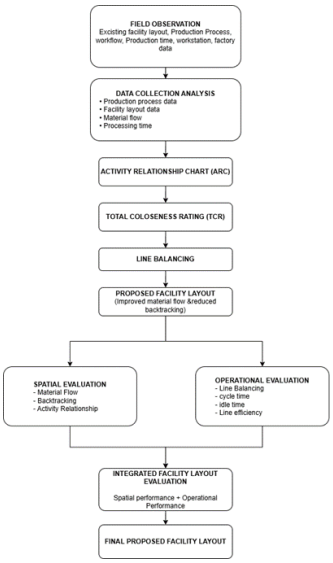
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Full Paper

Evaluation of Production Facility Layout to Minimize Backtracking: A Case Study of Green Tea Production at Factory X

Rizkyana Ismail, Alfi Raihan Firdaus, Agna Khairuni Aulia, Dafina Maharani Putri Gunawan
Department of Agro-Industrial Technology, Faculty of Agro-Industrial Technology, Padjadjaran University, Jatinangor 45363

*Corresponding author
rizkyana24001@mail.unpad.ac.id



Abstract
Facility layout plays a critical role in determining production efficiency, productivity, and the smoothness of material flow in manufacturing systems. This study aims to evaluate and improve the facility layout of a green tea factory at PT X to minimize backtracking and enhance production flow efficiency through the integration of Activity Relationship Chart (ARC), Total Closeness Rating (TCR), and line balancing methods. A quantitative descriptive approach was employed based on direct observation and interviews. The production system consists of seven main activities: raw material storage, sortation 1, roasting, cooling section, sortation 2, packing, and final storage. The initial layout condition indicates inefficient material flow, backtracking occurrences, a total idle time of 19 minutes per cycle, and a line efficiency of 55%. Based on ARC and TCR analysis, an alternative layout was developed by arranging facilities according to activity relationships and process sequence. Furthermore, the implementation of line balancing resulted in four workstations with reduced idle time of 1 minute per cycle and increased line efficiency to 96%. The proposed layout produces a more linear production flow, reduces unnecessary movement, and improves overall operational performance. The findings demonstrate that the integration of ARC, TCR, and line balancing is effective in optimizing facility layout and supporting a more efficient and productive production system.

Keywords: Facility layout, Green tea production, ARC, TCR, Line balancing, Production efficiency

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1. INTRODUCTION

The layout of production facilities is a critical component in manufacturing systems, as it significantly affects operational efficiency, particularly in terms of material flow, processing time, and production costs. An inefficient layout may lead to various forms of waste, including excessive material handling, prolonged waiting times, and the occurrence of backtracking, all of which can disrupt the continuity of the production process. Therefore, an appropriately designed facility layout is essential to ensure an effective and efficient production system [1]–[3]. In the food processing industry, particularly in green tea production, each stage of the process is highly interdependent, requiring a facility arrangement that supports a smooth and continuous material flow. Key processes such as raw material storage, sorting, roasting, cooling, and packaging must be systematically organized to minimize unnecessary movement. Inadequate layout design can increase material travel distance, elevate the risk of bottlenecks, and reduce overall production performance [4].

The green tea processing plant of PT. X represents a production system consisting of several sequential stages with seven primary activities: raw material storage, initial sorting, roasting, cooling, secondary sorting, packaging, and finished product storage. Based on the existing conditions, there is potential inefficiency in material flow due to facility placement that does not adequately consider the closeness relationships between activities. This results in repeated material handling and the occurrence of backtracking or reverse flows, which increase processing time, extend material movement paths, and reduce work efficiency, ultimately leading to decreased productivity [5]. These conditions highlight the need for a comprehensive layout evaluation to improve overall production efficiency.

In addition to productivity concerns, facility layout and the level of closeness between workstations also play a significant role in determining product quality. An improper layout, particularly one that does not consider process sequence and the separation between storage and processing areas, may increase the risk of product contamination. This can occur due to the intersection of pathways between raw materials, semi-finished products, and finished goods within the same area [5], [6], [16].

