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The Theory of Constraints (TOC) Approach in Overcoming Production Capacity Constraints in the Food Industry: A Case Study

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ABSTRACT

This study aims to overcome production capacity constraints in the HB Azaki Original Tempeh MSME using the TOC approach. The problem faced by this MSME is the imbalance between available production capacity and market demand, which results in late deliveries and waste of resources. Initial analysis using RCCP revealed bottlenecks at the soaking and fermentation workstations, with load percentages reaching 111.93% and 108.42%, respectively. Based on the study's results, the soaking and fermentation workstations experienced bottlenecks due to positive variance values and a load percentage exceeding 100%. After identifying these constraints, an optimization model was formulated using Lingo 20.0 to determine the optimal production mix while considering capacity limitations. Verification results showed that the fermentation workstation remained overloaded despite optimal scheduling, and thus, a constraint elevation strategy was implemented by adding one worker. This improvement reduced the fermentation workstation load to 48.65%, effectively eliminating the bottleneck and increasing throughput. The novelty of this study lies in integrating TOC with LP-based optimization, enabling simultaneous bottleneck identification and optimal production planning tailored to the characteristics of traditional food SMEs. This combined approach provides a practical, data-driven solution to improve capacity planning and support SMEs in meeting fluctuating market demand.

1. INTRODUCTION

The Tempeh industry, as one of the sectors of Small and Medium-sized Enterprises (SMEs), plays a vital role in the Indonesian economy. In addition to being a source of livelihood for many entrepreneurs and workers, this industry also supports national food security by providing nutritious, affordable, and easily accessible food products to the public. Per capita tempeh consumption in Indonesia not only reflects the tastes and eating habits of the community but also serves as an essential indicator of market demand dynamics for soybean products. However, the decline in average tempeh consumption in recent years has posed a challenge for producers, especially small and medium-sized tempeh producers. This decline necessitates that companies adjust their production strategies to remain competitive and meet the growing needs of an increasingly discerning market (BPS, 2024).

UMKM Tempeh Asli HB Azaki is engaged in tempeh production, located in Pekanbaru, Riau. The products can be customized to meet customer needs, also known as Make to Order (MTO). There are nine types of tempeh available for order: HB 4, HB 5, AZ 2, AZ 3, AZ 4 (270g), AZ 4 (290g), Demang, plain, and leaf tempeh. Based on the data in the Appendix, there is a significant fluctuation between the planned and actual product quantities for the period from September 2024 to March 2025. The total weekly production capacity of tempeh is 62,300 sticks. For the HB 4 tempeh type in the fourth week of September 2024, the SMEs planned to produce 12,060 sticks of tempeh; however, they were only able to produce 11,815 sticks in reality. Similar discrepancies also occurred in other weeks, which may indicate an imbalance in production capacity planning. This problem arises when SMEs receive large orders but are unable to complete them within the agreed-upon timeframe, resulting in delivery delays. Constraints in production capacity not only affect operational efficiency but also the ability of SMEs to meet market demand. The imbalance between production capacity and market demand can result in product delivery delays, a decline in tempeh quality due to uncontrolled processes, and increased production costs.

One approach used to overcome capacity constraints in production systems is the Theory of Constraints (TOC). By improving or increasing capacity at the main constraint point, it is hoped that the entire production system can run more smoothly and productivity can increase significantly (Napitupulu et al., 2018). The application of TOC has become one of the recent advances in optimizing production systems, especially in identifying and eliminating bottlenecks in various industrial sectors, including micro and small businesses in the food sector. TOC enables increased throughput through a systematic approach to production constraints, as examined in both classical and recent studies (Lockamy & Spencer, 1998; Umble et al., 2006). Current research trends show the integration of TOC with mathematical models, such as linear programming and constraint logic programming, which produce quantitative and adaptive solutions in capacity planning (Qassim, 2000; Sitek et al., 2017). This integration is particularly relevant for MTO SMEs, which face highly variable demand patterns, customized product specifications, and fluctuating workloads (conditions that often lead to unstable capacity utilization and in-consistent production output). LP enables optimization of production quantities under these constraints, while TOC ensures that the optimization focuses on the actual limiting resource driving system performance. In the context of traditional food-processing SMEs such as tempeh producers, capacity imbalance manifests not only as delivery delays but also as high variance between planned and actual production, irregular operator workloads, and inefficiencies in workstation utilization. These symptoms indicate the need for a combined TOC–LP approach that can diagnose bottlenecks, quantify their impact, and propose optimal production planning strategies aligned with fundamental capacity limitations.

