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Evaluating production process improvement strategies in a manufacturing SME: A case study

Ahmad Nazif Noor Kamar[1*], Cheng Jack Kie[2], Syed Radzi Rahamaddulla[3], Siti Zubaidah Ismail[4]
[1,2,3]Faculty of Industrial Management, Universiti Malaysia Pahang Al-Sultan Abdullah, Kuantan, Pahang, Malaysia; nazif@umpsa.edu.my (A.N.N.K.) jackkie@umpsa.edu.my (C.J.K.) syedradzi@umpsa.edu.my (S.R.R.)
[4]Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah; zubaidahismail@umpsa.edu.my (S.Z.I.).

Abstract: Growing competition and changing customer demands are driving manufacturers to rethink their production processes and adopt better improvement strategies. While larger manufacturers have successfully used advanced technologies to make their processes more efficient and customer focused, implementing these technologies requires significant investments in infrastructure, training, and system upgrades. This poses major challenges, especially for small and medium enterprises (SME). This study examines an SME specializing in the manufacturing of aluminum casting products. The company struggles to shorten the extended production time for its high-volume products to achieve the desired production planning targets. To address these challenges, the research utilizes discrete-event simulation (DES) modelling to predict how the production system behaves under several improvement strategies. The use of DES in this study has yielded promising results. The outcomes from proposed improvements demonstrate a remarkable 71% reduction in total production time required to produce monthly planned quantity, significantly enhancing existing production capacity. The simulation technique helps identify bottlenecks, address inefficiencies and evaluate different improvement scenarios in the production processes. It minimizes disruptions to operations, and supports the company decision-makers in selecting the best strategies to improve current processes.
Keywords: *Discrete-event simulation, Improvement strategy, Production process, SME.*

1. Introduction

The manufacturing industry is associated with large-scale production of goods driven by technological advancements. It remains an essential sector in both developed and developing countries, significantly contributing to national economies while fostering technological innovation. In Malaysia, the manufacturing sector encompasses a wide range of businesses, from large corporations to SMEs. These SME play a crucial role in the nation's economy, not only due to their substantial numbers but also their economic impact. Collectively, SMEs contribute 37.4% to Malaysia's gross domestics product, with the manufacturing sector alone accounting for 22.3% of this share [1]. The fast-changing global business environment has exerted pressure on SMEs to adapt swiftly to market demands, remaining agile and responsive, and devising effective business strategies to facilitate expansion. To address these challenges, the 12th Malaysian Plan outlines strategies to redefine the direction of SME manufacturers. Central to these initiatives is the transition to Industry 4.0 (I4.0) technologies. This shift holds significant potential to boost productivity, enhance efficiency, and improve cost-effectiveness, thereby equipping SMEs to thrive in a competitive environment [2].

Integrating I4.0 technologies with information systems significantly enhances decision-making, accelerates process improvements, enables quick reconfiguration, and support organizational learning, as companies can analyze their performance data and adapt to changing market demands [3]. Despite these advantages, a survey by the Malaysian SME Association revealed the use of I4.0 technologies among SME is limited. The study identified three key primary factors contributing to this situation,

* Correspondence: nazif@umpsa.edu.my

namely the substantial financial investment required, uncertainty among SME companies about how to get started and seek assistance, and doubts regarding their own readiness for implementation [4]. Among these challenges, the lack of financial resources stands out as the most significant obstacle for SME [5]. Limited budgets often prevent these companies from investing in the necessary equipment, software, and infrastructure to modernize their production processes. Beyond financial constraints, SME companies also face additional challenges, including employee skill gaps, the absence of clear improvement execution plans [6], insufficient training and qualifications, technical complexities, and the organizational transformation required for I4.0 adoption [7].

Alongside the adoption of I4.0 technologies, the Malaysian government has urged manufacturing sector to focus on enhancing key areas of business operations, including design, engineering, service planning, management systems, and production processes [8]. Improving production process is a highly complex undertaking, particularly for manufacturing companies, especially those classified as SME. Identifying the right areas for improvement is of utmost importance. Manufacturers must realign their current production processes by leveraging their internal resources and capabilities. The changes implemented should not solely revolve around their existing processes but also consider the need for adaptability to future challenges. Finding effective ways to improve the current production processes has proven to be a terrifying challenge [9]. Transitioning to improved conditions is a complex task, and initial attempts may not guarantee success. Some companies may experience a relapse into their previous practices. Implementing an improvement plan requires substantial commitment and investment from both management and the workforce. The process of operationalizing the improvement plan can be challenging due to its complexity and extensive scope [10].