Previous studies have demonstrated that facility layout optimization can be achieved using various approaches, including Material Flow Analysis, Activity Relationship Chart (ARC), Systematic Layout Planning (SLP), CORELAP, and Total Closeness Rating (TCR), which have been shown to reduce material handling distances, improve activity relationships, and enhance layout efficiency [1], [4], [7], [11]. Meanwhile, line balancing has primarily been applied to balance workstation workloads, reduce idle time, and improve production line efficiency [13], [14].[18] However, these approaches are generally implemented independently, resulting in optimization that focuses either on spatial arrangement or operational performance rather than integrating both aspects simultaneously [7], [11].[18]. This limitation represents the research gap addressed in the present study, as only limited research has combined facility layout optimization and production line balancing within a unified analytical framework, particularly in the green tea processing industry. Unlike many manufacturing systems, green tea production involves strictly sequential processing stages, highly perishable intermediate products that require continuous processing, limited production space, and one-way material movement to minimize backtracking and prevent cross-contamination [4], [6].[16]. Therefore, this study integrates Activity Relationship Chart (ARC), Total Closeness Rating (TCR), and line balancing into a comprehensive facility layout evaluation framework. ARC is employed to analyze qualitative relationships among production activities, TCR is used to prioritize facility placement based on these relationships, and line balancing is applied to evaluate workstation workload distribution and operational efficiency under the proposed layout. Consequently, the proposed framework not only improves the spatial efficiency of the facility layout but also evaluates its impact on production line performance, thereby providing a more comprehensive approach for facility layout improvement in green tea processing industries. The primary contribution of this study is the integration of Activity Relationship Chart (ARC), Total Closeness Rating (TCR), and line balancing into a unified facility layout evaluation framework that simultaneously considers spatial relationships and operational performance. Unlike previous studies that evaluate facility layout or production line balancing independently, this study demonstrates how both dimensions can be integrated to improve production flow efficiency in green tea processing industries characterized by sequential processing, limited production space, and contamination-sensitive operations. Based on the identified research gap, this study aims to evaluate and redesign the production facility layout of the green tea processing line at Factory X by integrating the Activity Relationship Chart (ARC), Total Closeness Rating (TCR), and line balancing methods. The proposed framework is expected to minimize backtracking, improve material flow, balance workstation workloads, and enhance overall production line efficiency

2. METHOD

This study was conducted at the green tea factory of PT X, with data collection carried out over a two-month period from February to March 2026. Figure 1 illustrates the methodological framework adopted in this study. The framework consists of two sequential stages: (1) spatial optimization using Activity Relationship Chart (ARC) and Total Closeness Rating (TCR) to generate the proposed facility layout, and (2) operational validation using line balancing to evaluate workstation performance, idle time, and line efficiency. This sequential integration ensures that the redesigned facility layout is assessed from both spatial and operational perspectives.

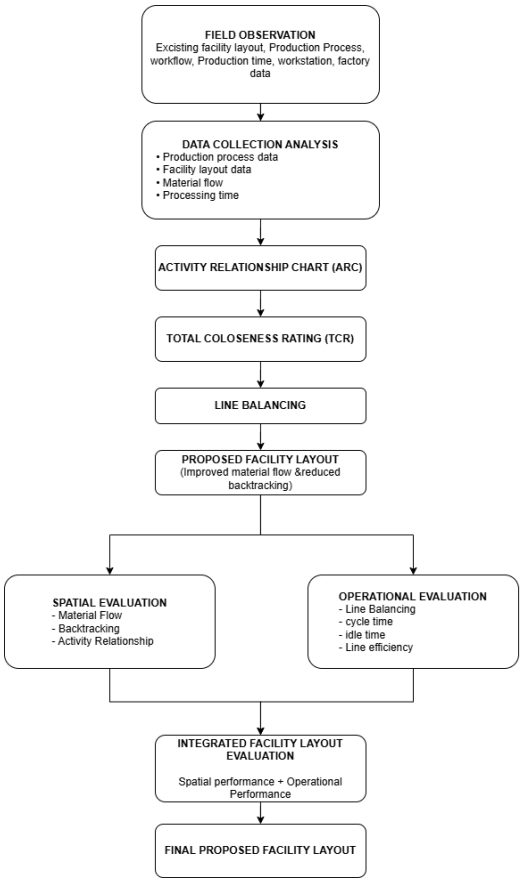


Figure 1. Integrated Methodological Framework for Facility Layout Evaluation

2.1. Types and Sources of Data

This study adopted a descriptive quantitative approach, which is intended to systematically describe the actual conditions of the research object through objective numerical data collection. Primary data were obtained through two main techniques, namely direct observation and structured interviews conducted at the factory site. Quantitative data obtained from observations were analyzed statistically to identify patterns and potential deviations, while qualitative data from interviews were examined using thematic analysis to explore recurring insights and underlying issues [8]. The data collected included the sequence of production processes, operation time at each stage, daily production capacity, dimensions of machines and equipment, number of workers at each workstation, and the closeness relationships among production activities.