Recent studies have even underscored the importance of developing models that are relevant to the unique and non-homogeneous food SMEs sector (Situmorang & Matondang, 2020). New approaches (emerging focus) in the context of SMEs are demonstrated by Garcia et al. (2024) through the chain substitution method, and Lizarralde Aiastui et al. (2020) with the Drum-Buffer-Rope approach in a Make-to-Order environment. The existing literature has not sufficiently explored the integration of TOC, RCCP, and Linear Programming within traditional food-based SMEs, where labor-intensive processes and limited resource flexibility strongly influence production constraints. In addition, fermentation-based production, such as tempeh, has unique biochemical and timing characteristics that differ from those of conventional manufacturing systems, requiring a more tailored TOC-driven analytical approach. To date, no prior studies have applied a combined TOC–RCCP–LP framework specifically to tempeh production, despite its biological variability and capacity imbalance issues. Therefore, the novelty of this study lies in presenting an integrated optimization constraint management model that addresses bottleneck identification, capacity evaluation, and production planning simultaneously within a traditional tempeh SMEs context.

2. RESEARCH METHODS

This study employs a quantitative approach to optimize the production system in SMEs using the TOC approach. The research steps are shown in Fig. 1. The methodology begins by measuring the time required for the production process. Time data was collected through direct observation at each workstation and recorded in seconds and minutes. The data were then subjected to normality, uniformity, and adequacy tests to ensure statistical validity and reliability for further analysis (Ahadi & Zain, 2023). After collecting work time data, operator performance was evaluated using the Westinghouse method, which considers expertise, effort, working conditions, and consistency. Performance ratings were then used to calculate normal time, accounting for allowances such as fatigue and breaks, to determine standard time (Utama et al., 2023).

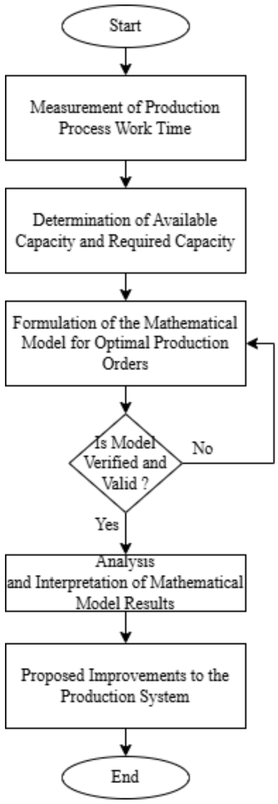

Fig. 1. Research flowchart

Next, available and required capacities for the production system were calculated using the Rough Cut Capacity Planning (RCCP) method. Available capacity was derived by multiplying effective working hours, operator count, and work efficiency. The required capacity was based on production requests and the standard time per unit. Comparing available and required capacity helped identify bottlenecks in the production process and highlight areas requiring improvement (Napitupulu et al., 2018). To optimize production, a linear programming (LP) model was developed in which the decision variables determined the optimal number of products to produce. The objective function aimed to maximize throughput or minimize total production time, while the constraints considered work capacity, production time, and available resources.

The final phase of the methodology entailed verifying the developed mathematical model using the Theory of Constraints (TOC) approach. In this study, the verification stage ensures that the mathematical model satisfies the operational logic of the production process and correctly represents the capacity constraints identified earlier. Following successful verification, an additional step, Analysis and Interpretation of

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Mathematical Model Results, is conducted. This approach ensured that the production system operated efficiently by subordinating all processes to the speed of the bottleneck station and considering elevation strategies to increase bottleneck capacity (Ikeziri et al., 2019; Umble et al., 2006). Pursuant to the findings of the verification process, a series of enhancements were proposed, including the incorporation of operators, refinement of workflows, and recalibration of production schedules. These measures were designed to address the identified impediments and optimize collective production efficiency.

3. RESULTS AND DISCUSSION

3.1. Measurement of Production Process Work Time

3.1.1. *The Calculation of Cycle Time*

Cycle time calculation by directly observing worker activity and then recording the duration of each work element using a stopwatch. The division of work elements varies for each workstation. Data collection was carried out 10 times for each work element, recording the time in seconds (Table 1).

3.1.2. *Data Normality and Uniformity Test*

A data normality test is conducted to ensure accuracy and reduce errors in decision-making. The data normality test is performed using SPSS. Based on the Kolmogorov-Smirnov test, the sig. Value for the work element is ≥ 0.05. This data indicates that it is normally distributed.

The data uniformity test is used to determine whether the data obtained is stable and consistent, and to identify differences in data that fall outside the control limits (Table 2). The following is the calculation of data uniformity at the work station for soaking the work element by opening the tap.

1. Mean Calculation

$$\bar{X} = \frac{\sum X_i}{n}$$

$$\bar{X} = \frac{26{,}39}{10} = 2{,}64 \text{ second}$$

2. Standard Deviation Calculation

$$\sigma = \sqrt{\frac{\sum(X_i - \bar{X})^2}{n-1}}$$

$$\sigma = \sqrt{\frac{(2{,}66 - 2{,}64)^2 + \cdots + (2{,}94 - 2{,}64)^2}{n-1}}$$

$\sigma = 0{,}22$ Second

3. Determined Upper Control Limit (UCL)

UCL = $\bar{X} + 3\sigma$

UCL = 2, 64 + (3 x 0,22)

