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Productivity Optimization in the Electronics Industry Using Simulation-Based Modeling Approach

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Abstract

Many industrial production lines today are initially constructed and outfitted with machinery that, despite its inherent capabilities, struggles to satisfy increasing demand over time. The goal of this research is to find solutions to bottlenecks and improve the efficiency of the production line to satisfy rising productivity demands. The study primarily looks at an existing bottle production line in the edible oil industry, where the product is witnessing a boom in demand. Data on processing times at various workstations and their capacities were thoroughly collected and analyzed. Simulation emerged as the preferred tool for investigating and addressing the production line's intrinsic difficulties. Using Microsoft Excel for statistical analysis, an existing simulation model was created using Flexsim simulation, a process-oriented simulation software, to detect bottlenecks in the production line using the Processor block in the simulation. As a result, a modified model was offered to reduce waiting times by 12%, increase productivity by 6%, and increase overall profitability while efficiently dealing with rising demand across all seasons. As a result, this research represents a complete effort to identify operational challenges and present viable solutions that correspond with the industry's changing objectives. The study aims to contribute to optimizing production lines by utilizing contemporary simulation tools and statistical analysis, guaranteeing that they stay adaptive and responsive in the face of rising productivity demands.

Keywords: Modeling, Manufacturing line, Optimization, Flex sim simulation.

1 | Introduction

In industrial advancements, Industry 4.0 technologies represent a transformative wave characterized by integrating digital technologies, data analytics, and the Internet of Things (IoT) into industrial processes. These technologies encompass cyber-physical systems, cloud computing, and cognitive computing, fostering

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a smart and connected ecosystem. Embracing the principles of automation, real-time data exchange, and enhanced process efficiency, Industry 4.0 technologies revolutionize traditional manufacturing paradigms. Simulation modeling stands out as a cornerstone of Industry 4.0, offering a dynamic platform to replicate real-world scenarios and analyze system behavior. It facilitates the assessment of various production scenarios, identifying bottlenecks, and optimizing processes, providing a comprehensive view of the industrial landscape. Simulation models enable decision-makers to evaluate the impact of changes, innovations, or improvements before implementation, thereby reducing risks and costs associated with trial-and-error approaches. The research gap in the context of productivity improvement often lies in the limited adoption of advanced technologies and methodologies, particularly in addressing specific operational challenges within production lines. While Industry 4.0 technologies hold immense potential, their application in production line optimization and productivity enhancement remains an area that requires focused exploration. This study aims to bridge this research gap by investigating the efficacy of simulation modeling, a crucial component of Industry 4.0, in the context of productivity improvement. It seeks to clearly define the role of simulation modeling in identifying bottlenecks, proposing modifications, and predicting outcomes within a specific production line, thereby contributing valuable insights to the broader discourse on leveraging Industry 4.0 technologies for operational excellence.

This research endeavors to provide a comprehensive solution for productivity improvement in the edible oil industry's bottle production line through a meticulous analysis of processing times and capacities at various workstations, coupled with the implementation of simulation modeling using Flexsim. The proposed modifications, informed by simulation results, aim to optimize waiting times, enhance productivity, and improve overall profitability, addressing the identified research gap and showcasing the practical application of Industry 4.0 technologies in industrial decision-making for productivity enhancement. In productivity optimization, this methodology allows for creating simulated environments where variables, scenarios, and operational parameters can be meticulously manipulated and studied. It is impossible to overestimate the importance of productivity optimization for industries aiming for sustainability and competitiveness. Increasing productivity guarantees cost-effectiveness and helps with lead times, better overall operational performance, and efficient use of resources. In this quest, a modeling method based on simulations proves to be especially effective, providing a platform for testing different optimization tactics in a safe and regulated virtual environment. The main objective of this research is to use simulation-based modeling to uncover the hidden potential in industrial processes. The study aims to maximize productivity metrics by streamlining operations, identifying bottlenecks, and suggesting customized tactics. The dynamic nature of simulation modeling aligns seamlessly with the evolving demands of modern industries, providing a nuanced understanding of complex systems that is often challenging to achieve through traditional analytical methods. An avenue for future research to pursue unheard-of efficiencies is investigating a modeling strategy based on simulation-based productivity optimization.

