subsequently verified through further simulation iterations.

In the process of further optimization, it was decided to make changes to the allocation of human resources by assigning some employees to perform tasks in different positions. This kind of multitasking led to better use of available resources and a reduction in downtime, which in turn was reflected in improved flow in the modeled system.

Initially, improvement efforts focused on the channel bar cutting station. In response to the observed overload at this stage, an employee previously assigned to assembly was reassigned, as their involvement in the production process was only required at the final stage. This decision enabled effective support for the cutting operations by alleviating the workload of the originally assigned operator. Additionally, the number of workers at the cutting station was increased to two, justified by the nature and intensity of the workload in this area. However, the implemented changes also revealed new constraints in the painting, welding, and drilling areas, as illustrated in Figure 17. These constraints are highlighted in red.

CUTTING PROCESS EMPLOYEE.ScheduledUtilizat	0.71598
PAINTING PROCESS EMPLOYEE.ScheduledUtiliza	1.0000
ASSEMBLY PROCESS EMPLOYEE.ScheduledUtiliza	0.86374
WELDING PROCESS EMPLOYEE_2.ScheduledUtiliz	1.0000
WELDING PROCESS EMPLOYEE_1.ScheduledUtiliz	0.53326
CUTTING WORKSTATION.ScheduledUtilization	0.73129
PACKAGING PROCESS EMPLOYEE.ScheduledUtiliz	0.09742
DRILLING PROCESS EMPLOYEE_2.ScheduledUtili	0.47438
DRILLING PROCESS EMPLOYEE_1.ScheduledUtili	1.0000
GRINDING WORKSTATION.ScheduledUtilization	0.29397
PAINTING WORKSTATION.ScheduledUtilization	1.0000
ASSEMBLING WORKSTATION.ScheduledUtilizatio	0.11713
WELDING WORKSTATION.ScheduledUtilization	0.76663
QUALITY CONTROL WORKSTATION.ScheduledUtili	0.44289
PACKAGING WORKSTATION.ScheduledUtilization	0.09742
QUALITY CONTROL PROCESS EMPLOYEE.Scheduled	0.44289
GRINDING PROCESS EMPLOYEE.ScheduledUtiliza	0.29397
DRILLING WORKSTATION.ScheduledUtilization	0.73719

Figure 17. List of scheduled utilization following modifications at the channel bar cutting station.

In order to further optimize the process, the operator assigned to drilling operations in the channel bar was simultaneously engaged in round bar drilling. This solution allowed for more efficient use of available human resources without the need to increase the overall number of employees.

In the subsequent phase, the organizational structure of the welding operations was revised. The former rigid allocation of operators to specific subprocesses—welding of construction components and welding of segments and frames—was supplanted by a more flexible operational model. This adjustment permitted both operators to undertake tasks across the entire welding process, thereby facilitating a more balanced distribution of workload. Consequently, this optimization resulted in an increased throughput, enabling the production of four completed units.

The painting process was subsequently identified as a new bottleneck within the production system. To mitigate this constraint, the number of available painting stations was increased to two, thereby alleviating the workload at this stage. Furthermore, an operator initially assigned to the packing operation was temporarily reassigned to support the frame painting process. These interventions contributed to a more balanced allocation of workload across the production system, a reduction in operation waiting times, and an overall enhancement of the manufacturing process flow.

Based on the simulation report findings, a decision was made to merge the grinding and painting construction workstations. Consequently, the operator previously assigned exclusively to grinding tasks was engaged in a broader range of activities, enabling more efficient utilization of their availability and alleviating the excessive workload on the painting operator.

As a result of the implemented improvement measures, the production of six finished products became achievable. A segment of the report presenting the scheduled utilization indicators for workstations and personnel is illustrated in Figure 18.

The simulation results confirm that the key factor for improvement was not the expansion of infrastructure, but rather an adaptive approach to work organization and flexible utilization of available resources. This approach assumes the rational use of existing resources alongside the pursuit of process optimization.