Table 1. Soaking workstation cycle time

No.	Work Elements	Replication (Second)									
		1	2	3	4	5	6	7	8	9	10
1	Opening the Faucet	2.66	2.77	2.63	2.10	2.69	2.53	2.61	2.71	2.75	2.94
2	Taking the Hose	3.54	3.22	3.49	4.25	3.99	3.98	3.65	3.91	3.91	3.75
3	Filling the Tank with Water	3720.11	3421.78	3761.90	4232.12	3589.55	3791.41	3666.01	3721.78	3892.27	4103.44
4	Closing the Faucet	3.75	3.15	3.28	3.40	3.02	3.59	2.99	3.13	3.05	3.26
5	Placing the Hose	4.09	4.23	4.05	3.64	3.56	3.76	3.77	4.43	3.82	4.19
6	Taking the Soybean Sack	8.65	8.31	7.36	8.04	7.63	6.98	7.91	7.38	7.91	6.58
7	Opening the Sack	5.18	5.48	6.11	4.84	5.07	4.84	4.81	4.83	4.90	5.31
8	Pouring the Soybeans into the Tank	11.91	12.23	12.11	12.75	13.92	11.86	13.91	13.44	14.75	13.83
9	Placing the Sack	2.58	2.81	2.74	2.34	2.32	2.31	2.50	2.45	2.89	2.47
Total		**3762.47**	**3463.98**	**3803.67**	**4273.48**	**3631.75**	**3831.26**	**3708.16**	**3764.06**	**3936.25**	**4145.77**

Table 2. Uniform test at the soaking workstation

No	Work Elements	Mean (X)	UCL	LCL	Desc.
1	Opening the Faucet	2.64	3.30	1.98	Uniform
2	Taking the Hose	3.77	4.67	2.87	Uniform
3	Filling the Tank with Water	3790.04	4501.12	3078.95	Uniform
4	Closing the Faucet	3.26	4.02	2.51	Uniform
5	Placing the Hose	3.95	4.81	3.10	Uniform
6	Taking the Soybean Sack	7.68	9.54	5.81	Uniform
7	Opening the Sack	5.14	6.38	3.90	Uniform
8	Pouring the Soybeans into the Tank	13.07	16.15	9.99	Uniform
9	Placing the Sack	2.54	3.17	1.91	Uniform

UCL = 3,30 seconds

4. Determined Lower Control Limit (LCL)

$LCL = \overline{X} - 3\sigma$

LCL = 2, 64 – (3 x 0,22)

LCL = 1,98 seconds

3.1.3. *Data Adequacy Test*

It is checked to see if the observation data are enough using data sufficiency testing. If not enough data is available, additional observation data must be gathered until sufficient data is collected. Here is the math used to determine the required data volume at the soaking workstation for the open-tap part. Table 3 outlines the data quality test for the Soaking workstation. Since N' is less than N, the data from the soaking machine is thought to be enough.

Table 3. Adequacy test at the soaking workstation

No	Work Elements	N	N'	Desc.
1	Opening the Faucet	10	9.91	sufficient
2	Taking the Hose	10	9.13	sufficient
3	Filling the Tank with Water	10	5.63	sufficient
4	Closing the Faucet	10	8.61	sufficient
5	Placing the Hose	10	7.47	sufficient
6	Taking the Soybean Sack	10	9.43	sufficient
7	Opening the Sack	10	9.30	sufficient
8	Pouring the Soybeans into the Tank	10	8.90	sufficient
9	Placing the Sack	10	9.74	sufficient

3.1.4. *The Calculation of Normal Time*

A worker's performance rating indicates how quickly or slowly they work in comparison to the average speed of their job. Grouping performance levels into distinct categories gives each category its own weight in the final score. Workers whose performance is considered average are assigned a score of 60, which serves as a baseline for evaluating the performance of other workers. An employee's performance is rated with a 70, indicating Good+, in a Performance Rating. The worker's performance is Good+, which is 70, and the normal speed is 60, then.

P (*Performance Rating*) = $\frac{Performance}{Normal}$

P (*Performance Rating*) = $\frac{70}{60} = 1{,}17$

Normal time is the time required by workers to complete their work at a standard speed or performance that has been adjusted to match their performance rating. An example of normal time calculation at a Soaking work station.

$$W_{normal} = W_{cycle} \times P$$
$$W_{normal} = 2{,}64 \ seconds \times 1{,}17$$
$$W_{normal} = 3{,}09 \ seconds$$

The normal time calculation for each work element at the Soaking workstation is shown in Table 4.

3.1.5. *The Calculation of Standard Time*

Flexible time provisions are based on the International Labour Organisation (ILO) Allowance. Fixed allowances consist of personal allowances (A) and basic fatigue allowances (B). In contrast, variable allowances consist of standing allowance (C), abnormal position allowance (D), use of muscle power or energy (E), lighting (F), air conditions (G), level of attention (H), noise level (I), mental strain (J), monotony (K), and boredom (L) [4]. Standard time is determined from the results of normal time measurements and the allowances given to workers. The following is an example of standard time calculation at the soaking workstation.

$$W_{Standard} = W_{Normal} \times \frac{100\%}{100\% - \%Allowance}$$
$$W_{Standard} = 3{,}09 \text{ seconds} \times \frac{100\%}{100\% - 11\%}$$
$$W_{Standard} = 3{,}55 \text{ seconds}$$

A summary of cycle times, normal times, and standard times for each workstation is provided in Table 5.