This novel approach is a focus point, shedding light on how businesses could achieve previously considered unachievable efficiencies. We shall carefully dissect the selected simulation modeling methodology as we move through the many complexities that come with it in the following sections of this study. In addition, a thorough investigation of empirical results will be conducted to assiduously support the overall goal of developing and perfecting productivity optimization solutions within the complex framework of industrial settings. These elements create a compelling story highlighting simulation-based methods' revolutionary potential. Simulation emerges as a powerful and complementary tool within industrial production lines, offering substantial potential for enhancing efficiency and productivity. The manufacturing sector, characterized by significant economies of scale, yields unique advantages across diverse segments, producing capital goods, intermediate goods, and most consumer goods. Acknowledged as a pivotal driver of development [1], this expansive manufacturing sector assumes a crucial role in shaping the economies of least developed nations within today's fiercely competitive market [2]. Integral to manufacturing industries, production lines serve as key components, guiding nearly all products through sequential operations—from raw material processing to refining, ultimately rendering them suitable for consumption [3]-[5]. The assembly line, a subset of the production line, reflects flow-oriented production widely employed in high- and low-quantity production scenarios [3], [4]. As the manufacturing sector assumes an increasingly prominent role, various engineering techniques, analytical methods, and software tools have spontaneously emerged to boost productivity [2]. Mathematical methods such as the Asynchronous, Synchronous, and Continuous model have been developed to optimize manufacturing processes. Amidst these methodologies, simulation stands out as a widely embraced engineering tool for analyzing and improving production lines within manufacturing systems [6]-[8]. The adoption of simulation aids in comprehending and refining complex production processes, contributing to enhanced operational performance. This utilization of simulation aligns with the imperative to foster innovation and efficiency within the manufacturing sector, which is crucial for sustaining economic growth in an ever-evolving global landscape.

Simulation involves the creation of a model for an existing or proposed system, enabling the identification of key system-controlling factors. Recent advancements in simulation technology have significantly increased awareness and utilization of simulation in various industries. Industry managers now recognize the substantial benefits of simulation techniques [9], [10]. The advent of advanced simulation technology has provided industries with a valuable tool for comprehending the impact of changes within a local system and assessing their repercussions on the entire system. This task can be challenging to achieve otherwise. Measurable impacts include parameters such as parts produced per unit time, time spent by parts in the system, duration of parts in the queue, time spent on transportation between locations, on-time deliveries, inventory buildup, work in process inventory, and the percentage utilization of machines and workers [9], [11]. Simulation facilitates the understanding of local system changes and quantifies their effects on various aspects of the overall system. These measurable impacts serve as crucial indicators for system performance, aiding managers in making informed decisions to optimize efficiency and resource utilization. The increasing recognition of simulation's potential underscores its importance as an invaluable tool for enhancing operational insights and strategic decision-making in diverse industrial settings. Ullah et al. [12]-[15] eloquently present insights in four papers addressing manufacturing excellence, operational scheduling, and equipment efficiency. These contributions are crucial for line balancing work [15]-[19]. Hossain et al. [20] discuss electricity generation from moving vehicles, proposing its potential application for ensuring machine continuity in a factory, aligning with the objectives of our production line work [13]. Rahman [21] explores the impact of supplier selection on the electronics sector, recognizing its significant role in product procurement, which considerably impacts overall profit work [5], [12], [21], [22]. Ullah et al. [12] utilize value stream mapping with a robust mathematical process, offering utility in research, especially in scenarios where extensive vehicle production is essential for production and manufacturing work [20]. The primary objective of this study is to employ simulation to replicate the current water bottle production line, identify bottlenecks within the system, and propose alternative models to enhance productivity by minimizing these bottlenecks. A comprehensive literature review has examined prior works in the relevant field, laying the groundwork for the current research. This review has identified and addressed limitations in previous research, as outlined in the research gap section.

