Research.

Bottleneck Analysis and Spreadsheet-Based Simulation for Enhancing Jersey Production Capacity at CV Wirakundara

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Abstract. In the small-scale garment manufacturing industry, identifying actual process capacity and analyzing operator performance are crucial yet often overlooked aspects. CV Wirakundara, a garment manufacturing company located in Sariwates, Bandung, faces uncertainty regarding its actual jersey production capacity and the utilization levels of operators in its sewing line. This study aims to (1) identify the actual process capacity of jersey production and determine its bottleneck point, and (2) measure the average performance and utilization of each operator.

The study employs the Bottleneck Analysis method to address the first objective and Spreadsheet-Based Computer Simulation to address the second objective. The results of the bottleneck analysis indicate that the overlocking process, with a processing time of 5 minutes, is the most critical bottleneck in the production line. By adding one operator and one overlocking machine, the cycle time can be reduced to 2.5 minutes, thereby increasing production capacity from approximately 96 pieces per day to 192 pieces per day.

The simulation results reveal that the utilization rates of Operator A and Operator B are 86.95% and 78.29%, respectively, with average waiting times of 21 seconds and 36 seconds. This study proposes several improvement recommendations, including enhancing the overlocking process, providing intermediate storage areas between production stages, and conducting further evaluation and training for operators to improve production capacity at CV Wirakundara.

Keywords: Bottleneck Analysis, Computer Simulation, Spreadsheet-Based Simulation, Production Capacity, Operator Utilization, Garment Industry.

INTRODUCTION

Background

The garment manufacturing industry is one of the sectors that significantly contributes to the national economy of various countries, including Indonesia. Many countries rely on this industry as a driver of the domestic economy, but on the other hand, this industry also faces various challenges in operational management and its supply chain (Dicken, 2003). Specifically, the small and medium-scale garment manufacturing industry in Indonesia, including in West Java, which is known as one of the largest textile and garment production centers in Indonesia, still lacks adequate understanding of the actual process capacity and workforce performance, making it difficult to respond to market demand optimally. To improve efficiency in the garment manufacturing process, it is important to identify the factors causing the low input-output ratio in the production line, which include inefficient production techniques, poor management, resource wastage, and lack of training and workforce awareness (Azad, 2025).

Operations and Supply Chain Management provides various analytical tools to help companies understand and improve the efficiency of their production processes. A well-designed supply chain management system will efficiently produce high-quality goods, but achieving that efficiency is often difficult due to uncertainty and variability in material flow, labor availability, and equipment (Khan et al., 2022). Traditional mathematical approaches such as sensitivity analysis are unable to adequately account for this variability, making computer simulation very important as an analytical tool (Marino et al., 2008). Through simulation, companies can study operational problems that are difficult to solve analytically, analyze various improvement scenarios, and make data-driven decisions without having to change the existing system (Schunk & Plott, n.d.). Among the available analytical tools, Bottleneck Analysis and Computer Simulation Method are two approaches that are highly relevant to be applied in the clothing manufacturing production line, as both are capable of identifying capacity constraints while empirically measuring human resource performance.

CV Wirakundara is a garment business located in Sariwates, Bandung, that produces various types of clothing, with its main product being jerseys. CV Wirakundara operates a sewing line with two operators: Operator A handles the Single Needle and Chain Stitching processes, while Operator B handles the Overlocking and Overdecking processes, with a working time of 8 hours per day. Since the beginning of its operations, CV Wirakundara does not yet know the actual production process capacity of its jerseys, nor has it measured the utilization and average performance of its two operators. Without this understanding, the company cannot optimally respond to large orders and cannot determine whether the current performance of the operators is adequate or needs improvement. Such conditions are commonly found in SMEs in the garment industry of developing countries, where low productivity and high non-value-adding activities pose persistent challenges that need to be addressed through a data-driven approach (Oelze, 2017). This research aims to address both issues through the Bottleneck Analysis approach and spreadsheet-based Computer Simulation.