2.2. Activity Relationship Chart (ARC)

An Activity Relationship Chart (ARC) was developed to analyze the closeness relationships among seven key production activities: Raw Material Storage (A), Sortation 1 (B), Roasting (C), Cooling Section (D), Sortation 2 (E), Packing (F), and Final Storage (G). The ARC is a qualitative method used in facility layout planning to evaluate the degree of relationship between activities, which is typically expressed through subjective judgments based on operational considerations [9]. This method examines functional closeness by integrating material flow requirements with non-material factors, such as noise, supervision, and environmental conditions [10]. The degree of relationship between activities was determined using eight reason codes: (1) production flow, (2) material flow, (3) no relation, (4) functional dependency, (5) noise, (6) odor, (7) dirt, and (8) hazard.

2.3 Total Closeness Rating (TCR)

Total Closeness Rating (TCR) analysis was performed based on the ARC results to determine the priority placement of each activity. Layout planning using the TCR method involves calculating the closest associated distance for each production activity, as described within the ARC, with all determinations fully referencing the TCR calculation results [11]. Assessments were based on qualitative ratings converted into relationship degree codes, ranging from "absolutely necessary" (A) to "undesirable" (X). The use of TCR is grounded in the principle that activities with the highest relationship intensity should be placed as close as possible in the final layout

arrangement, ensuring proper circulation, workforce safety, and minimal material handling distance within the production flow [12].

The integration of ARC, TCR, and line balancing was designed to optimize the production system from two complementary perspectives: spatial efficiency and temporal efficiency. First, ARC was employed to identify the qualitative closeness relationships among production activities, while TCR was used to prioritize facility placement based on the strength of these relationships. The alternative layout generated from the ARC–TCR analysis then served as the basis for the line balancing analysis. Unlike ARC and TCR, which primarily focus on the spatial arrangement of facilities, line balancing evaluates the temporal performance of the proposed layout by balancing workloads among workstations according to the cycle time. This sequential integration ensures that the redesigned facility layout not only minimizes unnecessary material movement and backtracking but also improves production flow efficiency by reducing idle time and optimizing workstation utilization.

2.4 Line Balancing

After the alternative facility layout had been developed through the ARC and TCR analyses, line balancing was applied using the Largest Candidate Rule (LCR) method to evaluate whether the proposed layout could support an efficient distribution of workload among workstations. Unlike ARC and TCR, which optimize facility arrangement based on activity relationships, line balancing evaluates production flow performance by minimizing idle time and balancing workstation capacity. Cycle time was determined from the ratio of available operating time (480 minutes) to production capacity (80 kg). In the LCR approach, work elements are arranged in descending order of processing time and assigned to workstations accordingly. The number of workstations, idle time, and line efficiency were then calculated to evaluate production line performance. The implementation of LCR has been shown to improve line efficiency compared to the initial condition [13], [14].

3. RESULTS AND DISCUSSION

The green tea factory of PT X consists of seven main activities with a total floor area of 106.5 m², forming an integrated production flow that includes raw material storage, sortation 1, roasting, cooling, sortation 2, packaging, and final storage. This sequence reflects a systematically arranged production process, starting from raw material handling to finished product storage. Each stage performs a specific function, such as initial sorting to remove unsuitable materials, roasting to reduce moisture content and develop product characteristics, and secondary sorting for quality classification.

3.1. Analysis of the Current Condition of the Green Tea Factory at PT X

Despite the structured sequence of processes, the overall operational performance is highly influenced by the spatial arrangement of facilities and the closeness relationships among activities. Inappropriate facility placement may result in inefficient material flow, increased handling time, and reduced productivity. Therefore, an evaluation of the existing layout is necessary to identify potential inefficiencies and to provide a basis for improvement. Based on field observations, the current factory layout is presented in Figure 1.