The methodology section details the systematic approach followed in this research, delineating the step-by-step procedure adopted. The analysis section then thoroughly examines the existing production model and outlines the necessary modifications. The results and discussion part delves into the research outcomes, providing insights into the implications of the proposed alternative models. In conclusion, the study's limitations are acknowledged in the concluding section, accompanied by suggestions for potential future research endeavors. Notably, the simulation tool Arena has been employed extensively throughout the research process, offering a comprehensive platform for tasks such as input data analysis, model construction, verification, and output analysis. In the insightful work by Faghidian and Mahmodi [23], a comprehensive exploration unfolds, delving into resource management, process standardization, efficient management practices, performance measurement, and the ongoing evaluation of customer satisfaction. The multifaceted insights provided by this research serve as a valuable foundation for our endeavors in production optimization, aligning seamlessly with the overarching goals of achieving operational excellence. Their findings furnish a roadmap for enhancing resource utilization, streamlining processes, and fostering a customer-centric approach, all of which are paramount considerations in our pursuit of optimizing production lines.

Moreover, a cluster of studies [24]-[27] scrutinizes the Information Technology Governance (ITG) mechanism, interpreting its intrinsic value in IT businesses. While originally tailored for the IT sector, these interpretations emerge as invaluable perspectives for our research in the broader context of production optimization within the framework of Industry 4.0. As elucidated by these researchers, the interplay between ITG mechanisms and production optimization offers a nuanced understanding that promises to significantly impact our approach to navigating the challenges and opportunities of the Industry 4.0 era. As we embark on our research journey, these insights beckon as crucial touchpoints, guiding our exploration of innovative strategies and practices for achieving optimal production outcomes.

Drawing from the work of John and Jenson Joseph [8], the research incorporates calculations of machine utilization and efficiency. Meanwhile, Manivel and Sandeep [3] conducted a simulation focusing on material flow arrangement within the shop, including considerations of cycle time and the number of operators, subsequently analyzing overall efficiency. Their findings indicated that the lathe and winding machines experienced longer queue lengths and waiting times. To address this, they recommended an optimized arrangement by minimizing shafts, and through Arena simulation, they identified a lathe machine with the highest utilization rate, reaching 26%. This research contributes to existing literature, which predominantly focuses on simulating specific machines within a shop or small manufacturing company. The unique aspect introduced here is the comprehensive analysis of an entire industrial production line, a perspective not explored in prior studies. Previous works have typically involved analyzing individual machines, identifying specific issues, and proposing solutions. In some instances, entirely new models were suggested to enhance overall system performance. However, the novelty of this research lies in its holistic examination of the whole production line of an industry. Furthermore, a cost estimation related to the proposed layout changes was conducted, providing insight into the financial viability of the proposed modifications. This approach adds a layer of practicality to the research, considering both operational efficiency and economic feasibility.

1.1 | Problem Statement

To fulfill the complete oil supply packaging for the visited industry, the process begins with refining RSO/SRPL in a seven-stage purification process within the refinery section. Subsequently, the Husky machine is utilized to manufacture the primary bottle, requiring a total cycle time of 21 minutes and 56 seconds. The produced bottle undergoes labeling through injection cavity molding and blow molding, utilizing PET resin as the raw material. The bottle cap is produced similarly as part of the bottle production flow. The substances are then prepared for the filling and packaging section, marking the conclusive phase of the water supply segment, which is of primary concern. A blend of automated and manual systems is employed, resulting in a fully assembled package ready for delivery. The manual entry of the bottle into the washing treatment section is swift and efficiently executed, with the bottle supplied directly from the production line, maintaining a constant inventory in safety stock to mitigate any potential shortages in the bottle supply. The subsequent processes, encompassing washing treatment, filling, capping, date putting, and manual cap sealing, follow an automated machine flow. Two workers are assigned to the manual cap sealing section, introducing an extra time allowance due to the manual nature of this operation.

Consequently, a queue forms in front of this line, requiring more output. We have proposed a modified approach that ensures the desired output. The feeding process and final sealing, apart from the cap sealing operation, are conducted through automated machines. This intricate combination of automated and manual operations ensures a streamlined and continuous process, meeting the industry's oil supply packaging requirements.