Process improvement in production is often viewed as a series of stages and factors that require careful development, which can pose significant challenges for SME due to the complexity and demands involved [11]. While universally applicable process improvement techniques exist, SME encounter unique challenges that can't always be addressed with generalized approaches [12]. Consequently, companies may require tailored techniques that align with their specific needs and circumstances to achieve their production process improvement goals. The choice of an appropriate process improvement technique depends on the nature of the problems being addressed and the type of analysis needed to find a suitable solution [13]. Different problems may require for different methods, making it crucial to fully understand the specific context and challenges before selecting the most suitable technique. Therefore, this study aims to assist an SME manufacturing aluminum casting products improve its production processes through a case study. The goal is to analyse the problems preventing the company's production from achieving its planned target within the specified timeframe. By combining process improvement principles with computer simulation techniques, the study explores potential modifications to streamline the current production processes.

2. Literature Review

Every company depends on various production processes to power its operations. When these processes take longer than expected, consume more resources than planned, or deliver inconsistent results, it indicates a process breakdown that making the production operations less effective. Thus, to address such challenges, process improvement is the great way to make sure the production processes remain efficient and reliable. Furthermore, it enhances the resilience of companies, particularly SME [11]. Process improvement techniques involving identifying bottlenecks in current production processes, analysing the root causes of inefficiencies, implementing corrective measures, and finding ways to optimize in a way that align with the company's goals. However, improving production processes is often perceived as a risk [14]. While some companies choose to extend production process improvement projects over several years to minimize the risk of failure, the initiatives usually result in significant changes within a relatively short time [15]. To be effective, such efforts must evolve alongside the organization, becoming a key strategy aligned with its business needs.

The quest for strategies grounded in process improvement, combined with the need to meet evolving business requirements, has driven many companies to modify their existing production processes. Case studies conducted by [13] and [16] demonstrate that improving production process

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within an organization can be achieved by reducing individual workstation cycle time, production throughput time, manufacturing lead time, the ratio of cycle time to takt time, and through work standardization. Moreover, the adoption of process improvement initiatives has demonstrated significant benefits, such as lowering work-in-process (WIP) inventory levels [17], reduce operational costs, improving on-time delivery [18], maximizing profits, enhancing shareholder value, and delivering significant benefits to SME [12]. However, as [19] point out, no single process improvement methodology has been able to fully meet all goals. This highlights the reality that there is no one-size-fits-all solution, emphasizing the need for tailored strategies and a suitable technique to address the unique challenges of each organization [20].

Despite process the advantages, there remains a limited understanding of how to embed and sustain improvement initiatives without regressing to previous practices [21]. [22] highlight that the primary challenge lies in effectively implementing changes. Similarly, [23] identify reasons for the failure of production process improvement initiatives in enhancing business performance, such as lack of commitment and support from top management, an underqualified team, insufficient training and learning, incorrect selection of methodologies and tools, scope creep, suboptimal team size and composition, inconsistent monitoring and control, and resistance to change. Thus, achieving success in these production process improvement attempt relies on adopting a structured technique that not only provides clear guidance for implementing planned improvements but also outlines the anticipated changes necessary for a smooth and effective transformation.

Among the various process improvement techniques available, lean method is considered the most suitable for this study to help the case company address its problems. This method has also been successfully applied in similar case studies conducted by [24], [25], [17], and [26]. The core principle of lean implementation revolves around eliminating waste to enhance the value stream of production processes. In the context of lean, waste is defined as any expenditure or effort that does not contribute to transforming materials into products that customers are willing to pay for. However, lean implementation has faced criticism, particularly for its time-intensive focus on waste elimination and the high costs associated with management changes [27]. Moreover, the implementation of lean varies significantly across companies, leading to differing opinions on the appropriate performance measures and a wide range of indicators used to evaluate its impact and benefits [28].

Although researchers have proposed various frameworks for lean implementation, value stream mapping (VSM) is widely recognized as a valuable tool to support practitioners [29]. Despite its popularity, VSM has notable limitations. It cannot fully capture or represent the realities of the production process [30], and it struggles to describe dynamic behaviours or manage complexity and uncertainty [31]. Additionally, VSM falls short in analysing the interactions between components of production processes and lacks the ability to verify or validate the performance of a proposed future system before implementation [32]. According to [33], VSM that performed in isolation may not produce meaningful results in various scenarios. It does not account for the sequence in which batches enter queues at each production processing stage, queuing delays, and capacity constraints.