CUTTING PROCESS EMPLOYEE.ScheduledUtilizat	0.73601
PAINTING PROCESS EMPLOYEE.ScheduledUtiliza	0.60871
ASSEMBLY PROCESS EMPLOYEE.ScheduledUtiliza	0.95582
CUTTING WORKSTATION.ScheduledUtilization	0.74664
PACKAGING PROCESS EMPLOYEE.ScheduledUtiliz	0.72233
DRILLING PROCESS EMPLOYEE_2.ScheduledUtili	0.82995
DRILLING PROCESS EMPLOYEE_1.ScheduledUtili	0.73186
GRINDING WORKSTATION.ScheduledUtilization	0.29702
PAINTING WORKSTATION.ScheduledUtilization	0.77162
ASSEMBLING WORKSTATION.ScheduledUtilizatio	0.19854
WELDING WORKSTATION.ScheduledUtilization	0.81055
QUALITY CONTROL WORKSTATION.ScheduledUtili	0.69696
PACKAGING WORKSTATION.ScheduledUtilization	0.18503
QUALITY CONTROL PROCESS EMPLOYEE.Scheduled	0.69696
GRINDING PROCESS EMPLOYEE.ScheduledUtiliza	0.69425
WELDING PROCESS EMPLOYEE.ScheduledUtilizat	0.81055
DRILLING WORKSTATION.ScheduledUtilization	0.78091

Figure 18. List of scheduled utilization after modifications.

5. Results of Adapting the Process to Changing Organizational Factors

The use of the Arena simulation environment marked the culmination of the entire design process for new technological solutions, which began with the analysis of the existing production system and the identification of its limitations.

Thanks to the precise replication of manufacturing processes and the ability to assess resource utilization, the simulation enabled the identification of bottlenecks and the testing of various optimization scenarios. This allowed for the verification and refinement of the proposed improvements without the need for physical intervention in the actual system, representing a key step towards the successful implementation of changes.

The analysis of workstation workload summaries before and after the implemented modifications allows for an assessment of the effectiveness of the applied improvements. The charts in Figure 19 indicate that utilization have become more evenly distributed, reflecting improved coordination of work within the production system.

The implemented modifications led to a significant reduction in the overload of critical production workstations. Workstations that exhibited full utilization in the pilot simulation, such as cutting and painting, were relieved to 75% and 77%, respectively, demonstrating a more balanced distribution of workload and a reduced risk of operational downtime. At the same time, the utilization of other workstations increased, reflecting a better allocation of operations across stations and a more coordinated workflow across consecutive production steps.

The results of the human resource workload analysis before and after the implemented modifications (Figure 20) confirm the effectiveness of the personnel management approach applied. The summary revealed a more balanced distribution of workloads among individual employees. Assigning workers to multiple production operations contributed to reducing unproductive time and increased the system's adaptability to variable demands. The results obtained indicate the potential for further development of multitasking strategies as a tool to support the optimization of the production system.

