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Application of Simulation Technique for Improving Plant Layout in Ceramic Factory

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Abstract

This study aims to design and improve the plant layout of a ceramic factory by adopting Systematic Layout Planning (SLP) and the simulation technique. A ceramic company in northern Thailand is selected as a case study. Three ceramic products including roof tiles, wall tiles and dishware are studied due to their highest production volume. Through the SLP approach, information regarding the number of departments and machines, the area of the plant, the frequency of movement and the distance between each department is collected for the analysis of the relationship between departments. Two plant layout designs are then proposed; the first one is derived from the Computerized Relationship Layout Planning algorithm (CORELAP), and the second one is the process layout. For selecting the most appropriate layout design, five criteria are considered including total distance, the average total process time of each unit produced, ease of movement, material flow and safety. To determine the distance and the average total process time per unit, Distance-Based Scoring and simulation techniques are conducted while the ease of movement, material flow and safety are rated based on whether the company satisfies each criterion. Employing the weight scoring technique, the results report that the CORELAP layout is the most suitable for further implementation due to its highest weighted score equal to 2.536 while the process layout receives 2.386. Implementing the CORELAP layout can reduce the total distance by 16.76% while the average total process time per unit of the CORELAP layout is not significantly different at the significance level of 0.05 as compared to the existing layout.

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1. Introduction

Ceramic products are diversely utilized in several forms including sanitary ware, electrical insulators, tiles, kitchenware, and tableware (Meena et al., 2022). With a vast array of colours, designs, and applications available, competition in the ceramic industry has become increasingly intense, particularly in Thailand where the main manufacturers are based.As per Rattanawiboonsom's (2022) research, Thailand held the second-largest market share for ceramic products in 2019, and the country's ceramic industry is expected to experience a growth trend due to the rise in domestic demand and increased production volumes for the domestic market. However, the ceramic industry in Thailand has been affected by such countries as China which offers the products to the low-end market (Rattanawiboonsom, 2022). To remain competitive in the face of both domestic and international rivals, Thai ceramic companies must identify customer perceptions in order to improve their product designs.(Kittidecha and Yamada, 2018).

Although the manufacturing and technology used in the ceramic industry are quite mature, such disruptions as the global pandemic and climate change may adversely affect the supply chains resulting in the lack of raw materials, interrupted production, insufficient inventory, and late delivery (Furrer et al., 2022). Therefore, in addition to product development, ceramic manufacturers must reduce manufacturing costs and lead times in order to prepare for unforeseen events.. One of the key techniques is an improvement of the facility layout (Romano et al., 2022).

A ceramic company in northern Thailand is selected as a case study of this research. It is a small and medium-sized enterprise (SME) that produces a wide range of ceramic products and most of the production processes are semi-auto, similar to most of the ceramic companies in Thailand. The company is currently facing unprecedented demand, especially when the orders exceed its production capacity which causes a delay in production and delivery. In addition, the plant layout is unsuitable as the items are not stored properly resulting in an increase in sorting time and safety problems. In defining the research scope, roof tiles, wall tiles, and dishware are selected for the study due to the highest production volumes.

The objective of this study is to improve the plant layout of the ceramic factory by employing Systematic Layout Planning (SLP) together with the simulation technique. This study contributes to prior literature by demonstrating the beneficial interplay between the two techniques, where the SLP focuses on distance and the simulation provides information about the process time and incorporates many uncertainties in the model. Despite being introduced in several contexts, this method is not well addressed in the context of the ceramic industry which most of the resources and machines are shared for a wide range of products. In addition to quantitative criteria such as distance and processing time, this research introduces additional qualitative criteria including safety, ease of movement, and material flow for the evaluation of the plant layouts which are used for the evaluation employing the scoring techniques. Importantly, this research accentuates the need for adopting both quantitative and qualitative criteria and multiple techniques when designing or selecting plant layouts.

2. Literature review

As introduced by Muther (1961), Systematic Layout Planning (SLP) is a systematic and structured approach that helps to minimize the material flow while considering the relationship between the rooms, the need for space, and available space. It has also been one of the most frequently used methods for designing a facility layout (Naqvi et al., 2016). The SLP consists of three important phases: data collection and analysis, proposing the layout designs, and the evaluation of the layout designs. The guideline for conducting the SLP proposed (Tompkins et al., 2010) is presented in Fig. 1.

