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Balancing the Popcorn Production Line Using Tecnomatix Plant Simulation

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ABSTRACT

Small and medium-sized enterprises (SMEs) significantly contribute to the country's growth, particularly in the snack food manufacturing industry. As a popcorn manufacturer, this company is now experiencing challenges with production efficiency and bottlenecks in creating a balanced line. Simulation software may save time and deliver key insights by simulating the production line in less time than human bottleneck detection. Therefore, this study focuses on identifying the bottleneck process and determining the productivity of the present popcorn manufacturing line using Tecnomatix plant simulation. This study utilized qualitative methodologies, including interviews with the manager of human resources and supervisor of the production department, as well as direct observation of the production line using time study sheets as data collection methods. The results indicate that three main bottlenecks currently exist at the modelled popcorn production line, namely the automated sealing machine, the labelling machine, and the grading tray stations, with lead times of 70.13%, 64.96%, and 36.01%. The simulation reveals that the popcorn production line's current efficiency is 70%. According to prior research, these bottlenecks may be resolved by enhancing worker skills through frequent training, scheduling equipment preventative maintenance, and expanding the number of machines. This study contributes to the existing body of knowledge and encourages the company to improve and take additional measures to increase production line efficiency and solve the identified bottlenecks in any manner possible.

Keywords: Popcorn, Small and medium-sized enterprises, Tecnomatix plant simulation.

1. INTRODUCTION

Small and medium enterprises (SMEs) are growing rapidly internationally, but so far have only received little attention, especially in Malaysia. SMEs are businesses characterized by their relatively small size, limited resources, and usually fewer employees than larger companies [1]. They play an essential role in driving economic growth, fostering innovation, and generating employment opportunities. In the manufacturing sector, the Food and Beverage (F&B) manufacturing industry holds approximately 20% of the 46.5% of the manufacturing sector's contribution to GDP [2]. The contribution of the F&B industry in the manufacturing sector notably affects the market value of popcorn product sales in Malaysia.

Popcorn market analysis involves analyzing the demand, sales, and market trends related to popcorn products. Consumer preferences, market trends and promotional activities influence annual sales of popcorn in Malaysia. Popcorn products are usually sold through various retail channels, including supermarkets, convenience stores, cinemas, and online platforms. Figure 1 shows the sales value of manufactured snack products in Malaysia from 2019 to 2022. The sales

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value of manufactured snack products in Malaysia is approximately RM2.83 billion in 2022, a slight increase compared to the previous year. The sales value of snack products in this country decreased in 2020 and 2021. According to data, 18% of the total sales value of snack products is derived from the popcorn industry. This shows the importance of the popcorn market in the snack industry in Malaysia [3].

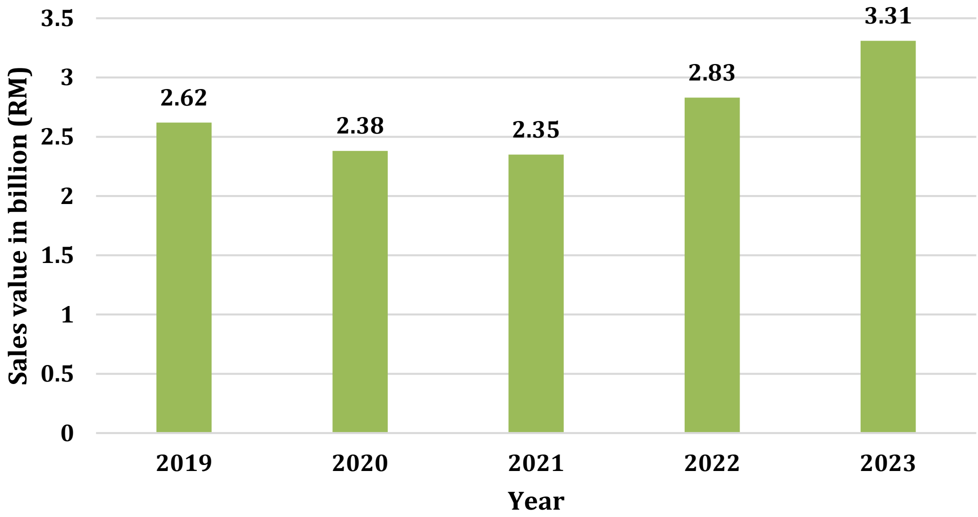

Figure 1: Sales value of manufactured snack products in Malaysia.