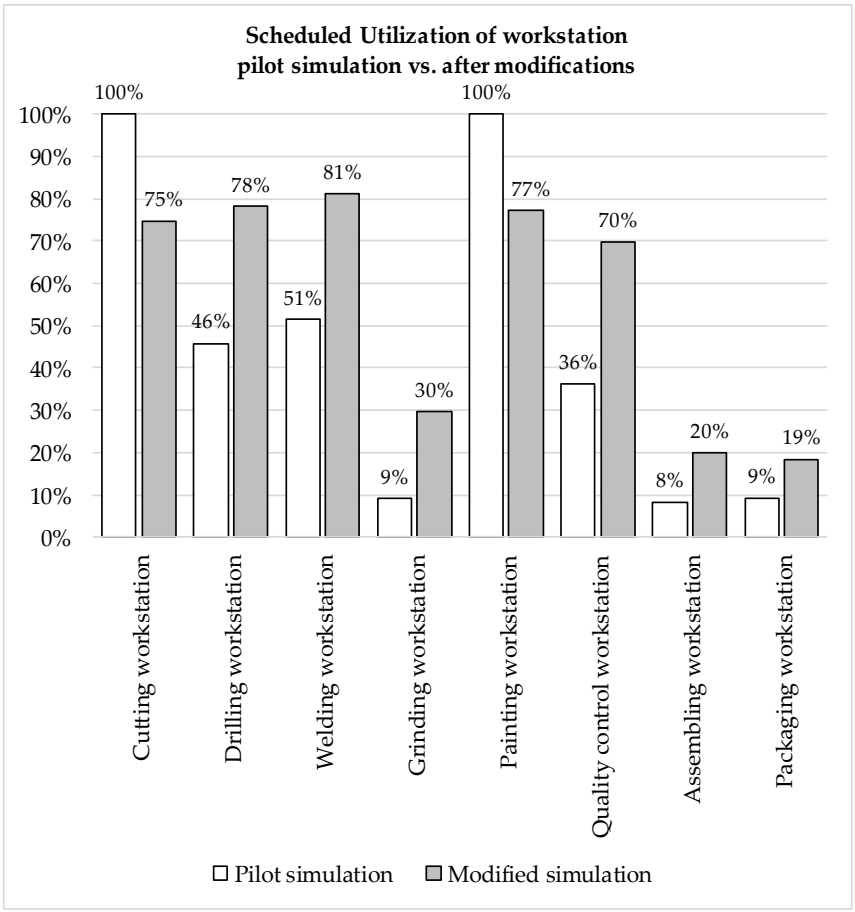


Figure 19. Scheduled utilization of workstation before and after the modifications.

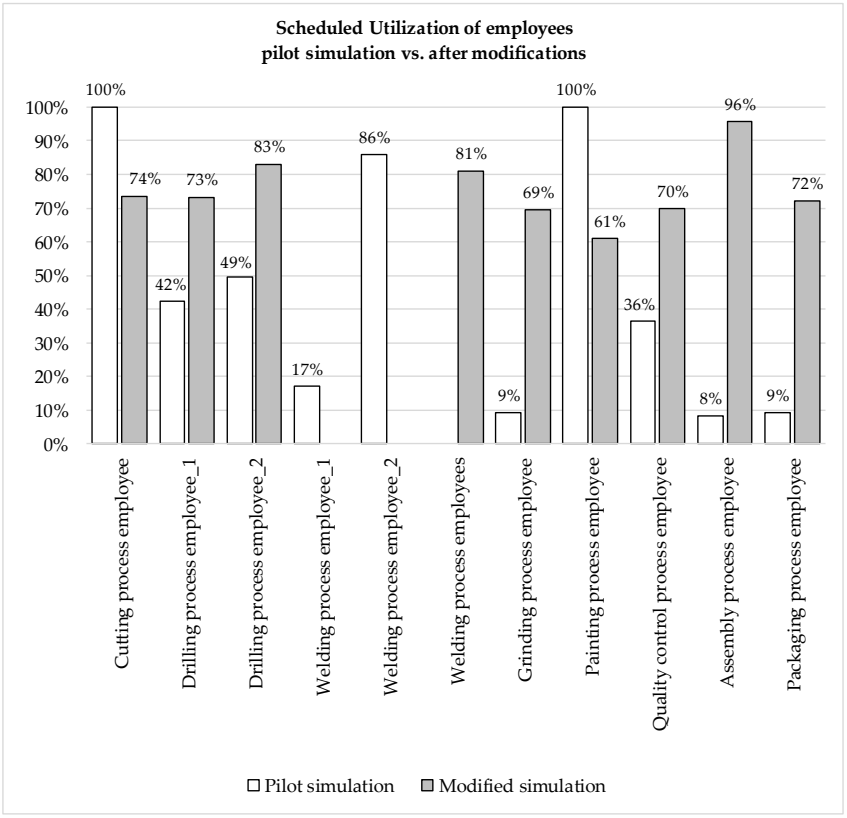


Figure 20. Scheduled utilization of employees before and after the modifications.

A summary of the average waiting times for individual operations within the production process is presented in Figure 21. The results illustrate the positive impact of the implemented modifications on the production system, which led to a reduction in downtime between consecutive production stages. The analysis confirmed that by eliminating bottlenecks and improving resource availability, it was possible to significantly reduce time losses throughout the entire production process.