Despite having the final layout design, implementing the layout can be costly and time-consuming. Therefore, the simulation technique is often applied for modeling a real-world system prior to actual implementation (Boonmee and Kasemset, 2019). The simulation also allows for testing various scenarios, finding bottlenecks, and improving manufacturing performance (Zahree et al., 2014).

As evidenced by previous research, the SLP and the simulation technique are conducted together. For instance, Liu et al. (2018) applied the SLP and proposed layout alternatives for Liquid Crystal Display (LCD) production which were then evaluated by the discrete-event simulation (Liu et al., 2018). Suhardi et al. (2019) used the ARENA simulation software to select the best layout of the garment factory with the minimum total material handling costs. Padilla et al. (2021) used the SLP and the simulation for developing the logistics management model for enhancing the service level. Recently, Boonmee et al. (2022) have employed the simulation technique to evaluate the efficiencies of plant layout designs in the healthcare industry. Despite being adopted by previous research, this method is still under-researched in the context of the ceramic industry which its characteristic includes sharing resources among various products, fixed machines such as kilns, and fragile products.

In light of the above literature review, this study, hence, adopts the SLP and the simulation techniques for proposing plant layout designs for the ceramic company.

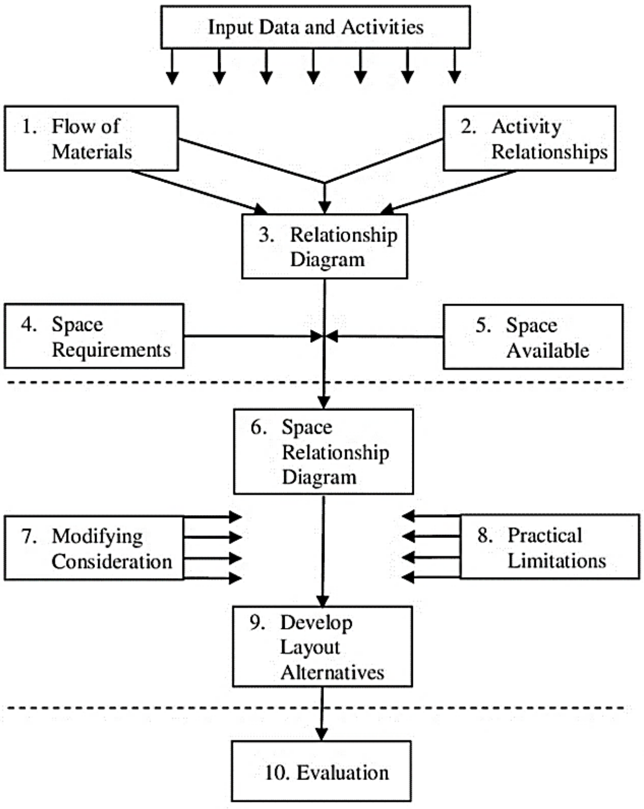

Fig. 1. Guideline for implementing the SLP (Tompkins et al., 2010)

3. Methods

3.1. Data collection

This research first selected a ceramic company in northern Thailand as a case study since it encountered uncertain demand, and, therefore, needed to reduce the production time and improve the plant layout efficiency. Given a wide range of products, this study focused on roof tiles, wall tiles, and dishware due to the highest total production volume. The manufacturing processes were studied and presented in Fig. 2.

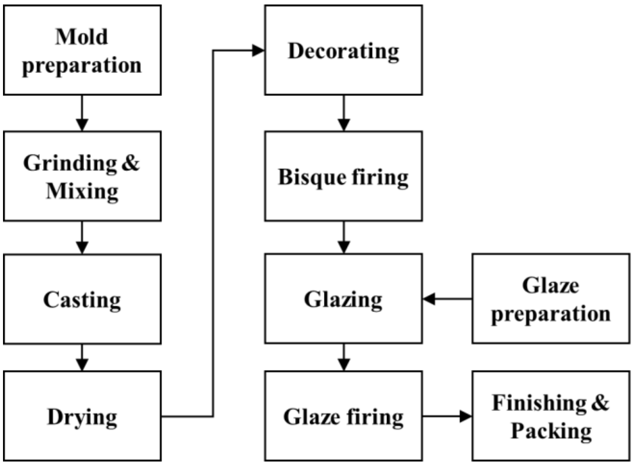

Fig. 2. Manufacturing processes of ceramic products

The data relevant to the number and locations of the machines and the size of the area were collected as shown in Table 1. The existing layout of this company (meter: *m*) was illustrated in Fig. 3.

