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Integrating systematic layout planning and fuzzy analytic hierarchy process in the design of sorting and packing fresh fruit facilities: A case study in Thailand

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Abstract

The aim of this study was to contribute to the sustainable development of small and medium-sized Thai fruit exporters who face challenges in business expansion due to limitations in the operational systems of their packing houses, which represent a critical unit in the fruit supply chain. The research had three objectives. The first is to develop a layout that is aligned with the business conditions of the case study entity, with a focus on efficient space utilisation and the incorporation of movement and sorting technologies guided by Muther's systematic layout planning principles. The second involves establishing criteria for selecting operational layouts for agro-businesses, based on the application of supply chain principles that emphasise operational efficiency, food production hygiene, and worker safety. These criteria were developed through a combination of literature review and expert input from agro-industry professionals and engineering academics, within the framework of the SCOR model. The final objective was to evaluate and select the developed layouts using MCDM methods. The results indicated that the requirements for a production system can be divided into export-oriented products, which demand more resource-intensive processes, and products for domestic auction markets. Activities were categorised into two types, processing and storage, and comprised seven activities, which were analysed to develop four distinct layout designs based on differences in input-output flow, production processes, and equipment positioning. Of the criteria considered for layout selection, the highest priorities for organisational management were efficient movement and maintenance (20.03%), effective space utilisation (19.93%) and non-overlapping flow directions (16.1%). Ultimately, the third layout alternative was selected at 30.40%, as it scored the highest on movement efficiency, and featured no overlapping transfer points, optimal space allocation, and minimal waste of space.

Keywords: Systematic layout planning, Fuzzy analytic hierarchy process, Agri-Businesses, Good manufacturing practices

1. Introduction

Thailand is a well-known tropical fruit harvesting area, due to its suitable climate, and durian, mangosteen, and rambutan fruits are among the important exports, with production bases located in the eastern part of Thailand. Over the last five years, exports of these fruits have totalled about sixteen thousand million baht per year [1], with the main export markets being China, the ASEAN countries, and Hong Kong. Farmers are increasingly confronted with significant challenges in complying with Good Agricultural Practices (GAP standards), alongside risks posed by weather conditions affecting crop yields, market mechanisms influencing farmgate prices, labour management complexities, and limited access to financing for acquiring tools and machinery. There is a tendency for farmers to choose to grow alternative plants which provide higher profits [2, 3]. In order to improve sustainability in agriculture, the government has developed a system that groups together farmers who produce agri-products, enabling them to work together through an area-based approach [4, 5].

We consider a case study based on one of the community enterprises in Thailand, which produces high-quality mangosteen, sorts and grades them, and sells them through the auction system to exporters and middlemen. At present, the operators have a policy that aims to increase work efficiency by using a sorting machine and conveyor belt system as well as determining goals for packaging produce, loading it into containers, and sales. As a result, improvements in the work space need to be implemented in order to follow the process of Good Manufacturing Practice (GMP), a system that supports the international food production standards [6]. The main limitations of the case study, in which it differs from other house packaging operators, are the size of the work space and the closed building, which can limit the directions of product flow.

Layout design in the industrial sector has been significantly developed by incorporating engineering principles into the design process and systematically using diverse criteria for evaluation. However, in the agricultural sector, and particularly in agricultural packing houses, , the application of engineering principles to enhance operational efficiency remains limited; for instance, the systematic layout planning (SLP) is underutilized in designing activity and workflow layouts, and multi-criteria decision making (MCDM) methods are seldom employed to facilitate more accurate decision-making processes. These evaluations should encompass both quantitative factors, such as distance and time, and qualitative factors, such as operational convenience, product flow direction, and flexibility for future expansion.

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The absence of these diverse and appropriate evaluation criteria, which can enhance operational efficiency, represents a major weakness in the agricultural sector. In our case study involving a fruit packing house, this problem is clearly reflected. Currently, most workflow layouts in fruit export packing houses are not extensively designed with consideration of engineering principles. Instead, they are primarily based on the personal opinions of management, leading to various issues, such as: overlapping movement routes and resulting in delays in operations. Hence, the improvement in the layout of the packing house is carried out under specific constraints, including a limited working area between two buildings, which affects the flow characteristics of the products, the movement of products within the enclosed building, and the requirement to redesign the operational layout to comply with the seven GMP standards: (i) establishment, (ii) control of operations, (iii) maintenance and sanitation, (iv) personal hygiene, (v) transportation, (vi) labelling, and (vii) training [7]. We address this research gap by conducting an in-depth study and developing new methods that respond to the issue whereby an agri-product packing house layout must be designed according to engineering principles, and analyse various factors to obtain appropriate criteria that are in line with GMP principles. Van Donk and Gaalman [8] have stated that the development of food production plant layout guidelines that emphasise hygiene management and standard practices will reduce the risk of contamination and support the production process in terms of quality, according to international standards.