To facilitate the implementation of process improvement initiatives and align them with company strategies, researchers often utilize computer modelling and simulation technique in their case studies, as these tools provide a risk-free and cost-effective environment for testing changes [34]. The compatibility between I4.0 technology and process improvement techniques, particularly lean, has shown a strong correlation [35]. Computer modelling replicates real-world systems or processes over time, enabling businesses to enhance performance in both new and existing scenarios. This technique aids decision-making by preventing potential failures from adjustments and offering a comprehensive understanding of system behaviour through numerical evaluation. A well-developed and validated computer model can address a wide range of questions about the simulated system, allowing organizations to explore different scenarios, visualize production processes clearly, and conduct flexible testing, thereby avoiding financial constraints [36].

3. Methodology

The research flow starts with formulation of the problem and followed by creation of research objectives. This step requires a comprehensive understanding of the existing production system and problems encountered by the case company. It involves determining the performance metrics that will be used to measure the system under study and outlining the performance objectives that the company aims to achieve. The next step involves data collection that encompasses the collection of input parameters, and any additional information needed to represent the system. The data source comes from various channels, including observations, conducted time studies, and historical records like production reports. Once the collected data is aligned with the established research objectives, the next step involves developing a detailed simulation specification and designing a computer simulation model that accurately represents the actual system.

The model defines the various components within the existing production processes, their interrelationship, and the flow of inputs and outputs throughout the system. The design phase starts with a thorough analysis of the system components, including machinery involved, production flow and sequence, and planning schedules. Each component is accurately defined to ensure that the simulation model encompasses all critical aspects of the production process. The interactions between those components are mapped out to capture the dynamic nature of the system, confirming that the built model reflects the complexities and interdependencies inherent in the actual production environment. Then, the working model must first undergo verification to ensure it behaves as intended. Following verification, the model undergoes validation, which involves comparing the simulation model's outputs to real-world data to evaluate how accurately it replicates the actual system's behavior.

The next steps involve conducting experiments based on the type of analysis required. This includes determining the scenarios to be explored by manipulating input parameters and conditions, and estimating model outputs using statistical methods. By running multiple simulations and analyzing the results, this study can gain insights into system behavior, evaluate various process improvement strategies, and assess the impact of changes. To effectively evaluate the results from a statistical perspective, it is crucial to understand how different inputs and configurations influence output measures. This process includes identifying scenarios that show significant differences in performance and determining which scenarios perform best or are most likely to excel among all those considered. The final step involves interpreting the simulation findings and communicating these insights to stakeholders. The results are documented in a report, accompanied by visualizations, statistical analyses, and explanations of the simulation outcomes.

4. Case Study

The case company operates a job shop production system consisting of three primary stages: die casting, secondary processing, and machining. Production is organized in batches, following a predefined process sequence and adhering to standard production cycle times, as illustrated in Figure 1. The product progresses through these three stages sequentially, moving to the next stage only after the batch has reached the predetermined quantity at each stage. As shown in Figure 1, the machining 2 and machining 3 processes are identified as bottlenecks, where the production flow slows down, thus limiting the overall capacity of the production system. Each process has a cycle time of 400 seconds per unit. According to information provided by interviewing the planner, the monthly available production time is calculated to be 1,702,800 seconds. This figure is based on two shifts per day, each lasting 10.75 hours, across 22 working days per month. As a result, the theoretical maximum production capacity of 4,257 units per month is calculated by dividing the total monthly available production time by the cycle time of the bottleneck process, assuming there are no constraints such as rejections or downtime.