Table 1. Departments and machines

No.	Departments	Number of Machines	Area (m^2)
1	Glazing machine	4	1.87
2	Glaze mixer	1	2.00
3	Storage (after bisque firing)	3	40.80
4	Casting machine	1	1.28
5	Mold storage	1	35.49
6	Extruding machine	2	6.50
7	Decoration area	1	24.00
8	Grinding machine	2	8.00
9	Glazing area	1	82.00
10	Kiln (before glazing)	1	6.25
11	Drying area	1	142.20
12	Kiln (after glazing)	2	12.50
13	Packing area	1	68.44
14	Warehouse	1	14.56

The flow process chart for each product was established to help understand and break down the key processes in Fig. 2. into sub-processes. Next, the time of each sub-process and the distance between each department were gathered with a sample size of 50 which was adequately large for being an input in the simulation software.

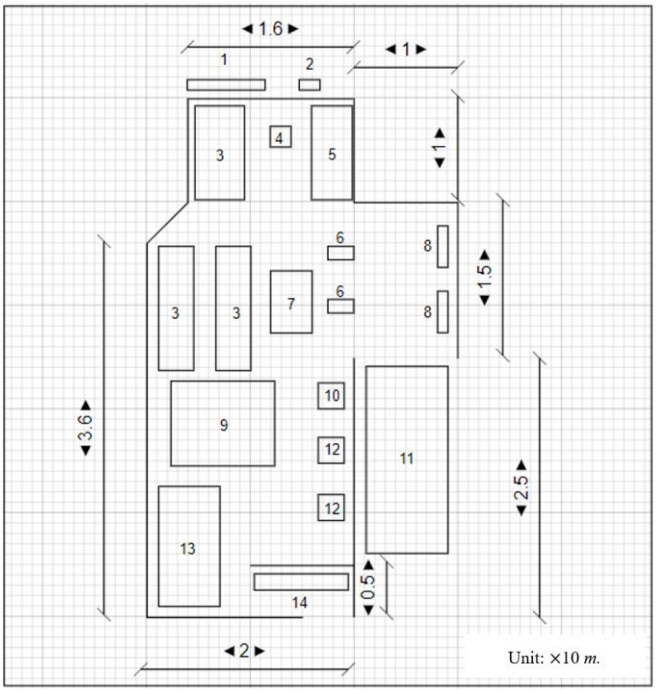

Fig. 3. Existing plant layout

3.2. Assessment of the relationship and closeness

In this step, the SLP technique was performed by investigating the relationship between every pair of departments. The frequency of movements was then translated into the relationship based on the criteria in Table 2 and denoted by Latin letters.. All relationships had their closeness rating ranging from -10,000 to 10,000. The closeness rating presented the degree of importance between each department. For example, if there were more than 22 movements between departments A and B, the relationship between these two departments would be classified as Absolute Necessary (A) and received a closeness rating of 10,000. Finally, the Total Closeness Rating (TCR) of each department was defined as the sum of the values of the relationships with other departments.

Table 2. Relationship and closeness criteria

Symbol	Relationship	Frequency	Closeness Rating
A	Absolute Necessary	> 22	10.000
E	Especially Important	18 – 22	1.000
I	Important	11 – 17	100
O	Ordinary	1 – 10	10
U	Unimportant	0	0
X	Undesirable	< 0	-10.000

3.3. Proposing layout designs

To purpose the plant layout, Computerized Relationship Layout Planning (CORELAP) was performed. The CORELAP is the constructive algorithm using the TCRs for selecting and placing departments in the new blank layout space. For instance, if department 12 received the highest TCR and therefore, was first placed in the center (location 0). Next, if department 9 had the second-highest TCR, it would be placed next to department 12. Performing this procedure, the placement proceeded until all departments were in place, resulting in the CORELAP layout. However, it should be noted that one important limitation in designing the layout was that the kilns (departments 9 and 12) were fixed and therefore, the proposed layout should be designed in accordance with the current condition of this company. In addition, to evaluate the CORELAP layout, the process layout was also proposed.