Problem Formulation

Based on the background above, the problem formulation in this research is:

1. What is the actual production process capacity of CV Wirakundara's jersey production, and if customers order in large quantities (for example, 100 pcs or more), which activities need to be improved to increase production capacity?
2. How is the average performance and utilization of each operator? Are the current conditions of the operators adequate or do they need improvement?

LITERATURE REVIEW

Bottleneck Analysis and Theory of Constraints

Bottleneck or production constraint is a stage in the process that limits the overall throughput of the system. Theory of Constraints (TOC) is a management philosophy that focuses on identifying and managing constraints to improve the overall performance of the system, emphasizing that companies must better understand their own process structures to survive in global competition (Rahman, 1998). TOC was developed by Goldratt since the late 1970s as a new approach in production and operations management. TOC has two main components: a philosophy underlying the principle of continuous improvement, and a generic approach to investigating, analyzing, and creating solutions called the thinking process (TP). The development and evolution of TOC over time, starting from the era of Optimized Production Technology, The Goal, to Critical Chain, demonstrate its continuously growing relevance in the context of modern manufacturing.

In the context of a production line, a bottleneck is a workstation with the longest processing time that determines the cycle time and system capacity. A systematic review of the literature identifies 14 different bottleneck detection methods, classified based on the information used: queue states, process states, or a combination of both; as well as three modes of operationalization: gemba walk, discrete event simulation (DES), and data science approaches (Skoogh et al., 2023).

A comprehensive review of the theory and techniques for identifying bottlenecks in manufacturing systems emphasizes that a bottleneck refers to a condition where the actual production capacity of a manufacturing system is less than or equal to the demand placed on those resources. Meanwhile, systematic reviews also show that only a small fraction of Industry 4.0 design principles and technologies have been integrated into the development of bottleneck analysis methods, leaving ample room for further research, including in the context of SMEs (Tang et al., 2024).

Simulation Method in Production System Analysis

Simulation is a method of modeling real systems used to analyze the behavior of the system under various operational conditions. Analysis of operational status, bottlenecks, and interdependencies of manufacturing activities between machines can be conducted simultaneously thru discrete event simulation, including considering machine efficiency, reliability, quality, and setup time; simulation can also identify bottlenecks and work-in-progress (WIP) status to propose process changes to improve production efficiency (Ummah, 2019).

Spreadsheet-based computer simulations utilize the historical frequency distribution of process times (frequency distribution) as the basis for generating simulation values. Each process time scenario is mapped based on the proportion of observed historical frequency, allowing the simulation to represent real variability in the field without requiring any specific statistical distribution assumptions. This approach is practical, easy to audit, and highly suitable for SMEs that do not have specialized simulation software (Kelton et al., 2015). The application of simulation in the garment industry has shown significant results. A study on the feasibility of simulation techniques for line balancing in the garment industry confirms that differences in efficiency among operators directly contribute to line imbalances and the emergence of bottlenecks, making simulation a highly appropriate tool for modeling and optimizing these conditions.

The research proposing the Assembly Line Balancing Problem (ALBP) approach for complex garment assembly lines using simulation-based optimization under stochastic task times successfully minimized cycle time by considering resource constraints and precedence relationships between processes (Bongomin et al., 2020b). Furthermore, the real-time data-based production line simulation approach has proven that simulation is capable of measuring overall productivity, individual productivity, and other key performance indices that are critical for the garment production line (Jung et al., 2022).