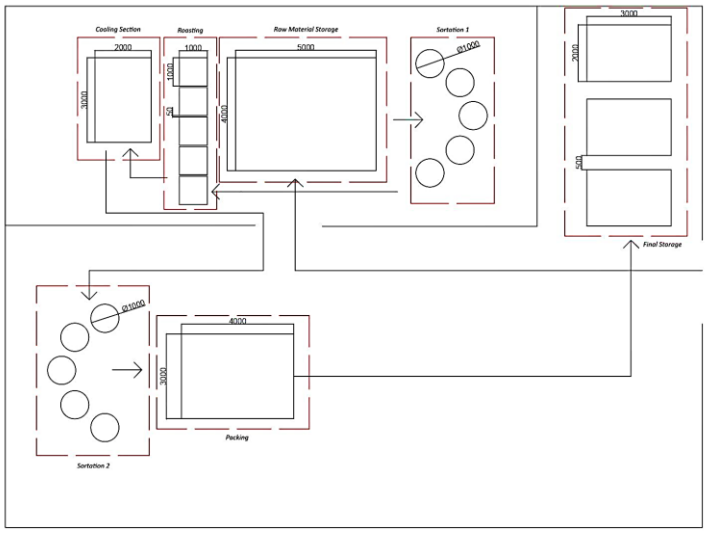


Figure 2. Current Layout of the Green Tea Factory at PT. X

Based on the current layout, the placement of production facilities has not fully considered the closeness relationships among activities, resulting in an inefficient production flow. The location of raw material storage in the middle of the production area leads to backtracking from the sorting process to roasting, thereby increasing material handling distance and processing time. In addition, the proximity and intersection of movement paths between sorting, processing, and storage areas may increase the risk of product contamination. Therefore, an analysis using the Activity Relationship Chart (ARC) is required to determine the degree of closeness among activities in order to develop a more efficient layout that also ensures product quality.

The current factory layout is evaluated using the ARC method, which is a qualitative approach for analyzing the closeness relationships among activities within a production system. This method is used to identify the importance level of relationships between work areas, providing a basis for designing a more optimal and efficient facility layout [4]. The ARC results for the current green tea production system at PT X are presented in Figure 2.

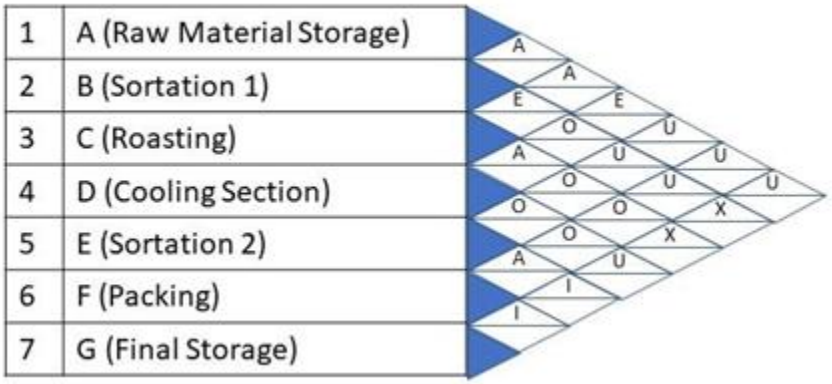


Figure 3. Current ARC of Green Tea Production at PT X

Based on the results of the current ARC development, the facility layout still indicates inappropriate and inefficient closeness relationships among work areas. This is reflected in the position of the raw material storage, which shows a high degree of closeness with several main processes such as sorting and roasting. From a production flow perspective, this condition does not align with proper layout design principles, as raw materials should ideally move in a linear sequence following the production process. Such inappropriate proximity may lead to backtracking, characterized by repetitive or non-directional material movement, which increases both travel distance and processing time.

In addition, the placement of raw material storage close to processing areas such as roasting may increase the risk of contamination and quality degradation. Unprocessed tea materials may be exposed to heat, dust, or residues from other processes, potentially affecting their quality before entering subsequent stages [6]. This condition indicates that the initial layout has not adequately considered the separation between clean areas and processing areas [16]. Therefore, an improved ARC is required to develop a more systematic layout that minimizes backtracking while maintaining the quality of green tea products. Following the analysis of closeness relationships among activities using ARC under the current conditions, an evaluation of production flow performance is carried out using a line balancing approach. This analysis aims to assess the distribution of workload across workstations and to identify potential idle time within the production system. By utilizing process time data for each activity and the predetermined production capacity, the current workstation configuration is obtained, as presented in Table 1. These results serve as the basis for evaluating production line efficiency and as a reference for developing improvement alternatives.