In today's constantly evolving industrial market, the pursuit of operational excellence is increasingly important for sectors across the board, including food manufacturing. With rising customer expectations, harsh competition, and shifting market dynamics, outdated manual ways of increasing production capacity are insufficient. The emergence of simulation software has become an interesting option, since it provides a comprehensive platform for modelling and analyzing manufacturing operations in a virtual environment [4]. By simulating real-world events and dynamics, simulation software allows manufacturers to acquire important insights into their operations, identify possible bottlenecks, and assess the impact of suggested modifications or enhancements before adopting them in the actual production environment [5]. In essence, simulation software constitutes a paradigm change in manufacturing management, providing a transformational answer to the issues of balancing workloads, optimizing resources, and increasing productivity.

Line balancing refers to allocating work equally across multiple workstations to improve productivity [6]. The goal is to eliminate the efficiency loss caused by an imbalance in operations and overproduction [7]. It involves determining the most efficient allocation of tasks, resources, and time for each workstation or process to achieve smooth and efficient production flow. Tecnomatix plant simulation is a software designed for logistics and production processes [8]. It is particularly useful for companies looking to reduce costs, improve productivity, and increase throughput. This allows users to identify bottlenecks, optimize resource utilization, reduce cycle times and improve production efficiency [9].

Efficiency measures how effectively a resource, such as time, money or energy, is used to complete a specific task or achieve a desired outcome [10]. It is concerned with maximizing output or result and minimizing input or expended resources. When describing efficiency, issues such as productivity, resource allocation, and waste minimization need to be considered [11]. Efficiency is important in the production and manufacturing sector because it helps identify the conditions under which products can be produced at the lowest unit cost. Production efficiency involves maximizing resources and minimizing waste, which results in increased revenue [12]. Improving efficiency also allows companies to produce more output using the same resources.

This study primarily focuses on increasing the efficiency of the present popcorn production line by replicating it using Tecnomatix plant simulation. Through this simulation, viable solutions are given to address the identified bottleneck, mainly to increase production volumes or efficiency.

2. EXPERIMENTAL PROCEDURE

In this study, data were collected using a qualitative technique, which included interviews, direct observation of the production process, and a time study. Data collection is the systematic process of gathering information or observations from several sources to get relevant and reliable data for analysis, research, or decision-making [13]. It entails establishing the necessary data, selecting appropriate techniques and equipment for data collection, and putting processes in place to assure the quality, consistency, and completeness of the information obtained.

The interview was carried out with the human resources manager and the popcorn production supervisor. The primary goal of this interview was to gather data and figures regarding the popcorn production line that might impact line balance. The data gathered might be utilized to create a Tecnomatix plant simulation model. The interview questions are provided in Table 1.

Table 1: Interview Questions.

No	Question	Answer
1	Can you describe the popcorn production line? How is the production process set up?	
2	How many workstations are on the production line, and what are their specialized tasks or operations?	
3	Are there any special requirements or variables that influence the balancing process in a popcorn production line?	
4	Have previous actions been made to resolve line balance issues? If so, what were the results?	
5	Is there any plan for future production line enhancements or adjustments affecting line balancing?	
6	Would you want to contribute any further insights or information regarding the popcorn production process and line balancing?	

Next, an observation was carried out at the popcorn-producing facility on November 1, 2023, at 2:30 p.m. Observation was carried out in the evening for 48 cycles, and data was collected from start to finish. The observation required the researcher to observe the whole popcorn production process, with an emphasis on tasks involving human labour and a machine. Time study is a systematic technique for observing, measuring, and analyzing the time necessary to perform a job or activity [14]. It was utilized to determine precise time requirements for completed jobs and evaluate and improve ways of working. It requires a trained observer who is knowledgeable about the whole process and uses simple equipment such as a stopwatch to record a worker's activities and assess how long it takes to accomplish a task. This aids in identifying hidden defects and weaknesses in allocating labour, machinery, and other production inputs.