Table 4. Normal time for the soaking work station

No	Work Elements	Cycle Time (Seconds)	*Performance Rating*	Normal Time (Seconds)
1	Opening the Faucet	2.64	1.17	3.09
2	Taking the Hose	3.77	1.17	4.41
3	Filling the Tank with Water	3790.04	1.17	4434.34
4	Closing the Faucet	3.26	1.17	3.82
5	Placing the Hose	3.95	1.17	4.63
6	Taking the Soybean Sack	7.68	1.17	8.98
7	Opening the Sack	5.14	1.17	6.01
8	Pouring the Soybeans into the Tank	13.07	1.17	15.29
9	Placing the Sack	2.54	1.17	2.97
Total				4483.54

Table 5. Cycle, normal, and standard time

No	Work Stations	Cycle Time (Seconds)	Normal Time (Seconds)	Standard Time (Seconds)
1	Soaking	3832.09	4483.54	5042.35
2	Washing	163.91	191.77	220.01
3	Boiling	675.48	790.31	895.35
4	Grinding	41.53	48.59	62.09
5	Fermentation	57.90	67.74	77.78
6	Drying	46.94	54.92	69.14
7	Pressing	47.75	55.87	67.44
8	Packaging	32.47	37.99	45.78
9	Printing	31.44	36.78	42.22

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3.2. The Determination of Available Capacity and Required Capacity through the Rough Cut Capacity Planning (RCCP)

3.2.1. *The determination of the Utility and Efficiency*

Before identifying constrained workstations, it is essential to calculate both the available and required capacities. Before determining the available capacity and the required capacity, it is necessary to ascertain the utility and efficiency (Table 6). The following is a list of the utilities at the soaking workstation.

Utility (U) = $\frac{normal\ time}{standartd\ time}$

Utility (U) = $\frac{4483.54}{5042,35}$

Utility (U)= 0,89 Seconds

The following example illustrates the calculation of efficiency at the soaking workstation.

Efficiency (E) = $\frac{Cycle\ Time}{Normal\ Time}$

Efficiency (E) = $\frac{3832,09}{4483,54}$

Efficiency (E) = 0,85 Seconds

Table 6. Utility and efficiency

No	Workstations	U	E
1	Soaking	0.89	0.85
2	Washing	0.87	0.85
3	Boiling	0.88	0.85
4	Grinding	0.78	0.85
5	Fermentation	0.87	0.85
6	Drying	0.79	0.85
7	Pressing	0.83	0.85
8	Packaging	0.83	0.85
9	Printing	0.87	0.85

3.2.2. *The Calculation of Required Capacity (CR)*

The requisite capacity is determined by multiplying the daily demand for each product by the time required to produce it. The time required to produce the product in a day is obtained by dividing the number of products in a day—9,800 pieces of tempeh—by the number of working hours in a day, which is 8 hours. The result of this calculation is 0.000816 hours/piece or 2.93 seconds/piece. The following data set contains information regarding the monthly demand for tempeh.

The calculation of capacity is necessary for September.

CR = (∑ Total product demand/month x Standard Labor Hours)

CR = 248,942 x 2.93

CR = 731,584.7 seconds

3.2.3. *The Calculation of Available Capacity (AC)*

The identification of bottleneck workstations is achieved through the calculation of variance and the percentage of load between the CR and the CA. The following example illustrates one of the variances and percentages at the soaking work station for September.

Variance = CR – CA
= 731584,7 – 653616
= 77968,65 detik

Percentage of Load = CR/CA x 100%
= (731584,7)/653616 x 100%
= 111,93%

Workstations that experience bottlenecks are those with positive variance and a load percentage exceeding 100%. The variance and load percentage calculations indicate that two workstations experience bottlenecks: the soaking workstation and the fermentation workstation.

3.3. The Formulation of A Mathematical Model

The formulation of mathematical models or constraint limitations is carried out using linear programming techniques. The objective of these techniques is to determine decision variables, objective functions, and constraint functions. The ultimate aim of this process is to obtain the optimal order quantity solution.

3.3.1. *Determination of Decision Variables*

The decision variables in this problem are related to the number of products to be produced for each type of tempeh. These variables are specified in Table 7.