3.4. Simulation

This study used the Arena software for the simulation. The *performance measure* of the model was the average total process time per unit. The objective of the simulation was to define the most appropriate layout with the minimum average total process time per unit. The *variables* for the simulation model were the production ratio of each product in October 2021, the process time for each process and the time for transferring products between departments. Since the process time for each process was stochastic, its probability distribution would be determined.

This step started with defining the basic assumption of the model defined as follows.

- Assuming that materials such as molds and colors were ready.
- Ignoring the drying and firing processes since all products were processed as a whole and the processing time was the same regardless of the amount of the products.
- Continuous flow of the products after the drying and firing processes, i.e., no interruption.
- One worker per machine.

The *resources* consisted of 17 workers (13 movers and 5 operators working in the departments). To develop the simulation model, there were several steps as follows.

The first step was defining the distribution of the data by inputting the time data into the Input Analyzer function of the Arena software. Second, the *entity* called 'Create Dirt' was created. For *the arrival pattern*, the dirt came to the system as a lot size of 125 units for every hour. The lot was then moved to the grinding process (Process Move Dirt). Next, a batch of 50 units was created for grinding and mixing (Batch Move to Dirt I). After that, a batch of 50 units was separated into 50 single units (Separate to Dirt). This process was presented in Fig. 4.

Next, each dirt was assigned to different products using Decide module (Decide To Product). Based on the data of production volume, the percentage of production for roof tile, wall tile, and crockery was 29%, 43%, and 28%, respectively. For each Assign module, it consisted of several attributes including the product type (e.g., 1, 2, and 3) and the time for decoration, glazing, and packing. The model of this step was presented in Fig. 5.

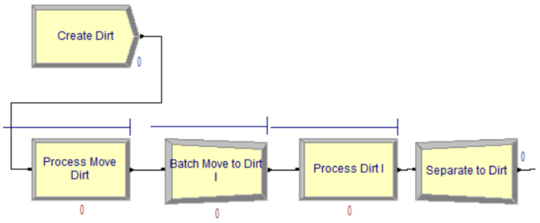

Fig. 4. Creating the entity

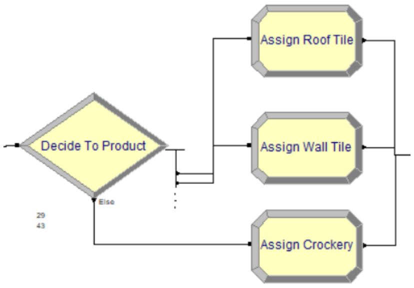

Fig. 5. Assigning the product type

The Assign module determines which entity should be sent to the production processes, from casting to packing, through the Decide model (Decide Process). The complete simulation model was shown in Fig. 6.

To satisfy the model adequacy, the number of replications (n) must be defined to yield the acceptable average error value of 0.5. The number of replications was randomly selected and the half width of the confidence interval was determined. Next, the average error was calculated by dividing the half width by the average process time per unit. After that, the appropriate number of replications was determined by using Equation (1)

$$n = n_0 \frac{h_0^2}{h^2} \tag{1}$$

Where n is the appropriate number of replications, n_0 is the initial number of replications, h is the desired half width and h_0 is the half width from the initial trial.

3.5. Evaluation of the layout designs

To evaluate the layouts based on the results from the simulation, first, the existing layout and the CORELAP layout were compared by performing the two-sample t-test. The significance level used for this research was 0.05 which has been conventionally accepted as the threshold to discriminate significant from non-significant results (Di Leo and Sardanelli 2020).

Depart from the quantitative approach which time and distance were considered, the qualitative approach was then conducted. To evaluate the layout designs, there were five criteria to be considered: distance, total process time, ease of movement, material flow, and safety. For the distance, this research adopted Distance-Based Scoring to define the total distance of each layout. In particular, the distance scores between every pair of departments were defined by multiplying the distance and frequency. Total process time could be obtained from the simulation outputs. Criteria for ease of movement, material flow, and safety were shown in Table 3.