In addition, the performance rating was established using the Westinghouse rating system. The rating came from the popcorn production supervisor. An allowance for the popcorn production line is 15% for each task, providing insights into the impact of unexpected delays or variability in task completion. This is necessary to cover unexpected events that could contribute significantly to the overall time required for the tasks. The standard time of every procedure was computed using Equation 1.

$$\text{Standard time} = \text{Normal time} \times \text{Allowance} \quad (1)$$

Qualitative data analysis is the act of studying and interpreting non-numerical data to identify patterns, themes, and insights [15]. It entails analyzing textual, visual, or aural material to better grasp its underlying meaning and context. In this study, simulation analysis was utilized to analyze qualitative data. It includes creating a virtual representation of the system, often known as a model, utilizing Tecnomatix plant simulation. This model simulates processes throughout time. The Tecnomatix plant simulation investigation yielded viable solutions for the observed constraints in existing popcorn production processes. The proposed solutions were validated again with the same simulation prior to presenting the solution to the company.

3. RESULTS AND DISCUSSION

3.1 Data Collection

The optimization of production processes is an essential component of every industrial business, including the food industry. It strives to improve efficiency, save expenses, and boost production. A detailed time study analysis was used to examine and improve the existing production line for popcorn manufacturing. This investigation required careful observation, data collection, and computation of various work durations in the cooking and packaging stations.

The cooking station is an essential aspect of the popcorn manufacturing process. A breakdown of the tasks at this station yielded an interesting result. According to Table 2, jobs measuring ingredients and loading the oil and corn kernels into the cookers had an average cycle time of 58.5 seconds. However, compared to the standard time of 61.89 seconds, this work has a performance rating of 0.92, suggesting somewhat poorer efficiency than the norm. The cooling process on the cooling conveyor followed the same pattern, with an average cycle time of 69 seconds compared to the standard time of 75.38 seconds, resulting in a performance rating of 0.95.

Table 2: Time study of cooking and packaging stations.

Task	Description	Average cycle time (s)	Performance rating	Normal time (s)	Allowance	Standard time (s)
Cooking station						
1	Measure the ingredients, put the oil and corn kernels into the cooking machine.	58.5	0.92	53.82	15%	61.89
2	Put the caramel into the cooking machine and wait until it is ready to produce popcorn.	243.0	0.94	228.42	15%	262.68
3	The heater is turned off and the popcorn mixes automatically on the conveyor.	58.5	0.93	54.41	15%	62.57
4	Popcorn goes through the cooling process on the Cooling Conveyor.	69.0	0.95	65.55	15%	75.38
5	Popcorn goes through the process of removing dregs at the Grading Tunnel.	39.5	0.92	36.34	15%	41.79
Packaging station						
6	The process of scooping popcorn into a container.	173.5	0.92	159.62	15%	183.56

7	Automatic sealing process.	81.0	0.95	76.95	15%	88.49
8	Automated labelling process on popcorn containers.	95.0	0.95	90.25	15%	103.79
9	The process of putting the container into the box.	18.0	0.94	16.92	15%	19.46

With attentive assessment, the packaging station is an important aspect of the popcorn production process. Table 2 shows that tasks like scooping popcorn into a container took an average cycle time of 173.5 seconds, somewhat less than the standard time of 183.56 seconds, with a performance rating of 0.92. However, the automated sealing process job yielded an average cycle time equivalent to the standard time. This demonstrates the optimum degree of efficiency. The research reveals that some jobs routinely operate at or below the standard time, indicating that all operations at the packaging station are efficient. However, tasks with a performance rating of less than one indicated a possible area for improvement [16]. For example, putting the container into the box has a performance rating of 0.94, suggesting that there is room for simplifying this task to align with standard time.