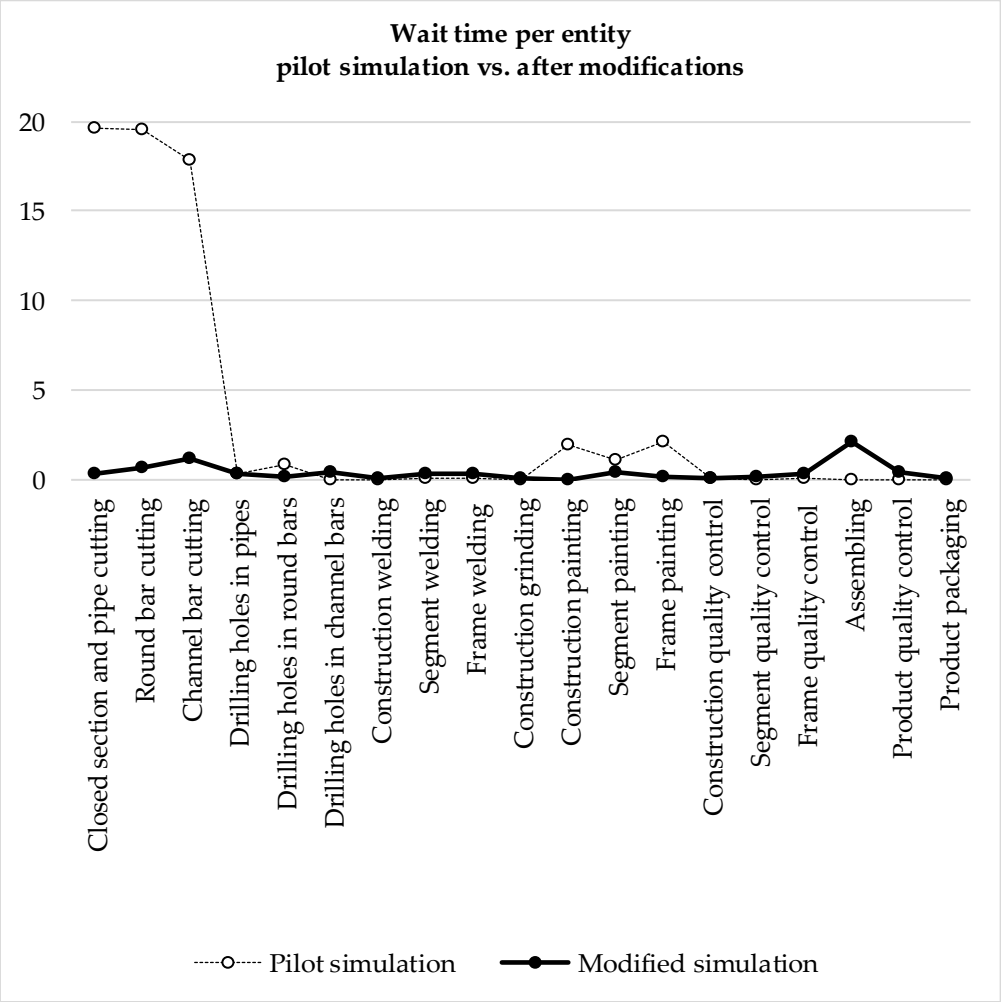


Figure 21. Wait time per entity before and after the modifications.

In the pilot simulation, waiting times for individual processes were not only higher but also highly variable, indicating uneven resource utilization and the presence of multiple bottlenecks within the production flow. Following the implementation of the improvements, the modified simulation exhibited significantly lower and more uniform waiting times across all production stages. This distribution reflects an effective balancing of workstation loads, better synchronization of operations, and the elimination of critical overload points throughout the entire production chain up to the finalization stage.

The results indicate that the implemented modifications, including adjustments to scheduling and resource allocation, can deliver measurable gains, including faster task execution, enhanced throughput, and a reduction in downtime risk. This stage served as an integral summary of all activities, enabling informed implementation decisions based on validated simulation data.

6. Discussion

Previous approaches to implementing innovation in manufacturing have focused mainly on selected phases, such as design or process optimization, ignoring the broader context of implementation. The presented research fills this gap by offering a comprehensive approach that enables a smooth transition from the conceptual to the operational phase.

The study focused on assessing the practical feasibility of new solutions within a specific medium-sized enterprise. The applied approach, based on case study analysis and simulations, allows for a reliable evaluation of processes under realistic operational conditions, while also taking into account the specificity of implementations and the complexity of the analyzed production system.

The practical implications of the study are multidimensional. Firstly, the proposed approach can serve as a guideline for the systematic design and organization of production processes, supporting their flexible adaptation to changing market and technological conditions. Moreover, it shows the importance of an interdisciplinary approach that combines creative design methods with analytical and simulation tools, allowing for a comprehensive assessment of solutions in terms of both their operational potential and practical feasibility. Furthermore, the study suggests that the implementation of such an approach may contribute to the standardization of implementation processes in mechanical engineering, which promotes the creation of more sustainable and responsible production environments. Finally, the results of the study are also relevant for guiding technological development processes, which are often characterized by high project variability and short production runs.