Table 1. Current Line Balancing Table

Stations	*Time Remaining*	*Eligible*	*Assign*	*Idle*
1	6		A	
	4	A		4
2	6		B	
	2	B		2
3	6		C	
	1	C		1
4	6		D	
	3	D		3
5	6		E	
	3	E		3
6	6		F	
	3	F		3
7	6		G	
	3	G		3
Total *Idle Time*				19

$$Idle\% = \frac{Total\ idle\ time}{Nmin\ \times Cycle\ time}$$
$$Idle\% = \frac{19}{42} = 0{,}45 = 45\%$$
$$Effective\% = 1 - 45\% = 55\% \quad (1)$$

Based on the calculations, the production line efficiency is relatively low at 55%, as indicated by a total idle time of 19 minutes per cycle. This suggests that the distribution of workload among workstations is not yet optimal and that inefficiencies still exist in the production flow. With an operating time of 480 minutes per day and a production target of 80 kg, the resulting cycle time is 6 minutes/kg, which should serve as the reference for balancing the production flow. Observations show that each workstation handles only a single activity (A–G), with idle time ranging from 1 to 4 minutes, reflecting an imbalance in workload distribution across stations. This condition is further influenced by a production flow pattern that is not yet arranged linearly, leading to potential backtracking in the form of repetitive or reverse material movement. Such movement increases handling time and contributes to higher idle time at several workstations.

Improving production flow efficiency can be achieved through the application of the line balancing method by redistributing work elements into workstations with total processing times close to the cycle time. Combining multiple work elements within a single workstation can serve as an alternative to reduce idle time and enhance operational effectiveness. Rearranging the facility layout is also necessary to support a one-directional production flow, thereby minimizing backtracking. The integration of improved workstation allocation and a more efficient production flow arrangement is expected to enhance production continuity and overall line efficiency. This approach is consistent with previous studies indicating that optimizing line balancing and designing an effective layout significantly contribute to improved production system performance [17], [18].

3.2. Analysis of ARC Alternatives and TCR Calculation

The results of the alternative ARC arrangement for the factory are presented in Figure 3.

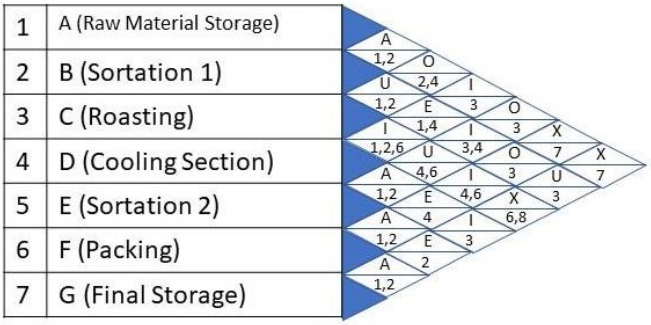


Figure 4. Alternative ARC of green tea production at PT X

Based on the Activity Relationship Chart (ARC) shown in Figure 3, the closeness rating among activities was determined according to production flow and functional relationships to optimize the facility layout. The undesirable relationship (code X) assigned between the roasting station and final storage was intended to prevent cross-contamination risks and operational disturbances that could reduce product quality. This approach is consistent with the principle of separating processing areas from storage areas in facility management [16].

Table 2. Alternative TCR Table

Activity	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**Calculation**	**TCR**
A		A	O	I	O	X	X	125+1+5+1+(-125)+(-125)	-118
B	A		U	E	I	O	U	125+0+25+5+!+0	156
C	O	U		I	U	I	X	1+0+5+0+5+(-125)	-114
D	I	E	I		A	E	I	5+25+5+125+25+5	190
E	O	I	U	A		A	E	1+5+0+125+125+25	281
F	X	O	I	E	A		A	(-125)+1+5+25+125+125	157
G	X	U	X	I	E	A		(-125)+0+(-125)+5+25+125	-95

Based on the Total Closeness Rating (TCR) calculation derived from the alternative ARC, differences in the level of proximity importance among activities can be identified. Activity E (Sortation 2) obtained the highest TCR value of 281, followed by Activity D (Cooling Section) with a value of 190, indicating that these two activities have the strongest relationships and should be prioritized in the facility layout design. Activities B (Sortation 1) and F (Packing) were classified in the medium category, suggesting that their closeness relationships are important but not the primary priority.