It is possible to find areas for focused improvement by identifying areas of inefficiency and tasks that are running slower than expected. This technique delivers practical insights on enhancing operational efficiency, removing production bottlenecks, optimising workflows, and boosting productivity in the popcorn production process. Furthermore, the observed data from the time study was used in the following stage, which involved simulating the manufacturing line with Tecnomatix plant simulation.

3.2 Current Popcorn Production Simulation Model

In the field of production optimization, Tecnomatix plant simulation software offers the benefit of a flowchart module that reflects and improves real-world production systems. The module is crucial in this study because it simulates, analyses, and refines the intricate production process. The flowchart module's main function is to visually represent operations, procedures, and interactions in the simulation model. These topics explore the complexity of the production line, job ordering, operation dependencies, and resource and machine interactions. Each module represents a task or procedure that involves merging the parameters derived from the gathered data. The modules act as interconnected nodes in the simulation model, allowing you to see the workflow route from the beginning of cooking to the end of packaging. Flowchart modules are components used in the model window to define the simulation process. Figure 2(a) depicts the presentation of the flowchart. The Tecnomatix plant simulation software has various fundamental process panel flowchart module types, including source, station, conveyor, and drain.

The data from the observations and tables were entered into the Tecnomatix plant simulation software. The popcorn production system module included the production flow on the model. Figure 2(b) depicts the simulation model of this study's popcorn production process, which may be modified and coded based on the data collected.

According to the evaluation of the existing popcorn production process (Figure 3), it includes the following: working status, setup, waiting, blocked, power up/down, failed, stopped, paused, and unplanned. These data analyses are intended to uncover important inefficiencies, possible bottlenecks, and opportunities for improvement in the manufacturing process. However, in this study, the row has nine processes since it represents the five stations in the simulation model, where the manufacturing process is at the cooking station and the remaining 4 tasks end with the packing process. The five stations are named after the cooking, grading, automated sealing, labelling, and packing stations.

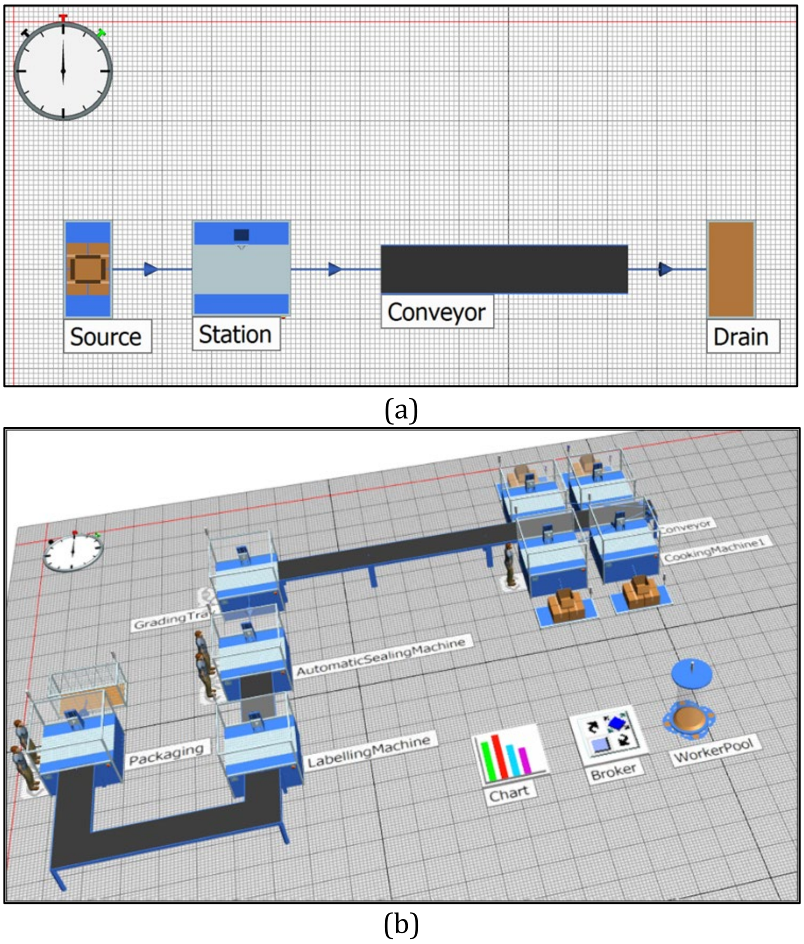

Figure 2: Technomatix plant simulation, (a) flowchart module, & (b) popcorn production line.