1.1.1 | Methodology

In the meticulous data collection phase at Edible Oil Limited, diverse processing times for various workstations were diligently observed over five days. Subsequently, the acquired data became the bedrock for our analytical endeavors. Harnessing the power of Flexsim simulation software, we conducted a comprehensive analysis and design evaluation of the existing model. This dynamic simulation environment allowed us to scrutinize the intricate details of the production line, unveiling its operational nuances and potential bottlenecks. Working within the Flexsim simulation software, our analysis unearthed problematic areas inherent in the current model. These identified challenges laid the groundwork for our subsequent efforts focused on strategic mitigation strategies to bolster productivity. The integration of Flexsim facilitated a detailed examination of the existing model and empowered us to envisage and implement targeted modifications, ensuring a more streamlined and efficient production process. This synergy between real-world data, simulation capabilities, and practical insights positions our study at the forefront of informed decision-making for optimizing industrial processes. Subsequently, a new and improved production line was proposed to rectify these issues. The methodology employed throughout this process is encapsulated in *Fig. 1*, outlining the systematic approach taken in data collection, analysis, and proposal development.

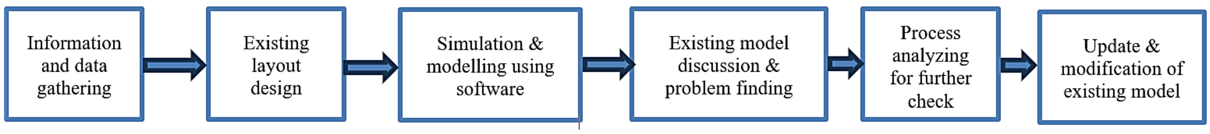

Fig. 1. Steps of the research study.

2 | Examination and Adjustment

The illustration of the prevailing production line intricacies was skillfully achieved using Flexsim ‘lation software. Employing a meticulous approach, each workstation found representation through the adept deployment of the Process module, ensuring a faithful emulation of real-world operational nuances. Complementary to this, the entry and exit points were precisely delineated using the Create and Dispose modules, encapsulating the entire production flow within the simulation environment. The intricate details of the existing line come to life in *Fig. 2*, where the simulation seamlessly captures the dynamic interplay of processes, providing a visually comprehensive representation that serves as the foundational framework for our analytical exploration and proposed modifications. Ullah et al. [14] and Rahman et al. [22] describe how line balancing works in production environments and how the efficiency and associated cost are related to the overall profit of a company, and we have used this helpful information regarding simulation optimization based on different scenarios for production line optimization works in our research methodology.

In Flexsim, the category overview and queue segments are integral components providing essential results for the analysis. The "Number Out" parameter stands at 15520, signifying that within a 4-hour timeframe, the current production line can manufacture 15520 fully packaged water bottles. Addressing schedule utilization is a notable aspect, evident in the model report. *Table 1* in the report outlines the schedule utilization rates for various components of the existing line obtained from the software. Notably, the Date Putting Machine and Laborer exhibit higher utilization rates than other elements, emphasizing these components' significance in the line's overall operational efficiency.

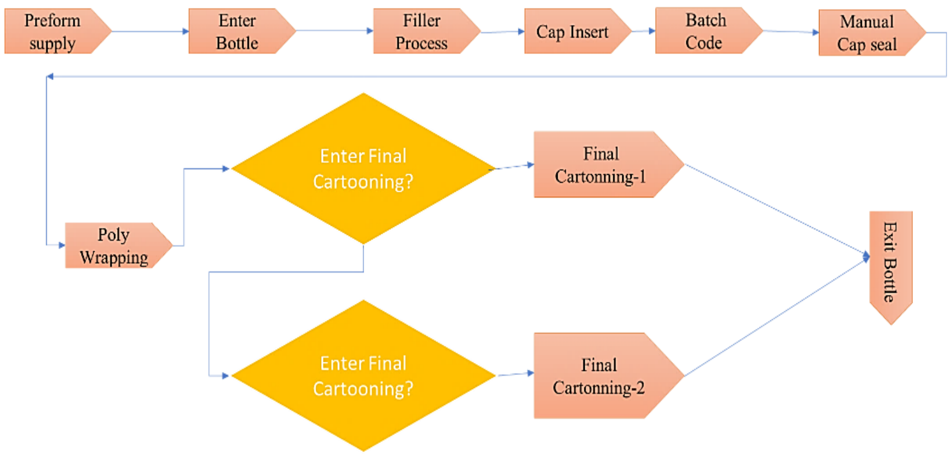

Fig. 2. Layout of the existing line.

Table 1. Tabulated data of schedule utilization rate (existing line) obtained from the software.