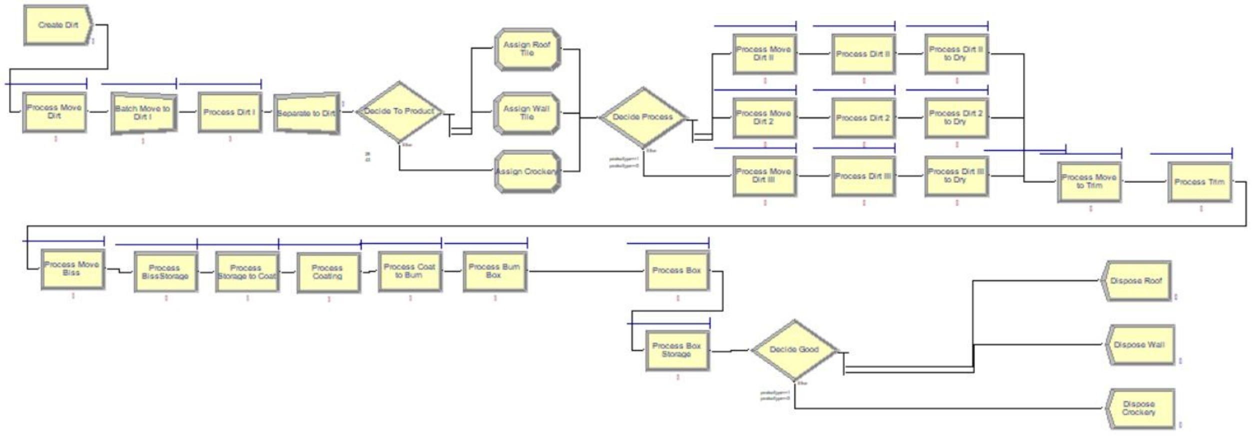

Fig. 6. Simulation model

Table 3. Criteria for ease of movement, material flow, and safety

Criteria	Sub-criteria
1. Ease of movement	a. machines or departments can be moved easily.
	b. operators can move to any department easily.
	c. material and products can be moved easily.
2. Material flow	a. material flow is not complicated.
	b. material and products can be transferred effectively.
	c. material flow is sufficiently flexible.
3. Safety	a. the positions of the machine are safe for operators and assets.
	b. the locations of the department do not damage the products.
	c. the positions of the machine are not too dense.

Since all criteria were not equally important, the Rank Order Centroid (ROC) was employed for assigning the weight to each criterion (Barron and Barrett, 1996). First, the company's top management, staff, and researchers together ranked the criteria based on how they were important for the selection of the plant layout. Next, the ROC weight of each criterion was calculated using Equation (2).

$$W_i = \frac{1}{M}\sum_{n=i}^{M}\frac{1}{n} \qquad (2)$$

Where n is the rank of criterion, M is the number of criteria and W_i is the weight for the ith criterion.

The next step was to evaluate the proposed layouts based on the *total weighted score,* which was the average of criterion scores, where each criterion carried a different amount of importance (i.e., weight). To perform this, first, for each layout, each criterion was assessed and received a *score* ranging from 1 to 4. The score represented the degree of preference of each criterion; the higher score, the better. The score could be obtained from Table 4 and Table 5.

Table 4. The score for the distance and the average total process time in the system per unit

Score	Explanation
4	Lowest among all layouts
3	Lower than the existing layout
2	Not different from the existing layout
1	Higher than the existing layout

Table 5. The score for ease of movement, the flow of material, and safety

Score	Explanation
4	All sub-criteria are satisfied
3	Only two sub-criteria are satisfied
2	Only one sub-criterion is satisfied
1	All sub-criteria are not satisfied

Next, the score of each criterion was then multiplied by its associated weight yielding *the weighted score* as shown in Equation (3).

$$\hat{W}_{ij} = S_{ij} \times W_i \qquad (3)$$

Where $\hat{W}_{ij}$ is the weight score for *i*th criterion and *j*th layout, S_{ij} is the score of *i*th criterion and *j*th layout, and W_i is the weight for the *i*th criterion.

Finally, the *total weighted score* of each layout was determined by summing all weighted scores. The layout with the maximum total weighted score would be selected as the most appropriate one.

4. Results and discussion

After assessing the relationships, a diagram was developed to display the importance of adjacency among departments, as presented in Figure 7. The results reported that departments 9 and 12, and departments 12 and 13 should be located next to each other.