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Source4	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	
CookingMachine1	89.62%	0.00%	10.38%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
CookingMachine2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	
CookingMachine3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	
CookingMachine4	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	
Conveyor	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
CoolingConveyor	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
GradingTunnel	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
AutomaticSealingMachine	29.87%	0.00%	70.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor2	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Drain	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
LabellingMachine	35.04%	0.00%	64.96%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor3	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
GradingTray	63.99%	0.00%	36.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Source1	0.00%	0.00%	23.65%	76.35%	0.00%	0.00%	0.00%	0.00%	0.00%	
Source2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	
Source3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	
Packaging	6.64%	0.00%	93.36%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Figure 3: Result of simulation for current popcorn production.

In the "Source1" section of the production line, there are large obstructions (76.35%) and waiting time (23.65%). This signals a severe problem: downstream processes may be insufficiently prepared to take input, resulting in workflow delays and blockages. However, "Source2", "Source3", and "Source4" are always in the "Paused" state (100%), suggesting that the machine is not in use when the observation is performed. Disruptions in this process demand urgent attention to determine if they are intentional or the result of operational concerns that must be resolved immediately.

Furthermore, "CookingMachine1" demonstrates remarkable efficiency, particularly while running in a "Working" condition (89.62%) with low waiting time (10.38%). This area of success on the manufacturing line shows the possibility for optimum operational efficiency. However, "CookingMachine2", "CookingMachine3", and "CookingMachine4" display a "Paused" status, which must be discovered before these machines can run and function properly.

In addition, the conveyors function well because they can run at 100% efficiency continuously. This suggests that the product moves smoothly through the production line and that the conveyors perform properly. However, stations such as the "GradingTray" have considerable waiting times (36.01%), which might be attributed to downstream processes not fully equipped to receive graded items on time. This type of waiting time is one of the stations that reduces the efficiency and throughput of the production line.

Overall, the study identifies various inefficiencies and possible bottlenecks in the current popcorn production. The key issue that requires immediate attention is resolving the problem of pauses and waiting times at many stations. Addressing these difficulties is crucial for improving production flow, decreasing downtime, eliminating bottlenecks, and synchronizing operations so that they run more smoothly and effectively. Thus, solving this challenge requires a systematic strategy that involves resource reallocation, process optimization, and increased coordination across stations [17]. Implementing these measures might cut waiting times at targeted bottlenecks and ensure continuous workflow, considerably increasing the total efficiency and output of the production, allowing it to meet market demand while retaining excellent quality. Using advanced simulation and modelling approaches to test and execute changes will aid in determining the impact of changes before their actual adoption. The company may improve efficiency, minimize waiting time, and improve productivity by continually modifying the manufacturing process using simulation analysis.

3.3 Simulation Model Improvement and Validation

Figure 4 demonstrates the working time data of the present manufacturing process for two cooking processes utilizing a single cooking machine capable of producing 48 containers. Meanwhile, Figure 5 shows the results after the improvement of working time, in which four cooking machines allow manufacturing to generate twice as many output containers for four times the cooking process.

The initial simulation depicts popcorn manufacturing utilizing "CookingMachine1" for processing 48 containers. Each container requires a two-step cooking method lasting 4 minutes and 3 seconds. "CookingMachine1" emerged as the most significant contributor, accounting for 89.62% of the working time. Furthermore, stations such as grading, sealing, labelling, and packaging play a vital role, with variable processing times for each container, affecting the overall efficiency of the production line.

By executing a strategic plan aimed primarily at increasing efficiency, it is strongly advised that the company make use of four existing cooking machines, thus doubling its production capacity to 96 containers. This major alteration lowered processing time per container by an average of 1 minute and 37 seconds (97 seconds) for 24 containers for each cooking machine. Stations such as grading, sealing, labelling, and packaging exhibit efficiency by maintaining or slightly improving processing time per container and demonstrating a potentially enhanced production workflow.