Activities A (Raw Material Storage), C (Roasting), and G (Final Storage) recorded negative TCR values, indicating relatively low or undesirable proximity relationships with other activities. This condition shows that, based on the alternative ARC, grouping activities with high TCR values should become the main consideration in determining the facility arrangement, while activities with lower values can be positioned more flexibly without disrupting the production flow. Therefore, the TCR analysis provides a quantitative basis for developing a more efficient facility layout with minimal backtracking potential.

3.3. Line Balancing Analysis

Based on the improved activity arrangement referring to the results of the ARC and TCR analyses, a recalculation of line balancing was conducted to obtain a more optimal workload distribution. With an operating time of 480 minutes per day and a production target of 80 kg, the cycle time was determined to be 6 minutes/kg. Furthermore, the minimum number of workstations was calculated by dividing the total processing time of all activities by the cycle time, resulting in a minimum requirement of four workstations, which served as the basis for allocating work elements into each station.

The results of the alternative line balancing calculation indicate a more efficient workstation distribution, as presented in Table 3.

Table 3. Alternative Line Balancing Table

Station	*Time Remaining*	*Eligible*	*Assign*	*Idle*
1	6	-	A, B	-
	4	A	B	-
	0	B	-	0
2	6	-	C	-
	1	-	-	1
3	6	-	D, E	-
	3	D	E	-
	0	E	-	0
4	6	-	F, G	-
	3	F	G	-
	0	G	-	0
Total *Idle Time*				1

$$\square\square\square\square\% = \frac{1}{24} = 0{,}0416 = 4\%$$

$$\square\square\square\square\square\square\square\square\square\% = 1 - 4\% = 96\% \quad (2)$$

Based on the results of the alternative line balancing calculation, the production flow performance showed a significant improvement, as indicated by the reduction of idle time to approximately 1 minute per work cycle (4%), resulting in a line efficiency of 96%. This value indicates that the workload distribution among workstations has reached a relatively optimal condition and approaches industrial efficiency standards. Previous studies have shown that the proper implementation of line balancing methods can increase line efficiency to a range of 85–98% while minimizing idle time [19]. The cycle time of 6 minutes/kg, used as the operational limit, enables each workstation to accommodate more than one work element, such as the combination of activities A–B, D–E, and F–G, thereby reducing time deviations from the cycle time. This condition reflects a well-balanced distribution of work elements and an improvement in operational effectiveness, as an optimal production flow balance can maximize resource utilization and reduce inefficiencies [20].

3.4. Analysis Results and Proposed Improvements

Based on the analytical results obtained through the application of the Activity Relationship Chart (ARC), Total Closeness Rating (TCR), and line balancing methods, a comprehensive overview was established regarding the closeness relationships among activities, the priority placement of production facilities, and the level of production flow efficiency at the green tea processing plant of PT. X. These findings subsequently served as the foundation for formulating proposed improvements to the production facility layout.

The restructuring of the production flow contributed significantly to enhancing the continuity of material movement between activities. The reduction in idle time resulted in a more continuous and stable production flow, while the systematic reorganization of work sequences effectively minimized backtracking activities, thereby yielding a substantial overall improvement in production flow efficiency. These findings are consistent with previous studies indicating that line balancing not only influences time efficiency but also contributes to production flow continuity and the reduction of process bottlenecks [13]. Overall, the integration of the ARC, TCR, and line balancing methods demonstrated a strong capability to improve the performance of the production system comprehensively, including aspects of time efficiency, workload balance, and production flow continuity. This integrated approach supports the development of a more effective, stable, and productive manufacturing system.