Next, the relationship – the Latin letters – in each pair of departments was converted into the closeness rating based on the criteria in Table 2. For example, focusing on department 1, the relationship between department 1 and department 2 and between department 1 and department 9 was ordinary (O), receiving the closeness value of 10, while the relationship of the other pairs was unimportant (U), receiving the closeness value of 0. Hence, TCR was calculated by multiplying 10 with 2 yielding the TCR of department 1 equal to 20. The total closeness rating (TCR) of each department was presented in Fig. 8

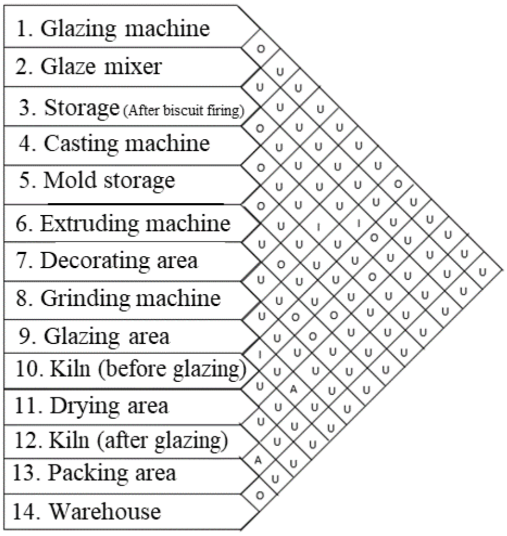

Fig. 7. Relationship diagram and closeness.

From to	Station														Relationship						TCRs
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	A	E	I	O	U	X	
1		O	U	U	U	U	U	U	O	U	U	U	U	U	0	0	0	2	11	0	20
2	O		U	U	U	U	U	U	U	U	U	U	U	U	0	0	0	1	12	0	10
3	U	U		O	U	U	U	U	I	O	U	U	U	U	0	0	1	2	10	0	120
4	U	U	O		O	U	U	I	U	U	O	U	U	U	0	0	1	3	9	0	130
5	U	U	U	O		O	U	U	U	U	U	U	U	U	0	0	0	2	11	0	20
6	U	U	U	U	O		U	O	U	U	O	U	U	U	0	0	0	3	10	0	30
7	U	U	U	U	U	U		U	U	O	O	U	U	U	0	0	0	2	11	0	20
8	U	U	U	I	U	O	U		U	U	U	U	U	U	0	0	1	1	11	0	110
9	O	U	I	U	U	U	U	U		U	U	A	U	U	1	0	1	1	9	0	10,110
10	U	U	O	U	U	U	O	U	U		U	U	U	U	0	0	0	2	10	0	20
11	U	U	U	O	U	O	O	U	U	U		U	U	U	0	0	3	0	10	0	30
12	U	U	U	U	U	U	U	U	A	U	U		A	U	2	0	0	0	11	0	20,000
13	U	U	U	U	U	U	U	U	U	U	U	A		O	1	0	0	1	11	0	10,010
14	U	U	U	U	U	U	U	U	U	U	U	U	O		0	0	0	1	12	0	10

Fig. 8. Total closeness ratings

Clearly, department 12 (Kiln - after glazing) had the highest TCR which would be placed in the layout first. On the other hand, the departments with the smallest TCR would be placed in the layout last while the departments with zero TCR would be eliminated from the layout. Finally, the allocation of departments was shown in Fig. 9 and the layout design derived from the CORELAP algorithm was presented in Fig. 10.

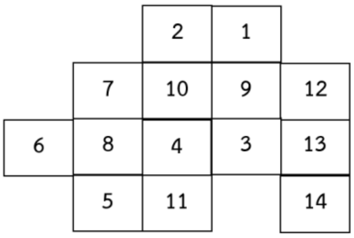

Fig. 9. The allocation of the departments from the CORELAP algorithm

However, given that the products were made-to-order and highly heterogeneous in terms of application and designs, the process layout was developed for comparison. The process layout was considered as an appropriate alternative to the CORELAP layout as most of the manufacturing processes for ceramic products were similar. Fig. 11 presented the process layout. It should also be noticed that for all proposed layouts, kilns (departments 9 and 12) were fixed and, therefore, placed in the original position.

Additionally, the simulation model of the existing layout was established with 60 replications yielding an error of 5% and acceptable half width. The two-sample t-test was performed to compare the results between the simulation model and the existing model. The statistical comparison between the actual time and the time from the simulation model yielded *p*-values of 0.595, 0.993, and 0.986 for roof tile, wall tile, and crockery, respectively, which were less than 0.05. Hence, this indicated that there were no significant differences between the results from the simulation and the actual data. The results from the simulation were thus appropriate for further decision-making.