Utilization and Performance of Operators in Manufacturing

Operator utilization refers to the proportion of an operator's productive time to the total available working time, and it is a key indicator in assessing the efficiency of human resources on the production line. A utilization rate that is too low indicates resource waste (idle time), while a utilization rate that is too high can lead to operator fatigue and an increased risk of production errors (Heizer & Barry, 2008). Empirical studies in garment facilities using industrial engineering tools such as time study, process mapping, and observation show that operators with lower capacity create bottleneck points that hinder the flow of production to the next operator, thereby directly contributing to line imbalance due to differences in efficiency among operators (Nabi, Farhatun, Mahmud, Rezwan, and Islam, 2015). Waiting time between workstations is the most common form of waste in the garment production line, where an unbalanced line condition results in idle time and

excessive workload simultaneously (Köksal et al., 2017). Buffer status analysis thru simulation can help determine the need for storage areas between processes to simultaneously improve the utilization of both operators (Bongomin et al., 2020a).

The garment industry in developing countries often faces persistent challenges such as low productivity, long cycle times, and high levels of non-value-adding activities. The integration of Discrete-Event Simulation (DES) with Lean Manufacturing tools has proven capable of identifying operational bottlenecks and improving overall line performance thru data-driven process improvements (Gessesse et al., 2026).

Application of Bottleneck Analysis and Simulation in the Garment Industry

Research on productivity improvement thru simulation-based line balancing at Almeda Garment Factory successfully demonstrated that this approach could increase system utilization from 0.53 to 0.69 and line efficiency from 42% to 58.42%, without incurring additional costs (Yemane et al., 2020). These findings confirm that computer simulation is an effective and efficient tool for improving the performance of garment production lines under real field conditions. A study on garment sewing lines showed that the machine balancing approach successfully increased line efficiency by 9% and labor productivity by 6%, by identifying bottleneck processes that hindered the achievement of hourly capacity targets — a finding consistent with the conditions at CV Wirakundara, where a 5-minute overlocking process created material queues and became a system capacity constraint (Saha, 2019).
A systematic review shows that most SMEs in the garment industry have not yet exploited the advantages offered by lean and simulation-based approaches, despite SMEs playing an essential role in the economy and inclusive business ecosystem (Chavez-Escobedo et al., 2026). This research aims to fill that gap with a case study of CV Wirakundara as a representation of garment SMEs in Bandung.

RESEARCH METHOD

Research Object

This research was conducted at CV Wirakundara, a garment business unit located in Sariwates, Bandung. The product that is the focus of this research is the jersey, which is the product with the highest production volume in this company. The jersey production line consists of four process stages carried out by two operators with an 8-hour workday.

Data Collection

Data was collected thru direct interviews with the owner and operators of CV Wirakundara, as well as field observations of the production process. The data collected includes: 1. Data for Bottleneck Analysis: Duration of each production stage for 1 piece of jersey. 2. Data for Simulation: Frequency distribution of production process time for 20 pieces of jersey for each operator. For the purpose of Bottleneck Analysis, the duration of each production stage was directly measured using a stopwatch during field observation, by recording the time taken to complete each process on a single jersey unit. Second, for the purpose of computer simulation, the frequency distribution data of the processing time was obtained thru interviews and direct observations with the owner and operators of CV Wirakundara. The combination of these two data collection methods was chosen to ensure that the bottleneck analysis reflects the measurable actual operational conditions, while the simulation is able to represent the real variability of process times that occur in daily production activities.

Table 1 shows the process duration data from observations for each stage of jersey production:

No	Procees	Duration (Minute)
1	Single Needling	2
2	Chain Stiching	2
3	Overlocking	5
4	Overdecking	1

And below is the flowchart of the Jersey production process along with its duration:

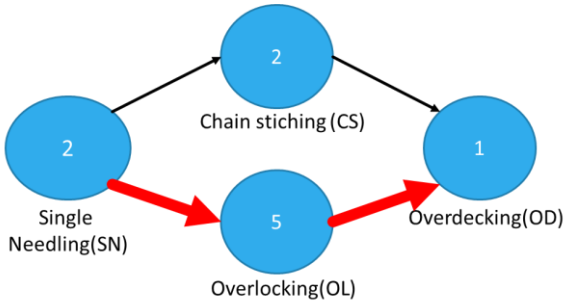


Figure 1 Flowchart of the Jersey Production Process

Based on the mapping of the jersey production process flow, the Critical Path was obtained on the Single Needling (SN) → Overlocking (OL) → Overdecking (OD) route with a total travel time of 8 minutes. This route determines the minimum flow time for each product unit because it includes stages with the tightest sequential dependencies. Considering that the SN and Chain Stitching (CS) processes are entirely performed by Operator A, while the OL and OD processes are performed by Operator B, the average processing time for each operator is assumed to be 4 minutes, which is obtained by proportionally dividing the total critical path time according to each operator's workload. This assumption serves as the basis for determining the input parameters in the computer simulation conducted in the next stage.

The Computer Simulation Method (Spreadsheet) is used to address Problem Statement 2. This approach was chosen because the queue system on the production line of CV Wirakundara is complex, where both operators work sequentially with varying processing times, making it impossible to calculate actual performance and utilization thru simple analytical methods. Computer simulation allows for the modeling of real variability in processing times empirically based on historical data collected directly in the field, without the need to assume a specific statistical distribution. Thus, the simulation results more accurately reflect the actual operational conditions of CV Wirakundara compared to theoretical approaches.

The data for the simulation was obtained directly thru interviews with the owner of CV Wirakundara, consisting of actual process time records of both operators in producing 20 pcs of jerseys. The data was then organized into frequency distribution tables for each operator, where each range of processing time was given class intervals proportional to their frequency of occurrence. Next, the simulation was run using Microsoft Excel: each jersey unit was simulated sequentially by recording the service start time, finish time, and wait time between operators. The accumulated results from all simulations are used to

calculate the average utilization and average waiting time of each operator as a basis for evaluating the performance of the production line. Below is the frequency table of time and random number intervals for operators A and B:

Table 2. Operator Time Frequency and Simulation Interval

Second	Time frequency for Operator A	Simulation Interval	Time frequency for Operator B	Simulation Interval
30	1	0-4	1	0-4
60	1	5-9	2	5-14
90	2	10-19	3	15-29
120	5	20-44	6	30-59
150	4	45-64	4	60-79
180	3	65-79	2	80-89
210	2	80-89	1	90-94
240	2	90-99	1	95-99
	20		20	

Time frequencies in the distribution table are obtained from actual production data of 20 jersey pieces at CV Wirakundara, thus reflecting the variability of the process time that truly occurs in the field.

Thus producing a range of proportional intervals as the basis for mapping simulation values for each production unit. In this case, CV Wirakundara does not have a temporary storage area (buffer storage) between processes, so each unit completed by Operator A is immediately transferred to Operator B without any waiting space in between. This condition makes the waiting time that appears in the simulation entirely a function of the difference in processing speeds between operators, not due to layout constraints or storage capacity.

RESULTS AND DISCUSSION

Bottleneck Analysis

Based on the process duration data in Table 1, a process flow analysis was conducted for each production unit. The following Table 2 shows the start and finish times of the first three units at each workstation:

Table 3. Start and end times for each Jersey production process

	Single Needling (2 Menit)		Chain Stiching (2 Menit)		Overclocking (5 Menit)		Overdecking (1 Menit)		*Flow time*
	SN Mulai	SN Selesai	CS Mulai	CS Selesai	OL Mulai	OL Selesai	OD Mulai	OD Selesai	
Unit	0	2	2	4	4	9	9	10	10