Table 7. Desicion variables

No	Decision Variable	Description
1	X1	HB 4
2	X2	HB 5
3	X3	AZ 2
4	X4	AZ 3
5	X5	AZ 4 (270 g)
6	X6	AZ 4 (290 g)
7	X7	Demang
8	X8	Plain
9	X9	Leaf

3.3.2. *Determination of Objective*

The objective function in this study is to maximize the number of products that can be produced. This is formulated mathematically as follows:

Max Z = $\sum(Cn \text{ x } Xn) - (Pn \text{ x } Xn)$

Max Z = (4000X1 + 5000X2 + 2000X3 + 3500X4 + 4000X5 +4000X6 + 4000X7 + 3300X8 + 5000X9) – (3036X1 + 3864X2 + 1564X3 + 2484X4 + 2484X5 + 2668X6 + 2668X7 + 2668X8 + 3404X9)

where C_n = Sale price of product n; P_n = Raw material cost for product n; and X_n = Product type

3.3.3. *Determination of Constraint*

Constraint functions are mathematical representations of existing limitations. Determining the capacity constraint function available at each workstation is essential for converting it into a mathematical model.

$$\sum(A_{mn} X_n) + T_{su} \leq B_m$$

where A_{mn}: Standard time for workstation m for product n; T_{su}: Setup time for each workstation; and B_m" Available capacity at workstation

The standard time per product at each workstation is derived by dividing the number of requests per day (9,800 pieces of tempeh) by the standard time. The available capacity, the standard time per product, and the setup time determine the constraint function for

Table 8. Optimal order quantity

Time	Products (Bar)								
	HB 4	HB 5	AZ 2	AZ 3	AZ 4 (270 g)	AZ 4 (290 g)	Demang	Plain	Leaf
September	42216	49506	0	10900	37079	52340	6750	403	12457
October	44972	50703	0	8200	42285	50104	6715	4369	11255
November	42545	48910	0	7850	45360	49523	6910	0	10453
December	31277	47215	0	10850	52325	52325	6065	0	11494
January	36745	51515	0	9200	49600	53532	6887	0	11124
February	28297	47479	0	9350	45187	49934	7077	0	10123
March	26177	51744	0	10650	49477	51376	7885	0	7190

each workstation in September 2024.

$1,514 \times (X1+X2+X3+X4+X5+X6+X7+X8+X9) + 3600 \leq 653616$

$0,022 \times (X1+X2+X3+X4+X5+X6+X7+X8+X9) + 600 \leq 1277856$

$0,091 \times (X1+X2+X3+X4+X5+X6+X7+X8+X9) + 1500 \leq 3877632$

$0,006 \times (X1+X2+X3+X4+X5+X6+X7+X8+X9) + 900 \leq 2291328$

$0,007 \times (X1+X2+X3+X4+X5+X6+X7+X8+X9) + 1200 \leq 1277856$

$0,007 \times (X1+X2+X3+X4+X5+X6+X7+X8+X9) + 900 \leq 4061232$

$0,006 \times (X1+X2+X3+X4+X5+X6+X7+X8+X9) + 600 \leq 609552$

$(41,62X1+47,66X2+45,20X3+44,60X4+46,05X5+43,94X6+46,24X7+45.66X8+51X9) + 600 \leq 9752832$

$42,28 \times (X1+X2+X3+X4+X5+X6+X7+X8+X9) + 600 \leq 8944992$

$X1 \leq 42116$

$X2 \leq 49506$

$X3 \leq 3004$

$X4 \leq 10900$

$X5 \leq 37079$

$X6 \leq 52340$

$X7 \leq 6750$

$X8 \leq 34790$

$X9 \leq 12457$

$Xn \geq 0$

3.3.4. *Determination of Optimal Order Quantity*

After identifying constraints and determining mathematical formulations, enter the formula into the *Lingo 20.0 software*. Preliminary calculations employing Lingo version 20 indicate an optimal value for the objective of IDR 262,968,800, with the subsequent optimal order results shown in Table 8.

3.4. The Verification of the Model

The model's accuracy and reliability are tested by synchronizing other workstations with the bottleneck workstation and increasing its efficiency and capacity. At the constraint subordination stage, the available capacity, required capacity, variance, and load percentage are recalculated based on the optimal order count results. The workstations continue to encounter bottlenecks, as evidenced by positive variance values and load percentages that exceed 100%. Although the optimization model redistributed the production load across workstations, the soaking and fermentation stations remained bottlenecks due to intrinsic process characteristics. The soaking process has an extremely long cycle time dominated by fixed-duration water absorption, making it resistant to scheduling-based improvements. Similarly, the fermentation process is constrained by biological reaction time, which cannot be shortened without compromising product quality. These structural constraints explain why both stations still exceeded 100% load even after optimization, indicating that mathematical optimization alone cannot eliminate bottlenecks driven by inherent process limitations. Consequently, the subsequent stage, constraint elevation, is initiated.

Despite the exploitation of system constraints and subordination, there are still soaking and fermentation workstations that experience bottlenecks. The processing output indicates that throughput is not yet optimal due to a reduction in production volume, as illustrated in Table 9.