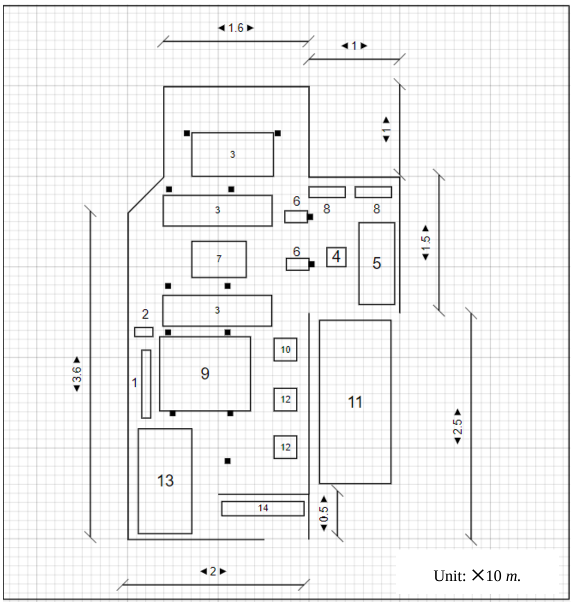

Fig. 10. Plant layout from CORELAP algorithm

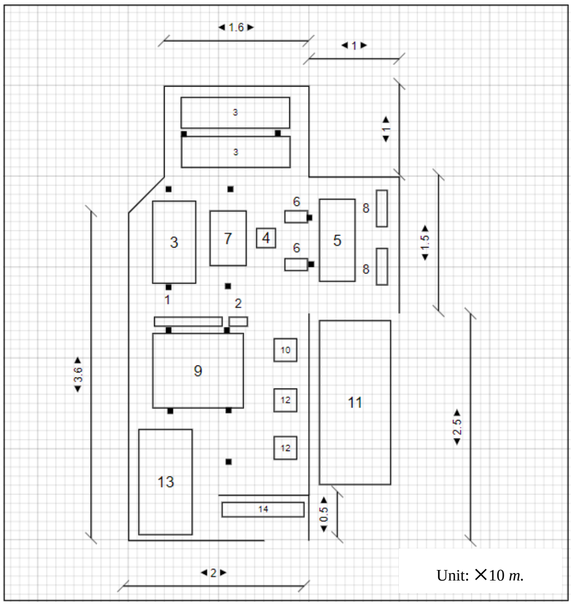

Fig. 11. Process layout

Table 6. Distance and average total process time per unit of each layout design

Layout design	Total distance (*meter*)	Average total process time per unit (*second*)
Existing layout	3,327.00	312.791
CORELAP	2,769.44	309.987
Process Layout	3,168.97	326.537

Table 6 reported that the CORELAP layout had the lowest total distance and average total process time per unit when compared with the existing layout and the process layout. However, although the average total process time per unit of the CORELAP layout was lower than that of the process layout, Fig. 12 presented that it was not statistically different at the significance level of 0.05 when compared with the existing layout. Therefore, additional criteria (e.g., ease of movement, the flow of materials, and safety) should be considered for the evaluation.

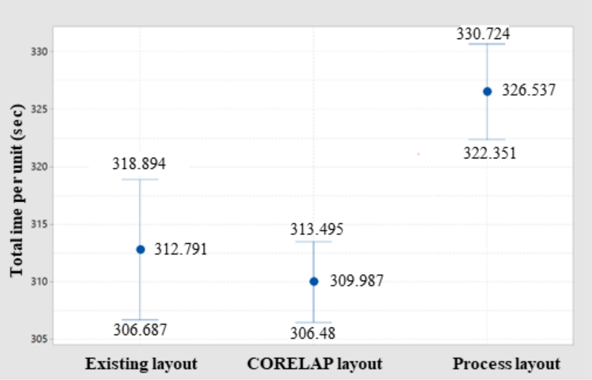

Fig. 12. The 95% confidence intervals of total process time per unit

Table 7. Weighted score for layout selection

Criteria	Weight	Score / Weighted score	
		CORELAP layout	Process layout
1. Process time per unit	0.457	2 0.914	1 0.457
2. Safety	0.257	2 0.514	4 1.028
3. Distance	0.157	4 0.628	3 0.471
4. Material flow	0.090	4 0.360	3 0.270
5. Ease of movement	0.040	3 0.120	4 0.160
Total weighted score		2.536	2.386

Table 7 reported that for the weight, the process time per unit was the most important criterion (0.457) followed by safety (0.257) and distance (0.157), respectively. This indicated that both quantitative and qualitative criteria were important for the evaluation of the plant layout.