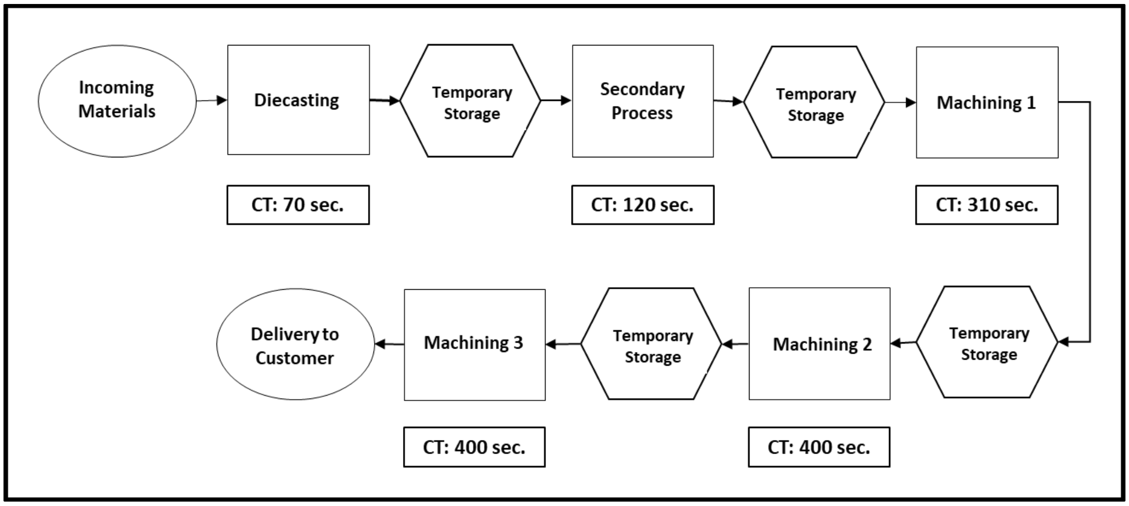

Figure 1.
Production process flow chart.

The company's challenges are illustrated in Figure 2, which compares planned and actual production outputs as well as planned and actual production times over a six-month period. While the planned production output and production time remain fixed each month, the actual production time fluctuates, reflecting trends in actual production output. According to the production records, actual production output consistently falls short of planned targets, except in the first month. In that month, actual production exceeded the planned output, but this was achieved through overtime, causing the actual production time to surpass the planned time. This indicates significant deviations from the plan and highlights inefficiencies in the production process. Further observations reveal that the production time recorded in individual process reports does not fully capture the sequential and interdependent nature of the production process. Variability and dependencies between processes involved introduce inefficiencies that are often overlooked in the company's production reports. Consequently, the recorded production times may present an incomplete and potentially misleading picture of the overall production system's performance.

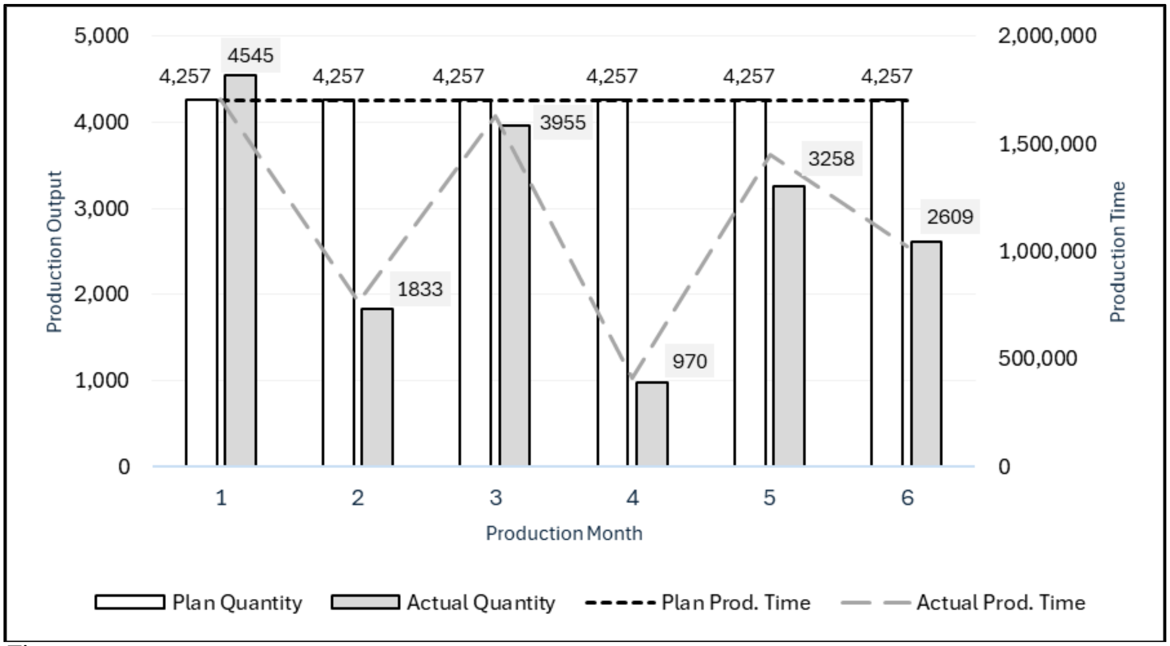

Figure 2.
Plan versus actual in production record.