Table 9. Recapitulation of calculation results in September 2024

Products	Demand (Bar)	Optimal Results (Bar)	Shortage (Bar)
HB 4	42116	42216	-100
HB 5	49506	49506	0
AZ 2	3004	0	3004
AZ 3	10900	10900	0
AZ 4 (270 g)	37079	37079	0
AZ 4 (290 g)	52340	52340	0
Demang	6750	6750	0
Plain	34790	403	34387
Leaf	12457	12457	0

Preliminary estimations indicate a production deficit in September 2024, except for the HB 4 type of tempeh, which is projected to have an excess supply of 100 sticks. For the AZ 2 type, there is a shortage of 3,004 tempeh sticks, and for the plain tempeh type, there is a shortage of 34,387 tempeh sticks. To optimize system performance, it is necessary to either remove or alleviate the existing constraints. The measures implemented entail allocating additional resources to workstations experiencing delays, specifically those designated for fermentation processes.

3.5. Proposed Improvements

The proposed enhancement to increase the

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efficiency and capacity of critical workstations involves augmenting the labor force to enhance production capacity at the Tempeh production site. The subsequent calculation provides an estimate of the personnel increase at the fermentation workstation in September 2024.

$$Ft = \frac{CR - CA}{CA/F}$$

$$Ft = \frac{731584{,}7 - 609552}{609552/1}$$

Ft = 0,020413 ≈ 1 orang

where Ft: Addition of Workers; CR: Required Capacity; CA: Available Capacity; and F: Number of Workers Before.

According to the calculation outlined above, the fermentation workstation will require an additional worker in order to meet its capacity requirements in September 2024. The number of workers present at the fermentation workstation will increase from one to two following the addition. To demonstrate the absence of bottleneck workstations, a recalculation of available capacity and required capacity is conducted.

To clearly demonstrate the improvement achieved through the TOC elevation step, a comparison between the system's performance before and after adding one worker at the fermentation workstation is presented in Table 10. This table highlights changes in capacity, load percentage, and throughput.

Table 10. Summary of system performance before and after improvement

Parameter	Before Improvement	After Improvement	% Change
Fermentation Load (%)	108.42%	48.65%	–55.2%
Soaking Load (%)	111.93%	47.56%	–57.5%
Number of Bottleneck Stations	2	0	100% improvement
Throughput Feasibility	Several SKUs unfulfilled	All SKUs feasible	Full improvement

The optimal number of orders for each product type per month is determined by applying the aforementioned mathematical formula and calculating the additional manpower required. Based on the results of the variance (Table 11) and the load of percentage after the addition of the worker (Table 12), the optimal order quantity after adding labor is obtained (Table 13). The decision to add one worker to the fermentation workstation is grounded in both TOC and capacity analysis principles. Since fermentation is labor-intensive and not machine-limited, increasing the workforce is the most direct and cost-efficient way to increase capacity. Alternative interventions were evaluated but found less suitable for this context.

1. Shift restructuring would require extending operating hours, which is incompatible with the non-continuous nature of fermentation cycles that depend on fixed biochemical timing.
2. Machine or equipment upgrades offer limited gains because the restriction is primarily labour rather than machinery.
3. Introducing WIP buffers may reduce waiting time, but does not increase throughput, and therefore does not resolve the actual capacity limitation.

The findings of this study strongly align with previous studies that applied TOC to industries facing capacity constraints. Research by Situmorang & Matondang (2020) showed that capacity imbalances in the instant noodle industry, particularly at the mixing and cooking stations, can be addressed through the integration of TOC, continuous improvement, linear programming, and RCCP, ultimately transforming bottleneck stations into non-bottleneck stations. These results align with this study, which states that bottlenecks at the soaking and fermentation stations can be identified and eliminated through an integrated RCCP–TOC–LP approach. Furthermore, research by Ukey et al. (2025) in the furniture industry found that TOC implementation identified and eliminated key constraints that hinder productivity and profitability, demonstrating its effectiveness not only in automated manufacturing but also in labor-intensive sectors such

Table 11. Variance after the addition of a worker

Time	Soaking	Washing	Boiling	Grinding	Fermentation	Drying	Pressing	Packaging	Printing
September	685237.22	655861.22	3255637.22	1669333.22	655861.22	3439237.22	597109.22	9130837.22	8322997.22
Oktober	708381.26	678026.06	3364461.26	1725280.46	678026.06	3554181.26	617315.66	9435501.26	8600733.26
November	685531.10	656155.10	3255931.10	1669627.10	656155.10	3439531.10	597403.10	9131131.10	8323291.10
Desember	685531.10	656155.10	3255931.10	1669627.10	656155.10	3439531.10	597403.10	9131131.10	8323291.10
Januari	708381.26	678026.06	3364461.26	1725280.46	678026.06	3554181.26	617315.66	9435501.26	8600733.26
Februari	639830.79	612413.19	3038870.79	1558320.39	612413.19	3210230.79	557577.99	8522390.79	7768406.79
Maret	662680.95	634284.15	3147400.95	1613973.75	634284.15	3324880.95	577490.55	8826760.95	8045848.95