Object	Portion	Count	Sum	Mean Value	Standard Deviation
Source4	0.00%	0	0.0000	0.0000	0.0000
CookingMachine1	89.62%	48	3:14:24.0000	4:03.0000	0.0000
CookingMachine2	0.00%	0	0.0000	0.0000	0.0000
CookingMachine3	0.00%	0	0.0000	0.0000	0.0000
CookingMachine4	0.00%	0	0.0000	0.0000	0.0000
Conveyor	100.00%	1	3:36:55.0718	3:36:55.0718	0.0000
CoolingConveyor	100.00%	1	3:36:55.0718	3:36:55.0718	0.0000
GradingTunnel	100.00%	1	3:36:55.0718	3:36:55.0718	0.0000
AutomaticSealingMachine	29.87%	48	1:04:48.0000	1:21.0000	0.0000
Conveyor2	100.00%	1	3:36:55.0718	3:36:55.0718	0.0000
Drain	0.00%	48	0.0000	0.0000	0.0000
LabellingMachine	35.04%	48	1:16:00.0000	1:35.0000	0.0000
Conveyor3	100.00%	1	3:36:55.0718	3:36:55.0718	0.0000
GradingTray	63.99%	48	2:18:48.0000	2:53.5000	0.0000
Source1	0.00%	0	0.0000	0.0000	0.0000
Source2	0.00%	0	0.0000	0.0000	0.0000
Source3	0.00%	0	0.0000	0.0000	0.0000
Packaging	6.64%	48	14:24.0000	18.0000	0.0000

Figure 4: Before the improvement of working time.

Object	Portion	Count	Sum	Mean Value	Standard Deviation
Source4	0.00%	0	0.0000	0.0000	0.0000
CookingMachine1	22.83%	24	1:37:12.0000	4:03.0000	0.0000
CookingMachine2	22.83%	24	1:37:12.0000	4:03.0000	0.0000
CookingMachine3	22.83%	24	1:37:12.0000	4:03.0000	0.0000
CookingMachine4	22.83%	24	1:37:12.0000	4:03.0000	0.0000
Conveyor	100.00%	1	7:05:44.4409	7:05:44.4409	0.0000
CoolingConveyor	100.00%	1	7:05:44.4409	7:05:44.4409	0.0000
GradingTunnel	100.00%	1	7:05:44.4409	7:05:44.4409	0.0000
AutomaticSealingMachine	30.44%	96	2:09:36.0000	1:21.0000	0.0000
Conveyor2	100.00%	1	7:05:44.4409	7:05:44.4409	0.0000
Drain	0.00%	96	0.0000	0.0000	0.0000
LabellingMachine	35.70%	96	2:32:00.0000	1:35.0000	0.0000
Conveyor3	100.00%	1	7:05:44.4409	7:05:44.4409	0.0000
GradingTray	65.20%	96	4:37:36.0000	2:53.5000	0.0000
Source1	0.00%	0	0.0000	0.0000	0.0000
Source2	0.00%	0	0.0000	0.0000	0.0000
Source3	0.00%	0	0.0000	0.0000	0.0000
Packaging	6.76%	96	28:48.0000	18.0000	0.0000

Figure 5: After the improvement of working time.

3.4 Potential solution for the identified bottlenecks

Efficiency in the production process is critical for meeting demand and maintaining consistent quality. In the context of this study, data analysis from Tecnomatix plant simulation revealed crucial bottlenecks that limit optimal efficiency. Automatic sealing machines, labelling machines, and grading trays have been identified as bottlenecks in the production process, and solutions to these problems must be addressed. The data collected reveals the waiting time at three distinct stations, indicating a bottleneck that impacts total processing. Automatic sealing machines had a remarkable 70.13% waiting time, closely followed by labelling machines at 64.96%. The grading tray had a lower percentage (36.01%), which resulted in production delays.