5. Results and Discussion

The production process flow chart provided in Figure 1 serves as the basis for developing the DES simulation model, as depicted in Figure 3. By modelling the entire production process, the simulation incorporates the interdependencies and variability between different stages, offering a comprehensive understanding of the production system's performance and identifying potential areas for improvement. Inputs for each module of the simulation model are derived from information provided by the planner and data from production records. Using these inputs, the modelling process is carried out, and the total production time obtained from the simulation result is compared with the total production time from the production records for validation purposes. Additionally, the mean absolute percentage error (MAPE) method is employed to validate whether the simulation model accurately represents the real production process. The calculated MAPE value of 3.8% indicates very accurate predictions, as classified by [37]. Therefore, the developed computer model accurately imitates the existing production process and can be reliably used for the experimentation and scenario testing.

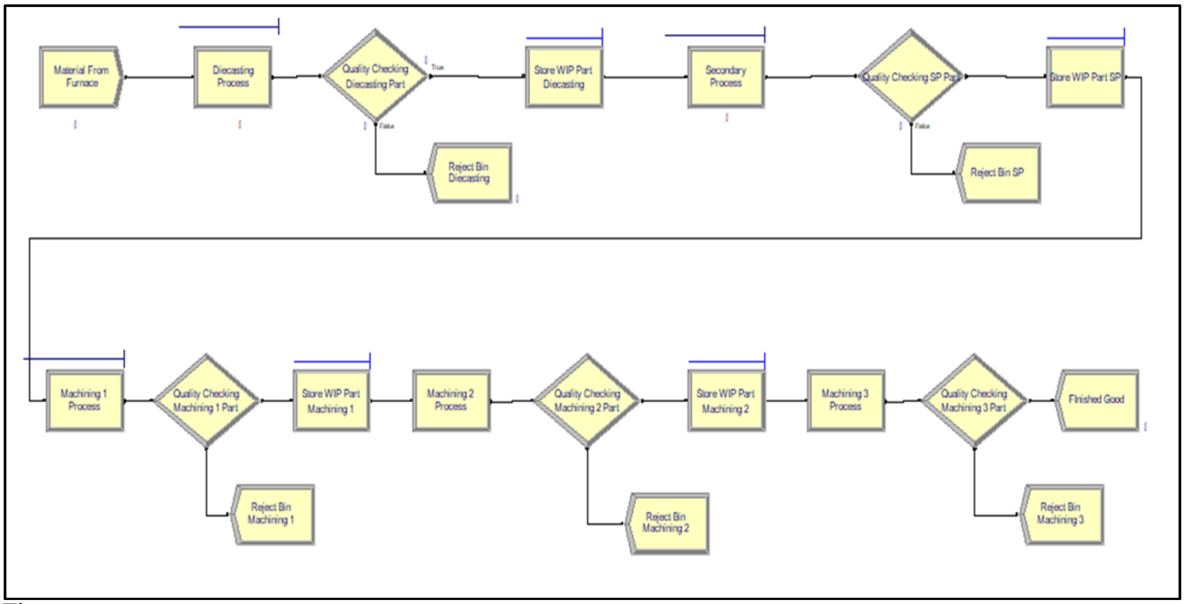

Figure 3.
DES model of current production process using arena software.

The simulation results show that the DES model in Figure 3 requires 3,887,520 seconds of production time to meet the monthly production target, with an average waiting time of 95,946 seconds for the product to be processed at each stage. These results clearly indicate that the production department will not meet the planned production targets within the allocated timeframe. The shortfall in meeting the production targets underscores the need to explore alternative solutions to address the ongoing challenges and achieve the desired production goals. In response, this study focuses on analysing the bottleneck processes, reducing waiting times for product processing, and optimizing the total production time required. Following discussions with the process owner, adjustments were made to the initial DES model, which represented the current production process. In the first scenario testing, machining processes two and three were rearranged to run in parallel, aiming to reduce the waiting times between these two stages. This change, as part of the improvement strategy, was implemented based on the similarity between the processes, with the only difference being the type of cutting involved.