Name of the Workstation	Schedule Utilization Rate
Compressor	65.9
Batch code machine	89.5
Filler-capper	74.5
Cap seal	54
Laborer	98.5
Cartooning machine	77.8
	76.7

This data is graphically represented in *Fig. 3* for more clarification. Date Putting Machine and Laborer are most utilized, which is seen in *Fig. 3* by the most uprising bar showing that those two resources have the highest utilization rate, so the queue is seen to form in these workstations.

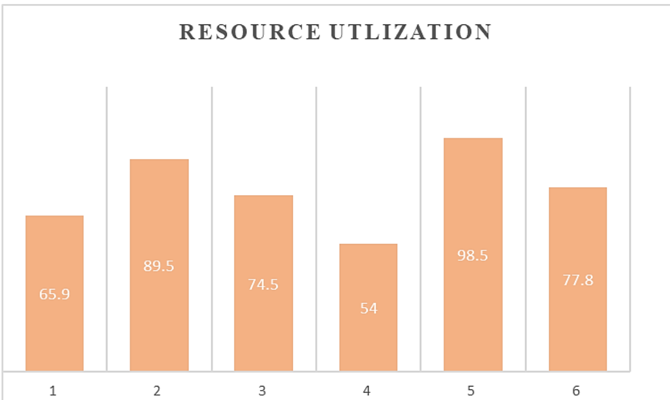

Fig. 3. Utilization of resources for existing line.

The quantification of this notion can also be articulated through the waiting time metrics outlined in *Table 2*. The data unmistakably reveals that the Date Putting and Manual Cap Sealing workstations, which employ the Date Putting Machine and Laborer as resources, exhibit the longest waiting times within the workflow. In contrast, other stations experience significantly fewer or fewer queues than these two. These findings collectively signify that the Date-Putting and Manual Cap Sealing workstations serve as critical process bottlenecks, and this research focuses on minimizing these bottlenecks to achieve its objectives.

Table 2. Delay time for existing line in flexsim.

Name of the Workstation	Waiting Time in Second
Injection molding	0.92
Filler in oil	0.49
Capper in line	0.59
Batch-coding	1173
Cap insertion manually	190.3
Poly wrapping	0.72
Cartooning 1	4.99
Final cartooning	51.02

Again, sensitivity analysis was done through a process analyzer to find out the effect of different workstations on the final output of the existing model.

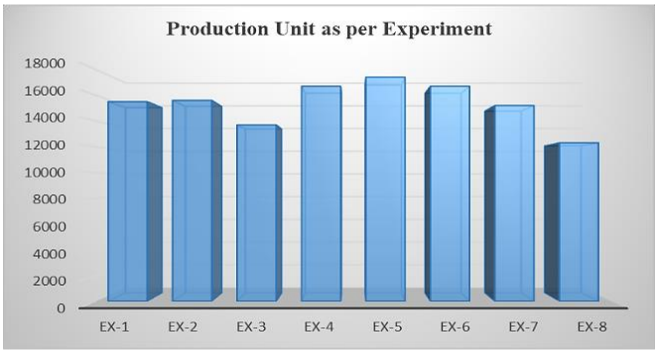

Fig. 4. Bottle number output response of process analyzer.

It is shown in the chart given below in *Fig. 4* that Scenario 6, which is affecting the output most, is the scene controlled by manual capping. Further analysis was done to assess the effect of scenario six on the reduction of waiting time.

Based on the preceding analysis, the pivotal area requiring rectification for enhanced productivity is the manual cap-sealing process. As a strategic solution to this bottleneck, a novel proposal introduces a semi-automated cap sealing machine and cap insertion machine instead of the current manual operation. This proposed modification, delineated in *Fig. 5*, transforms two workstations, elevating the production capacity from 350 bottles per minute (bpm) to an impressive 1200 bpm. Importantly, all other operational processes remain unaltered, with the proposed changes confined to the manual cap sealing and cap insertion segments, which are now transitioning to automated operations. The crux of this proposed modification revolves around recognizing that manual cap sealing poses a significant constraint to the line's overall efficiency. By incorporating semi-automated machinery for cap sealing and cap insertion, the production line undergoes a transformative enhancement in its capacity, paving the way for a substantial increase in productivity. This strategic shift aligns with the overarching goal of streamlining operational processes to meet the rising demand effectively. It is imperative to emphasize that while the proposed modification introduces automation to specific segments, it does not alter the fundamental integrity of the remaining processes. The essence of the production line, encompassing processes like bottle production, labeling, and filling, remains consistent. The proposed transformation singularly targets manual cap sealing, recognizing its pivotal role in dictating overall production efficiency.