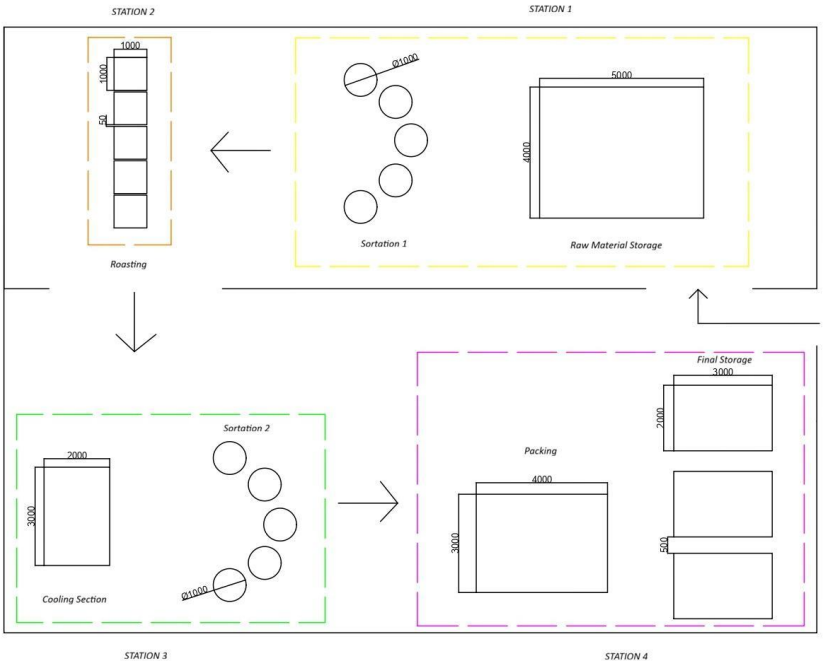


Figure 5. Alternative layout for green tea production at PT X

The proposed facility layout was developed by considering the estimated dimensions of the existing production area (approximately 17.30 m × 7.55 m). The proposed redesign does not involve any changes to the number or physical dimensions of the existing production machines; instead, it only rearranges the positions of the existing machines according to the activity relationships and production sequence identified through the Activity Relationship Chart (ARC) and Total Closeness Rating (TCR) analyses. As a result, the proposed layout is considered practically feasible for implementation within the available production area without requiring additional production space. It should be noted that the production area dimensions presented in this study are estimated because detailed architectural drawings of the factory were unavailable.

To evaluate the effectiveness of the proposed layout, its production flow performance was compared with the existing layout. Based on the previous analysis, the existing layout shows a line efficiency of 55% with a total idle time of 19 minutes per cycle, indicating an imbalance in workload distribution and suboptimal material flow. In addition, the non-linear flow pattern in the initial layout caused backtracking and extended material transfer paths. In contrast, the alternative layout developed based on the Activity Relationship Chart (ARC) and supported by line balancing improvements demonstrates a significant increase in line efficiency, reaching 96%, with idle time reduced to approximately 1 minute per cycle. With the same production capacity, this improvement indicates that the production flow has become more efficient, more directed, and minimally obstructed. The arrangement of facilities according to the process sequence, while also considering the closeness relationships among activities, further contributes to reducing unnecessary movement and improving overall process fluidity. Therefore, compared to the actual layout, the proposed alternative layout has proven to be more effective in enhancing the overall performance of the production system.

Overall, the proposed layout represents an improved alternative, as it integrates the quantitative results obtained from the Activity Relationship Chart (ARC), Total Closeness Rating (TCR), and line balancing analyses

to achieve a more efficient production flow. The proposed design improves line efficiency, reduces idle time, and minimizes backtracking while maintaining compatibility with the existing production area. These findings demonstrate that the integrated application of ARC, TCR, and line balancing provides an effective approach for improving production facility layouts. This result is consistent with the principles of modern facility layout design, which emphasize the optimization of material flow and operational efficiency [21].

4. CONCLUSION

This study successfully achieved its objective of evaluating and improving the production facility layout of the green tea processing line at Factory X through the integration of Activity Relationship Chart (ARC), Total Closeness Rating (TCR), and line balancing. The proposed facility layout reduced backtracking, decreased total idle time from 19 minutes to 1 minute per production cycle, and increased line efficiency from 55% to 96%, demonstrating significant improvements in both spatial and operational performance. The integration of ARC, TCR, and line balancing constitutes the primary scientific contribution of this study by providing a unified evaluation framework that simultaneously considers facility layout optimization and production line performance. Unlike previous studies that primarily focus on either spatial layout design or operational efficiency, the proposed approach provides a more comprehensive basis for improving production systems in green tea processing industries. From a practical perspective, the redesigned layout enables smoother material flow, more balanced workstation utilization, and has the potential to improve production continuity and support higher daily production capacity without requiring additional production space or structural modifications. Future studies are recommended to implement the proposed facility layout under actual industrial conditions and evaluate its long-term impact on production capacity, material handling costs, operator productivity, and overall manufacturing performance.

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