Implementing Industry 4.0 solutions can bring significant benefits, such as increasing production efficiency through automated workflows, improving process flexibility with reconfigurable manufacturing systems, enabling real-time monitoring using IoT sensors, and supporting data-driven decision-making via digital twins and predictive analytics. However, adopting these technologies in practice is often challenging, especially for small and medium-sized enterprises. The methodology proposed in this study supports the practical implementation of such solutions by providing a structured framework that integrates design, operational planning, and feasibility assessment, allowing companies to coordinate multiple tools effectively while considering organizational, technical, and economic constraints.

The results highlight the importance of a holistic approach, particularly in the context of increasing market volatility and the growing need for rapid adaptation to technological change. The findings obtained during implementation form the basis for further work on standardizing implementation processes in mechanical engineering, as well as for their potential application in diverse industrial contexts.

It should be emphasized that the methodology is primarily suitable for small and medium-sized enterprises (SMEs) that possess a minimum level of resources necessary for effective implementation. Favorable conditions for its application include:

- Organizational: clearly defined production processes, the ability to implement organizational changes, staff readiness to collaborate during the implementation of new solutions, and management support in the decision-making process.
- Technical: basic digital infrastructure (ERP systems, CAD/CAM software, such as AutoCAD and Solid Works, sufficiently powerful computers), the ability to collect and analyze production data, and access to simulation tools.
- Economic: availability of a budget for implementing simulation tools, personnel training, and potential support from external consultants or technical experts.

It should also be noted that enterprises with limited human, financial, or technological resources may face significant challenges in fully implementing the proposed methodology. Potential barriers include resistance to organizational change, a shortage of skilled personnel, high costs of tools or technologies, limited operational capacity or time constraints, and insufficient management support. In mass-production environments, processes are highly standardized and optimized, allowing little opportunity for experimental or flexible approaches. Implementing new solutions using the proposed methodology could disrupt schedules and workflows, leading to costly production interruptions or quality issues. On the other hand, in single-item production within small enterprises with minimal technological infrastructure, limited personnel, and modest financial resources, fully applying this methodology may be impractical or overly demanding.

This limits the possibility of directly generalizing the conclusions to other sectors of the economy and organizations of a different scale and nature of activity. A broader application of the results obtained in various industries would require comparative studies covering diverse production environments. Such an approach would allow for a more systematic identification of factors specific to individual industrial sectors while also providing the basis for the development of comprehensive guidelines aimed at the standardization and continuous improvement of production organization. In turn, this could contribute to enhancing the overall effectiveness of practices, ensuring more efficient utilization of available resources, and strengthening the adaptive capacity of enterprises in the face of dynamic and changing market conditions.

Expanding the analysis to include larger datasets would enable the application of statistical methods, facilitating more robust validation of findings and supporting the formulation of conclusions across different organizational contexts and industrial sectors.

7. Conclusions

As a result of the conducted research, an integrated approach to the implementation of new technological solutions in manufacturing enterprises has been developed. This approach encompasses all key stages of implementation—from concept development and variant evaluation to production preparation and process management. The study demonstrates that combining creative design methods with analytical assessment and simulation tools enables a comprehensive, multi-dimensional analysis of proposed solutions. Such an approach facilitates early identification of potential risks and the optimization of production parameters already at the planning stage, which significantly improves decision-making accuracy and reduces the risk of implementation failure.

The main achievements of this study may be summarized as follows:

- The development of a comprehensive and integrated approach that supports the effective implementation of new technological solutions under real manufacturing conditions.
- The demonstration of the advantages resulting from the combination of creative design methods, analytical evaluation, and simulation tools, which jointly facilitate risk identification and improve the accuracy of decision-making processes.
- The empirical confirmation that the proposed model contributes to reducing implementation time, lowering costs, and minimizing the risk of production downtime.
- The formulation of a universal framework that can be adapted to the specific requirements of different industrial sectors and flexibly adjusted to dynamic market and technological conditions.

The directions for further improvement of the proposed approach include the following:

- The incorporation of real-time data integration and digital twin technologies in order to enhance predictive accuracy and system adaptability.

- The validation of the framework through studies carried out across a wide spectrum of industrial sectors.
- The extension of the approach to incorporate sustainability assessment metrics, allowing evaluation of environmental and social impacts.
- The application of advanced artificial intelligence and machine learning methods to strengthen predictive analytics and to support more autonomous management of the implementation process.

Author Contributions: Both authors contributed significantly to all major aspects of the work. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

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