1									
Unit 2	2	4	4	6	9	14	14	15	13
Unit 3	4	6	6	8	14	19	19	20	16

Based on the results of the Bottleneck Analysis, the cycle time of the jersey production system at CV Wirakundara is determined by the workstation with the longest processing time, which is the Overlocking process with a duration of 5 minutes per unit. Thus, the system process capacity can be calculated as follows:

$$\frac{60\ menit}{5\ menit/unit} = 12\ unit/jam$$

Considering the operator's working hours are 8 hours per day, the actual processing capacity of CV Wirakundara is 96 pcs/day.
In addition to capacity, an analysis is also conducted on the system's flow time, which is the total time required from when a unit starts being processed until it is completed at all workstations. Based on the data of the first three units in Table 2, the flow time for each unit is 10 minutes, 13 minutes, and 16 minutes, so the average flow time is

$$\frac{10+13+16}{3} = 13\ menit$$

This value reflects an increasing queue buildup as the number of processed units rises, which is a direct indication of the presence of a bottleneck at the Overlocking station.
With an actual capacity of 96 pcs/day, CV Wirakundara is not yet able to fulfilll an order of 100 pcs in one working day. Therefore, if CV Wirakundara wants to receive orders in that quantity, an increase in capacity is needed at the bottleneck stage, which is the Overlocking process. This improvement can be achieved by adding one operator and one overlocking machine, thereby reducing the process duration at that station from 5 minutes to 2.5 minutes per unit, which directly increases the system capacity to 192 pcs/day.

Computer Simulation Analysis

The computer simulation was run using a Microsoft Excel spreadsheet with a table structure that includes columns for Random Number, Start Time, Performance Time, Finish Time, and Wait Time for each Operator A and Operator B, as well as a Storage Space column between them with a value of zero, indicating that there is no temporary storage area between processes. Each jersey item is simulated sequentially, where the Start Time of Operator B for each unit is determined by the Finish Time of Operator A or the Finish Time of Operator B from the previous unit, depending on which is greater. And here is the simulation table for operators A and B with a total of 1200 simulation rows.

Table 4. Simulation Table of 1200 trials for Operator A and Operator B

Item Number	Operator A					Storage Space	Operator B					Average Time/Unit	Total Time	Total Time Cumulative	Average Time in System
	Random Number	Start Time	Performance Time	Finish Time	Wait Time		Random Number	Start Time	Performance Time	Finish Time	Wait Time				
1	31	0	120	120	0	0	7	120	60	180	120	180.0	180	180	180.0
2	89	120	210	330	0	0	87	330	180	510	150	255.0	390	570	285.0
3	1	330	30	360	150	0	21	510	90	600	0	200.0	270	840	280.0
4	31	510	120	630	0	0	20	630	90	720	30	180.0	210	1050	262.5
5	47	630	150	780	0	0	77	780	150	930	60	186.0	300	1350	270.0
6	54	780	150	930	0	0	71	930	150	1080	0	180.0	300	1650	275.0
7	62	930	150	1080	0	0	61	1080	150	1230	0	175.7	300	1950	278.6
8	70	1080	180	1260	0	0	93	1260	210	1470	30	183.8	390	2340	292.5
9	32	1260	120	1380	90	0	92	1470	210	1680	0	186.7	420	2760	306.7
10	22	1470	120	1590	90	0	8	1680	60	1740	0	174.0	270	3030	303.0
1193	36	197310	120	197430	0	0	63	197430	150	197580	0	165.6	270	352140	295.2
1194	83	197430	210	197640	0	0	12	197640	60	197700	60	165.6	270	352410	295.2
1195	53	197640	150	197790	0	0	46	197790	120	197910	90	165.6	270	352680	295.1
1196	48	197790	150	197940	0	0	69	197940	150	198090	30	165.6	300	352980	295.1
1197	97	197940	240	198180	0	0	67	198180	150	198330	90	165.7	390	353370	295.2
1198	93	198180	240	198420	0	0	37	198420	120	198540	90	165.7	360	353730	295.3
1199	30	198420	120	198540	0	0	77	198540	150	198690	0	165.7	270	354000	295.2
1200	70	198540	180	198720	0	0	52	198720	120	198840	30	165.7	300	354300	295.3
Total		**118581720.0**	**172800.0**	**118754520.0**	**25920.0**			**118780440.0**	**155580.0**	**118936020.0**	**43260.0**	**198166.8**	**354300.0**		**353193.2**