In the second scenario testing, the modifications from the first scenario computer model were retained, with additional adjustments introduced to further enhance production efficiency. A key improvement involved dividing the total production quantity into smaller batches, a strategy known as production levelling. This approach introduced greater flexibility during product transitions between stages. However, this strategy was applied only from the secondary process onward, as implementing it from the beginning would be impractical due to the fast cycle time of the die-casting process, which is fully automated. For the third scenario testing, the model retained the smaller batch improvement strategy from the second scenario but reverted the arrangement of machining 2 and 3 from a parallel configuration back to the original series configuration. Surprisingly, the simulation outcomes for the third scenario showed significant improvements compared to both the first and second scenarios. A detailed comparison of the simulation results for all three improvement strategies, along with the current production process, is presented in Table 1.

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Table 1.
Simulation result from scenario testing.

Simulation result	Current production process	Proposed improvement strategies		
		Scenario one	Scenario two	Scenario three
Total production time (tpt) require (sec.)	3.887.520	2.844.480	1.428.480	1.132.560
% Reduction of TPT from current production process	-	26.8	63.3	70.9
Average waiting time for product processing (sec.)	95.946	70.314	34.410	27.012
Available production time – total production time (sec.)	(2.184.720)	(1.141.680)	274.320	570.240

This comparison offers valuable insights into how each scenario testing or modification reduces the total production time required to meet the monthly planned target by nearly 71%, significantly minimizing the average waiting time for products to be processed, amounting to an excess of 570,240 seconds which creates opportunities to further expand production capacity and explore improvement strategies for substantial productivity gains. By analysing the simulation results, the management of the case company can identify the adjustments that deliver the most significant benefits and those that may need further refinement. This comprehensive evaluation highlights the critical role of data-driven decision-making in optimizing production processes, enabling the company to prioritize impactful changes and drive sustained growth effectively. Subsequently, Table 2 presents a detailed analysis of significant improvement strategies, with a particular focus on minimizing waiting times at each stage of the production processes, as demonstrated by the simulation results. These improvements play a crucial role in boosting production outputs while minimizing delays that could disrupt the overall production workflow, ensuring a smoother and more efficient operation.

Table 2.
Comparison of waiting time at each production process involved.

Queuing location	Average waiting time (sec.)			
	Current process	Scenario one	Scenario two	Scenario three
Diecasting process	366	366	366	366
Temporary storage after diecasting	3.312	3.312	3.324	3.324
Secondary process	5.772	5.772	5.940	5.940
Temporary storage after secondary	5.778	5.778	1.440	1.440
Machining 1 process	13.992	13.992	0	0
Temporary storage after machining 1	14.004	14.004	270	6.648
Machining 2 process	19.164	10.074	6.078	9.000
Temporary storage after machining 2	19.068	10.074	0	0
Machining 3 process	19.272	11.448	16.656	297

The modifications have significantly reduced waiting times, particularly in the bottleneck processes at machining 2 and machining 3, where waiting times were recorded at 9,000 seconds and 297 seconds, respectively. Accurately assessing the impact and effectiveness of these modifications would have been both challenging and time-consuming without the use of simulation technique. By leveraging computer modelling and simulation, the case company has been able to evaluate the potential effects of proposed production process improvement strategies within a controlled, risk-free environment, allowing for comparison under varied conditions, and streamlining the decision-making process.

6. Conclusion and Recommendation

Understanding which production process improvement techniques to apply is essential for manufacturing companies, particularly SMEs, to meet customer demands in today's fast-paced environment. This study highlights the effectiveness of combining lean principles, a widely adopted process improvement approach, with simulation techniques that empirically evaluate proposed improvement strategy scenarios. This synergy has delivered convincing results, enabling the case company's management to make informed decisions that unlock greater value and optimize profitability. By addressing the identified problems, the company successfully redesigned its production processes, reducing the total production time required and improving production capacity and overall efficiency.

This study also contributes to academic knowledge by demonstrating the real-world application of simulation techniques, bridging the gap between theoretical research and industrial practice. To develop a more comprehensive framework, future research should explore a broader range of production processes, company sizes, and challenges across diverse manufacturing sectors. Expanding research into various industries will refine and adapt the methods to specific needs, ensuring they address a wide array of operational challenges. By evaluating the techniques across multiple contexts, researchers can develop a more universally applicable and effective strategy for improving production processes.

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