3.4.1 Automatic sealing machine.

The automatic sealing machine is a crucial component in the popcorn production process. However, inefficiency is a significant obstacle to total production. A regular predictive or preventive maintenance program is required to guarantee that the automatic sealing machine operates effectively with minimal malfunctions [18]. Using this method, the maintenance staff may detect early indicators of degradation or imminent problems with the automated sealing equipment. Regular inspections are supplemented by analysis of previous performance data to help anticipate probable problems. Establishing procedures for frequent inspections and proactive repairs allows possible breakdowns to be discovered and repaired before they progress into unanticipated severe breakdowns that can shut down the production line. This preventive maintenance strategy seeks to reduce unscheduled downtime, increase machine uptime, and extend equipment life to enhance overall productivity.

In addition, offering specialized and periodic training to machine operators is critical in optimizing equipment settings and boosting troubleshooting capabilities [19]. Induction training for operating certain machines is essential to provide personnel with complete information and know-how about every machine. This not only improves the operator's understanding of the equipment but also their ability to recognize and resolve small faults quickly. These problem-solving abilities enable machine operators to handle problems without needing prolonged downtime, hence reducing disturbance to the production process. This method not only lowers downtime but also helps to produce a more efficient and informed staff, hence increasing the production line's resilience. Implementing this strategy will dramatically minimize unexpected downtime, improve machine dependability, and raise the efficiency of their production line.

3.4.2 Labelling machine.

Automated solutions may improve efficiency by completing labelling tasks faster and more precisely than manual labor. Robots with accurate labelling ability save waiting times and guarantee consistent and efficient execution of repeated operations. This shift to automated procedures may streamline operations and allow human resources to focus on complex jobs, resulting in increased overall productivity.

Furthermore, incorporating a quality inspection module directly into the labelling machine deployment configuration is a proactive method to ensure product quality control and reduce delays. This proactive quality standard comes from the labelling station. Consequently, this strategy can eliminate quality-related delays while also contributing to a smoother and more efficient workflow. A comprehensive review of existing procedures reveals inefficiencies and bottlenecks. Streamlining processes, removing superfluous stages, and reorganizing tasks can improve resource utilization and reduce waiting times. This workflow optimization helps to increase throughput, minimize waiting times, and enhance overall production efficiency.

3.4.3 Grading tray.

Adding more grading trays seems to be an important strategy for increasing the efficiency of the grading tray. This method, which allows simultaneous processing across numerous trays, can decrease the capacity strain caused by growing workloads. The capacity to perform many tasks at once can minimize waiting time and bottlenecks while enhancing throughput and overall productivity in the production line.

Streamlining processes, reducing superfluous stages, and reorganizing tasks can all improve workflow efficiency. The functioning of the grading tray has been optimized through process improvement, allowing for smoother and more efficient processing, thus enhancing overall efficiency. Balancing the availability of labour and equipment resources is critical for avoiding delays and maintaining operational efficiency. Optimal resource allocation helps guarantee that the grading tray area performs to its maximum ability during times of high demand. This combination of manpower and equipment availability can reduce waiting time and increase productivity while also contributing to greater efficiency.

4. CONCLUSION

The study revealed significant efficiency gains through simulation-driven methods using Tecnomatix plant simulation. Identifying bottlenecks, optimizing operations, and maintaining quality, researchers aimed for a daily production target of 500 packets. However, interviews with managers and supervisors found only around 350 packets were produced due to raw material shortages and client demands. This suggests a 70% daily efficiency rate. The simulation identified "AutomaticSealingMachine," "LabellingMachine," and "GradingTray" as potential bottlenecks, with the latter experiencing a 36.01% wait time. "AutomaticSealingMachine" and "LabellingMachine" had 70.13% and 64.96% wait times, respectively, influenced by the efficiency of the preceding "GradingTray" process. Solutions such as increased working time, equipment utilization, maintenance schedules, training, automation, quality inspections, and adding trays could boost efficiency by up to 80%, addressing bottlenecks and enhancing overall manufacturing. This multifaceted approach improves efficiency, addresses production issues, and maintains line balance.

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