In the score/weighted score column, the upper-left corner of the cell represents the *score* of each criterion based on Table 4 and Table 5. The results reported that the strength of the CORELAP layout was from the distance and material flow receiving the maximum score followed by the east of movement. However, the process layout was better in all criteria except the process time per unit compared with the CORELAP layout. Specifically, it received the maximum score for safety and ease of movement.

The figures in the lower-right corner of each cell were the weighted score obtained by multiplying weight with the score of each criterion by using Equation (3). As shown in Table 7, the CORELAP layout was selected as the most appropriate layout due to a higher total weighted score (2.536) than the process layout (2.386). Specifically, the CORELAP was better than the process layout in all criteria except the ease of movement.

5. Summary and conclusion

The following research focused on an improvement of the plant layout for a ceramic company in the northern part of Thailand by adopting the Systematic Layout Planning and simulation technique. Roof tile, wall tile, and dishware were the focus due to the highest production volume. Given the analysis of the relationship between departments, there were two proposed layouts; one was the CORELAP algorithm and another was the process layout. The simulation models via the ARENA software were developed for determining the average total process time per unit for each layout design.

Compared with the existing layout, the total distance from the CORELAP layout was reduced by 16.76%. The average total process time per unit of the CORELAP layout was lower than that of the process layout but was not significantly different from the existing layout at the significance level of 0.05. Hence, ease of movement, the flow of material, and safety was considered in addition to the distance and the average total process time per unit. The results from the scoring technique indicated that the CORELAP layout was the most suitable for future implementation given the highest weighted score. However, since the scores of both layout designs were not significantly different, this research suggested that the selection of the layout for this case should be based on the policy of the company. For example, if safety is the main priority, the company may choose the process layout given the highest preference score in terms of safety.

The key contribution was that this study was among a few attempts that applied the SLP and the simulation in the context of the ceramic industry. This study demonstrated that to re-layout the ceramic plant may not significantly reduce the average total process time per unit. This might be because of the nature of the ceramic factory which some departments such as kilns, drying, and packing areas could not be moved. However, despite those fixed departments, the plant manager might consider the departments that had a strong relationship with each other such as the warehouse and packing departments, and then move them to be close to each other to improve the material flow and alleviate safety issues. Furthermore, this research illustrated that introducing several criteria, both quantitative and qualitative, could enhance the evaluation of the plant layout design. Importantly, the suitable plant layout of the ceramic company should provide not only the lowest process time per unit and total distance but also a safe working environment. Additionally, the selected company can appropriately represent the ceramic industry in Thailand, the findings from this study can be generalized to other countries and industries, especially those which are associated with fragile products such as glass as well as sharing and fixed machines.

Acknowledgements

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在陶瓷工厂中，模拟技术的应用可以用于改进工厂布局。

關鍵詞
工厂布局
系统布局规划CORELAP
SLP
模拟

摘要

本研究旨在采用系统化布局规划（SLP）和模拟技术，设计和改进陶瓷工厂的厂区布局。选取泰国北部的一家陶瓷公司作为案例研究对象。由于生产量最高，研究了三种陶瓷产品，包括屋顶瓦、墙砖和餐具。通过SLP方法，收集有关部门和机器数量、工厂面积、移动频率和每个部门之间的距离信息，以分析部门之间的关系。然后提出两种厂区布局设计；第一种设计来自计算机化关系布局规划算法（CORELAP），第二种是流程布局。为选择最适合的布局设计，考虑了五个标准，包括总距离、每个单位的平均总过程时间、移动方便性、物料流动和安全性。为确定每个单位的距离和平均总过程时间，采用基于距离的评分和模拟技术进行，而移动方便性、物料流动和安全性则基于公司是否符合每个标准进行评分。采用加权评分技术，结果显示，CORELAP布局是最适合进一步实施的，因为其加权得分最高，为2.536，而流程布局得分为2.386。实施CORELAP布局可以将总距离减少16.76%，而CORELAP布局每个单位的平均总过程时间与现有布局在0.05的显著性水平下没有显著差异。