This proposed modification heralds a paradigm shift, introducing efficiency-driven automation to a critical juncture in the production line. The envisaged transition from manual to semi-automated cap sealing and cap insertion addresses identified bottlenecks and positions the production line to meet increased demand with heightened productivity and operational agility.

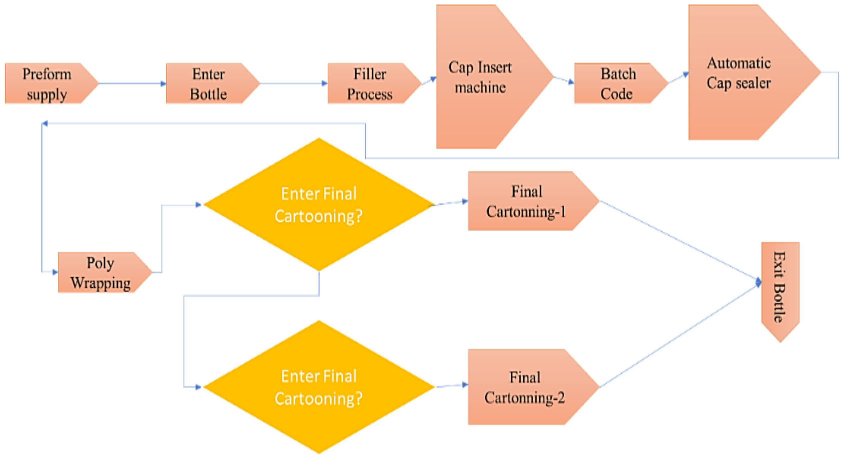

Fig. 5. Modified proposed system.

Following the integration of the new machine into the existing line and the provision of the requisite input for this modification, the output now stands at 12012 units per shift. Concerning this outcome, the individual workstation's schedule utilization rate has decreased from 86% to 79%, as illustrated in *Table 3*. This change aligns with the patterns observed in other workstations.

Table 3. Tabulated data of schedule utilization rate (proposed line) obtained from the software.

Name of the Workstation	Schedule Utilization Rate
Capping slot	75.2
Date putting machine	99.2
Filling slot	80.2
Heating machine	39.9
Capping machine	83.4
Packaging machine	82.6
Washing slot	81.1

It is graphically shown in *Fig. 6*, where the bar of the respective resource has come to a safe percentage of utilization rate.

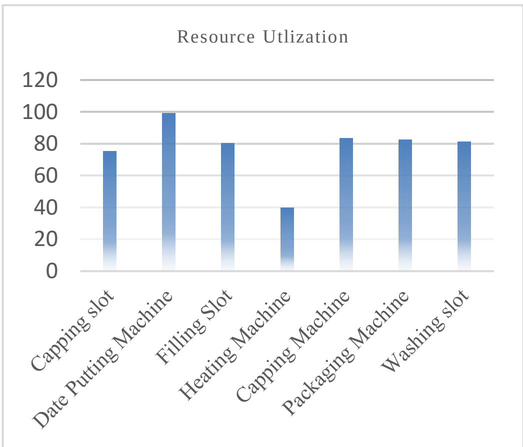

Fig. 6. Resource utilization (graphical view) of the modified line.

A considerable change has come to the waiting line presented in *Table 4*, for which a queue was forming before, and it has been reduced from 180.19 seconds to 7.49 seconds.

Table 4. Delay time from software for the proposed production line.

Process Station of Filling	Delay Time(s)
Injection molding	5
Filler line	0.64
Capper	0.92
Batch coding	1130.6
Bundle heater	6.49
Poly shrink method	0.62
Cartooning 1	5.58
Final cartooning	45.76

Introducing a new machine to the production line necessitates determining the timeframe within which the industry can recover the additional costs incurred for the machine. A breakeven analysis was conducted to assess this, revealing that the breakeven point reached 98,000 units. The industry can produce over 2 million monthly bottles, considering the operational hours. Consequently, the industry is poised to offset the incurred costs and generate profits in the initial month following the machine addition.