Table 12. The percentage load after the addition of the worker

Time	Soaking	Washing	Boiling	Grinding	Fermentation	Drying	Pressing	Packaging	Printing
September	47.58	48.67	16.04	27.15	48.67	15.32	51.02	6.38	6.95
Oktober	47.56	48.65	16.03	27.13	48.65	15.31	51.00	6.37	6.95
November	47.56	48.65	16.03	27.13	48.65	15.31	51.00	6.37	6.95
Desember	47.56	48.65	16.03	27.13	48.65	15.31	51.00	6.37	6.95
Januari	47.56	48.65	16.03	27.13	48.65	15.31	51.00	6.37	6.95
Februari	47.56	48.65	16.03	27.13	48.65	15.31	51.00	6.37	6.95
Maret	47.56	48.65	16.03	27.13	48.65	15.31	51.00	6.37	6.95

Table 13. Optimal order quantity after adding labor

Time	Products (Bar)								
	HB 4	**HB 5**	**AZ 2**	**AZ 3**	**AZ 4 (270 g)**	**AZ 4 (290 g)**	**Demang**	**Plain**	**Leaf**
September	42216	49506	0	10900	37079	52340	6750	403	12457
Oktober	44972	50703	0	8200	42285	50104	6715	4369	11255
November	42545	48910	0	7850	45360	49523	6910	0	10453
Desember	31277	47215	0	10850	52325	52325	6065	0	11494
Januari	36745	51515	0	9200	49600	53532	6887	0	11124
Februari	28297	47479	0	9350	45187	49934	7077	0	10123
Maret	26177	51744	0	10650	49477	51376	7885	0	7190

as tempeh production. Furthermore, a study by Orue et al. (2021) in an MTO environment highlighted the importance of protective capacity at non-bottlenecks as a key factor in the subordination stage (TOC step 3), which supports the results of this study that optimization is not sufficient through scheduling alone, but requires a deep understanding of the capacity interactions between workstations. Thus, this study extends the existing literature by demonstrating that integrating TOC, RCCP, and Linear Programming is highly effective for fermentation-based food production systems characterized by biological variability and labor dependence.

4. CONCLUSION

The Standard times for each workstation were determined as follows: soaking station, 5042.35 seconds; washing station, 220.01 seconds; boiling station, 895.35 seconds; grinding station, 62.09 seconds; fermentation station, 77.78 seconds; drying station, 69.14 seconds; pressing station, 67.44 seconds; packaging station, 45.78 seconds; and printing station, 42.22 seconds. The capacity calculations, employing the RCCP method, revealed that the pressing station encountered a bottleneck, as indicated by positive variance and workload percentages exceeding 100%. The mathematical model, which maximizes the optimal production quantity based on profit for each tempeh type, was formulated using variables specific to each tempeh type. Constraints were defined based on available capacity, monthly demand, and non-negativity. The utilization of software such as Lingo 20.0 facilitated the determination of optimal order quantities. However, the subsequent verification process revealed that both the soaking and pressing stations continued to encounter bottlenecks, with the workload surpassing 100% of their capacity.

To rectify the congestion at the pressing station, it is recommended that an additional worker be assigned to augment capacity and prevent further delays. The introduction of an additional worker is expected to enhance production efficiency and optimize workload distribution in accordance with available resources. Future research could focus on further optimizing workstation times through automation or technology, conducting a sensitivity analysis to assess the model's robustness to changes in demand or capacity, and exploring more effective resource allocation strategies, such as adjusting work shifts or upgrading equipment. The incorporation of real-time data collection has the potential to enhance decision-making processes by dynamically adjusting resources in response to fluctuations in actual demand, thereby enhancing overall production efficiency. Future studies may include a techno-economic extension to evaluate the financial justification of labour addition or other improvement alternatives.

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Appendix

Appendix 1. Number of products (sticks) over 7 months

Month	Week-	Products (Sticks)								
		HB 4	HB 5	AZ 2	AZ 3	AZ 4	AZ 4	Demang	Plain	Leaf
September 2024	1	10110	11869	555	2800	8265	12730	1975	7880	3065
	2	10100	11572	620	2400	9085	12442	1505	8120	3004
	3	9846	11365	690	2500	8549	12527	1005	8231	2978
	4	12060	14700	1139	3200	11180	14641	2265	10559	3410
Oktober 2024	1	10132	11668	675	2000	8755	11332	1775	8525	2576
	2	10170	11460	705	2000	8815	11966	1785	9040	2492
	3	10125	11515	620	2300	9230	11157	1395	8825	2630
	4	14545	16060	945	1900	15485	15649	1760	12290	3557
November 2024	1	9870	11010	1175	1800	10615	11428	1505	9300	2428
	2	9859	11268	705	1850	10395	11675	1655	8835	2170
	3	10300	11580	1205	1800	10235	11740	1645	9895	2925
	4	13765	15052	1230	2400	14115	14680	2105	13515	2930
Desember 2024	1	11030	12225	745	2300	11325	12260	1645	11430	2489
	2	10965	12170	735	2550	11220	11760	1435	11760	2975
	3	10070	11270	650	2400	10600	11755	780	11595	2955
	4	15150	17245	960	3600	16065	16550	2205	17140	3075
Januari 2025	1	9535	10445	590	1300	9580	10440	1520	9532	2286
	2	11114	12125	725	2100	11602	12577	1858	11590	2603
	3	11285	12110	755	2800	11317	12346	1839	12135	2660
	4	16904	16835	1070	3000	17101	18169	1670	16887	3575
Februari 2025	1	11354	12310	850	2250	12069	12940	1690	12625	2600
	2	11345	11775	850	2400	11237	12865	1858	12976	2588
	3	11064	11319	828	2600	10955	11962	1780	11917	2410
	4	11227	12075	960	2100	10926	12167	1749	12042	2525
Maret 2025	1	13717	13235	730	2850	11555	11820	2035	14474	750
	2	12076	11960	1074	2400	11447	12494	2240	14557	2413
	3	12014	11625	1085	2000	11511	12120	2270	13065	2560
	4	13768	14924	1087	3400	14964	14942	1340	17162	1467