Based on the accumulated simulation results for 20 pcs of jerseys, all operator performance metrics are calculated by dividing the total value of each variable by the number of simulations run, which is 1,200, the total number of simulations run in the spreadsheet. Meanwhile, operator utilization is calculated as the ratio of the total performance time of the operator to the total system output time, reflecting the proportion of the operator's productive time compared to the total system running time.
Below is the graph of the average time in the system and the average time per unit from the simulation conducted:

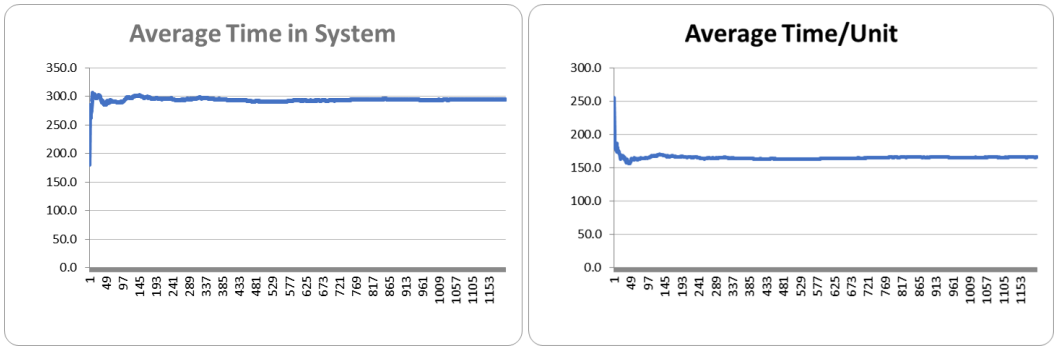


Figure 2 Average time in the system graph

Both graphs show a similar pattern: the average values fluctuate quite significantly at the beginning of the simulation (from item 1 to around item 100), then start to stabilize and converge toward a fixed value as the number of simulated items increases. Average Time in System converges around 294 seconds, while Average Time/Unit converges around 165 seconds. This convergence pattern indicates that the simulation has reached a steady state condition, meaning the simulation results are stable and representative as an estimate of the system's long-term performance. The difference between the two values (294 − 165 = ±129 seconds) reflects the average total waiting time incurred by each unit while transitioning from Operator A to Operator B.

Next, the utilization of each operator, average performance, average waiting time, average time per unit, average time in the system, and average duration were calculated. The utilization calculation for Operator A was obtained from the total performance time of Operator A (172,800 seconds) divided by the total system output time (198,720 seconds), resulting in a value of 86.95%. The utilization for Operator B was obtained from the total

performance time of Operator B (155,580 seconds) divided by the total system output time (198,720 seconds), resulting in a value of 78.29%. The average performance time for Operator A is 172,800 ÷ 1,200 = 144 seconds/unit, while the average performance time for Operator B is 155,580 ÷ 1,200 = 129.65 seconds/unit. The average system output time is 198,840 ÷ 1,200 = 165.7 seconds, and the average time per unit is 198,166.8 ÷ 1,200 = 165.13 seconds. The average time spent by each unit in the system overall is 353,193.2 ÷ 1,200 = 294.32 seconds. In terms of waiting time, the average waiting time for Operator A is 25,920 ÷ 1,200 = 21.6 seconds/unit, while the average waiting time for Operator B is 43,260 ÷ 1,200 = 36.06 seconds/unit.
And below is a summary table of the calculation results for Operator A and Operator B at CV Wirakundara:

Table 5. Summary of the Calculation Results of Operator A and Operator B

Process	Operator A	Operator B
Utilization	*86.95%*	*78.29%*
Average Performance	*144 Detik*	*129 Detik*
Average Wait Time	*21.6 Detik*	*36.06 Detik*
Average time per unit	*165.13 Detik*	
Average System Time	*294.32 Detik*	
Average Output Time	*165.7 Detik*	

Based on the table above, the simulation results show that Operator A works with a higher utilization rate (86.95%) compared to Operator B (78.29%), with a higher average performance time as well. This indicates that Operator A bears a heavier workload per unit. Meanwhile, Operator B has a longer average waiting time (36.06 seconds) compared to Operator A (21.6 seconds), confirming the imbalance in flow between stations due to differences in processing speed and the absence of buffer storage between them.