3 | Result and Findings

Upon a meticulous comparison between the existing production model and the proposed modifications, a notable revelation emerges – three workers are no longer necessary for machine setup on the production line. However, a crucial observation surfaces: while productivity shows an upward trend, the production cost per unit experiences a simultaneous increase. A comprehensive examination of both production lines, scrutinized through *Fig. 7* bar charts, provides a detailed comparison encompassing productivity, waiting time, schedule utilization rate, and profit. It is discerned that the existing machine yields 42,000 units per month, whereas the proposed machine remarkably elevates the output to nearly 100,000 units. The charts underscore that, despite a reduction in waiting time and schedule utilization and a slight cost increase in the proposed line, there is a substantial surge in profit. This noteworthy profit increase is particularly remarkable, given the relatively modest percentage improvement in productivity achieved. The comparative charts effectively delineate the intricate balance between productivity enhancements, operational efficiency, and financial outcomes, elucidating the trade-offs and benefits associated with the proposed modifications.

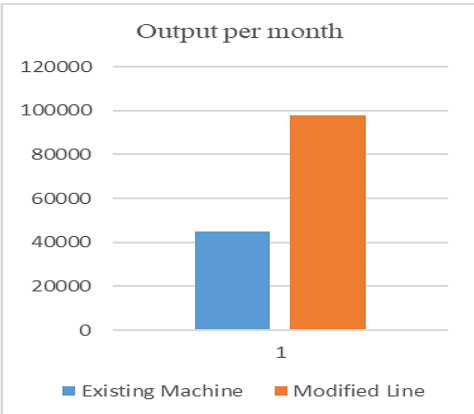

Fig. 7. Comparison of production rate per month.

The significant alterations in contrast to the preceding line are briefly outlined in the summarized form in *Table 5*.

Table 5. Process optimization summary.

Sl. No.	Sector of Differentiation	Remarks
1	Manufacturing capacity	Increased by 6%
2	Average delay time	Decreased by 13.23%
3	Utilization rate as scheduled	15.11% reduced
4	Profit from optimization	36000 USD increased/Yr.

4 | Conclusion

This study focused on identifying bottleneck areas within an existing production line to pave the way for model rectification and increased productivity through simulation. The developed model utilized FlexSim simulation to represent a bottle production line in a chosen industry. After simulating the existing line, a substantial bottleneck was identified at the Manual Cap Sealing workstation. This bottleneck was addressed by replacing it with an automated Bottle Cap Sealing machine and cap insertion machine, reducing average delay time and increasing overall productivity. Cost and revenue calculations based on the collected data revealed that the reduction in line costs corresponded with a significant increase in profit. Despite these positive outcomes, certain limitations persisted. The simulation study assumed no consideration of worker fatigue and machine breakdown, and the proposed model lacked practical application. Additionally, due to industry-specific terms and conditions, obtaining exact cost and revenue data proved challenging, leading to average values. A potential avenue for future research in this field could involve justifying the proposed model through practical implementation, considering factors such as worker fatigue and machine breakdowns.

4.1 | Future Work and Potential Limitations

Dynamic simulation with real-time data: future research could explore integrating dynamic simulation models with real-time data feeds to enhance the accuracy and responsiveness of the simulation. It would incorporate live data on machine performance, worker productivity, and material availability to create a more dynamic and adaptive simulation environment. Incorporating human factors: to further refine the simulation model, future studies could consider the impact of human factors, including worker fatigue, learning curves, and ergonomic considerations. Integrating these aspects into the simulation could provide a more comprehensive understanding of the production line dynamics and aid in designing strategies that optimize both machine and human efficiency. Exploring the integration of Industry 4.0 technologies, such as the IoT and data analytics, into the simulation model could offer opportunities for further optimization. It could involve implementing sensor networks to collect real-time data, predictive analytics for proactive maintenance, and other Industry 4.0 advancements to enhance overall efficiency. Data accuracy and representativeness: the accuracy and representativeness of the collected data could be a potential limitation. Variations in processing times, machine capacities, or other parameters might not be fully captured, impacting the reliability of simulation results. Assumption sensitivity: the simulation models are built on certain assumptions, and their sensitivity to changes in these assumptions might influence the accuracy of predictions. Sensitivity analysis should be conducted to assess the robustness of the models.

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