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Appendix 2. Actual product quantity (sticks) over 7 months

Months	Week	Products (Sticks)								
		HB 4	HB 5	AZ 2	AZ 3	AZ 4	AZ 4	Demang	Plain	Leaf
September 2024	1	9917	11667	535	2660	8195	12398	1905	7370	2621
	2	7196	11396	620	2280	9015	12157	1455	7514	2639
	3	9430	10833	690	1995	8479	12239	975	7537	2552
	4	11815	14519	1134	3040	11090	14290	2185	9867	2953
Oktober 2024	1	9941	11447	675	1820	8685	11084	1705	8054	2216
	2	9989	11223	705	1900	8745	11718	1715	8432	2182
	3	9910	11326	620	878	9136	10937	1335	8209	2296
	4	14053	15574	945	1810	15073	15118	1680	11117	2889
November 2024	1	9660	6667	715	1728	10381	11219	1503	8678	2169
	2	9487	6819	705	1776	10152	11427	1600	8835	2159
	3	10050	7164	980	1720	10103	11477	1645	9324	2548
	4	13516	9074	745	2304	13903	14176	2105	12921	2597
Desember 2024	1	10791	7352	735	2208	11152	11982	1570	10754	2162
	2	10729	7211	650	2450	11046	11440	1361	10975	2451
	3	9863	6841	632	2304	10460	11484	750	10999	2455
	4	14025	10847	590	3456	15865	16200	2095	15865	2660
Januari 2025	1	9433	6390	582	1248	9314	10440	1320	9322	2171
	2	11095	12111	725	2100	11602	12577	1718	11590	2595
	3	11285	12110	755	2800	11317	12346	1839	12135	2660
	4	16884	16835	1070	3000	17101	18169	1670	16877	3575
Februari 2025	1	11354	12310	745	2250	12069	12940	1690	12625	2600
	2	11345	11775	850	2400	11237	12865	1858	12976	2588
	3	11064	11319	828	2600	10955	11962	1780	11917	2410
	4	11227	12075	960	2100	10926	12167	1749	12042	2525
Maret 2025	1	13717	13235	730	2850	11555	11820	2035	14474	750
	2	12076	11960	1074	2400	11447	12494	2240	14557	2413
	3	12014	11625	1085	2000	11511	12120	2270	13065	2560
	4	13768	14924	1087	3400	14964	14942	1340	17162	1467

Appendix 3. Number of backorder products (units) over 7 months

Month	Week	Number of Backorder Products (Bar)								
		HB 4	**HB 5**	**AZ 2**	**AZ 3**	**AZ 4**	**AZ 4**	**Demang**	**Plain**	**Leaf**
September 2024	1	193	202	20	140	70	332	70	510	444
	2	2904	176	0	120	70	285	50	606	365
	3	416	532	0	505	70	288	30	694	426
	4	245	181	5	160	90	351	80	692	457
Oktober 2024	1	191	221	0	180	70	248	70	471	360
	2	181	237	0	100	70	248	70	608	310
	3	215	189	0	1422	94	220	60	616	334
	4	492	486	0	90	412	531	80	1173	668
November 2024	1	210	4343	460	72	234	209	2	622	259
	2	372	4449	0	74	243	248	55	0	11
	3	250	4416	225	80	132	263	0	571	377
	4	249	5978	485	96	212	504	0	594	333
Desember 2024	1	239	4873	10	92	173	278	75	676	327
	2	236	4959	85	100	174	320	74	785	524
	3	207	4429	18	96	140	271	30	596	500
	4	1125	6398	370	144	200	350	110	1275	415
Januari 2025	1	102	4055	8	52	266	0	200	210	115
	2	19	14	0	0	0	0	140	0	8
	3	0	0	0	0	0	0	0	0	0
	4	20	0	0	0	0	0	0	10	0
Februari 2025	1	0	0	105	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0
Maret 2025	1	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0

http://dx.doi.org/10.30656/intech.v11i2.11384