CONCLUSION AND SUGGESTIONS

Conclusion

Thru this research, both problem formulations can be answered with the results of the conducted study.
For RQ1: What is the actual production process capacity of CV Wirakundara's jersey production, and which activities need to be improved to increase production capacity? The research results show that the system's cycle time is determined by the Overlocking process as the bottleneck point with a duration of 5 minutes per unit, resulting in CV Wirakundara's actual production capacity of 12 units/hour or 96 pcs/day. The average flow time for the first three units is 13 minutes, confirming the queue buildup due to the bottleneck. With this capacity, CV Wirakundara is not yet able to fulfilll an order of 100 pcs in one working day, so an increase in capacity at the Overlocking station, which is on the critical path along with the Single Needling and Overdecking processes, is necessary. Adding one operator and one overlocking machine can reduce the cycle time to 2.5 minutes, increasing the capacity to 192 pcs/day.

For RQ2: What is the average performance and utilization of each operator, and is the current condition adequate? The results of the computer simulation using a spreadsheet show that the utilization of Operator A is 86.95% and Operator B is 78.29%, with an average performance time of 144 seconds and 129.65 seconds per unit, respectively. The average waiting time for Operator A is 21.6 seconds per unit (equivalent to a 7%

efficiency loss per unit), while for Operator B it is 36.06 seconds per unit (equivalent to a 12% efficiency loss per unit). This condition indicates an imbalance in the workload between operators, stemming from differences in process speed and the absence of buffer storage between workstations. The simulation graph also shows that the system has reached a steady state condition with an Average Time in System converging around 294 seconds and an Average Time/Unit around 165 seconds.

Suggestions

Based on the research results, there are three main suggestions that CV Wirakundara can implement to improve the operational performance of its jersey production line:

1. Increase Overlocking Station Capacity: It is recommended that CV Wirakundara add one operator and one overlocking machine to reduce the process duration from 5 minutes to 2.5 minutes, thereby increasing the daily capacity from 96 to 192 pcs/day and allowing orders over 100 pcs to be fulfilled in one working day. Alternatively, CV Wirakundara can adjust the overlocking duration from 5 to 3 minutes and the overdecking from 1 to 3 minutes to achieve better line balance without adding new machines.
2. Evaluation and Training of Operator B: Considering that the utilization of Operator B (78.29%) is lower than that of Operator A (86.95%) with an average waiting time of 36.06 seconds per unit, which is equivalent to a 12% efficiency loss per jersey. In this case, CV Wirakundara needs to check the conditions and obstacles faced by Operator B. If technical or competency barriers are found, adequate facilitation and further training should be provided to reduce the utilization gap between operators and minimize efficiency losses.
3. Provision of Buffer Storage Between Processes The absence of temporary storage areas between workstations has proven to be the main cause of the waiting time for both operators. CV Wirakundara is advised to provide buffer storage between processes to minimize the waiting time for Operator A (21.6 seconds/unit) and Operator B (36.06 seconds/unit), which are equivalent to efficiency losses of 7% and 12% per jersey unit produced, respectively. With the availability of temporary storage areas, the flow of production between stations becomes smoother, and both operators can work more independently without having to wait for each other.

By gradually implementing the three recommendations above, CV Wirakundara is expected to be able to increase production capacity, balance the workload among operators, and reduce the efficiency losses that have been occurring, thereby sustainably improving overall competitiveness and business profitability.

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