2. Background

2.1 Review of the SLP principle and industry implementations of layout design

The aim of layout design is to manage work areas, equipment and processes within a factory or work area with appropriate levels of efficiency, safety and resource utilisation [9]. An effective layout design will help to maintain a continuous flow of materials and information, thereby reducing waste, increasing flexibility to adapt to future changes, and supporting operations carried out to meet international standards. Layout design also plays an important role in reducing costs and increasing efficiency, including meeting the product standards of the industrial and agricultural sectors. Previous studies have divided layout design into two main approaches: greenfield design, which involves creating entirely new layouts, and re-layout design, which focuses on improving existing layouts to address deficiencies and enhance performance [10-12].

Layout design is a widely adopted process that is used to optimise space and processes for maximum efficiency. Many industries apply this approach to meet demands for quality, safety, and cost-effectiveness. For instance, in the agricultural sector, which encompasses diverse products and processes, layout design is used to achieve various improvements. These include enhancing agricultural production processes to reduce operational waste, minimising contamination from the environment, optimising space utilisation, and improving capacity with the current workforce [13-15]. In addition, the design of agricultural distribution centres must consider the diversity of stored and transported products, such as fruits, vegetables, and meat [16]. Integrated agricultural land management, which combines various activities within a single area, is another domain of application for layout design [17].

2.2 Evaluation of criteria weights and alternatives

The development of an optimal facility layout requires a systematic selection of workflows or operational systems that are tailored to align with feasibility constraints and practical applicability for future implementation. In this study, the SCOR model [18] is adopted as the theoretical foundation for constructing and prioritising layout evaluation criteria. The SCOR model is widely recognised for its role in improving supply chain efficiency through five core activities: production planning, sourcing of materials and services, manufacturing, product delivery, and product return. The evaluation framework integrates five key performance metrics: reliability, responsiveness, agility, cost, and asset management efficiency.

In this research, MCDM is employed, as it is a comprehensive approach to evaluating criteria weights and alternatives. MCDM is a widely recognised method for complex decision-making processes, particularly in business, industrial applications, and logistics [19-22]. Examples of the application of the SCOR model include the development of an evaluation matrix for the footwear manufacturing industry [23], the use of SCOR-based criteria in detergent manufacturing to redesign supply chain strategies using the analytic hierarchy process (AHP) [24], and the integration of multiple MCDM techniques to calculate criteria weights and rank alternatives [25]. In addition, SCOR-based evaluation criteria have been adapted to fit the contextual needs of specific businesses; for instance, in the large-scale retail industry, supplier selection was conducted using AHP with customised criteria (cost, quality, organisation, service, and relationship), which were tailored to the retailer's operational requirements [26].

The technique used in this study is fuzzy AHP (FAHP), an advanced extension of the traditional AHP. FAHP incorporates the principles of fuzzy logic, and was first introduced by Lotfi A. Zadeh in 1965 to manage the uncertainty and vagueness inherent in decision-making processes [27]. This enhancement has made FAHP increasingly popular for evaluations and decision-making in various industries. Examples of its use include assigning weights for sustainable supplier selection in the textile supply chain [28], developing custom criteria for supplier selection in the automotive industry [29], selecting reverse logistics providers for e-commerce retailers with a focus on sustainable operations [30], and evaluating manufacturing layouts by integrating quantitative measures such as distance [31]. The extended analysis method (EAM) was selected for this study to simplify the calculations and reduce the computational iterations needed to determine the fuzzy weights. In this method, average opinions from respondents are calculated as triangular fuzzy numbers $(\widetilde{M}_{gi})$ and the value of the fuzzy synthetic extent (S_i) is then determined to evaluate the degree of possibility (V) [32]. The computational process involves three main steps, which are described below.

2.2.1 Calculating the relative weights for each criterion

In this step, the fuzzy weight is calculated for each criterion (S_i) by summing the triangular fuzzy numbers $(\widetilde{M}_{gi})$ from pairwise comparisons and normalising them using the following formula:

$$S_i = \sum_{j=1}^{m} \widetilde{M}_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} \widetilde{M}_{gi}^{j}\right]^{-1} \quad (1)$$

where $\widetilde{M}_{gi}$ represents the fuzzy number that captures the pairwise comparison between criteria g and i.

2.2.2 Calculating the degree of possibility

The degree of possibility between fuzzy numbers is calculated to determine the extent to which one criterion dominates another. It is defined as:

$$V(\widetilde{M}_1 \geq \widetilde{M}_2) = \sup_{y \geq x} \left[\min(\widetilde{M}_1(x), \widetilde{M}_2(y)\right] \quad (2)$$

For computational simplification, the degree of possibility can also be expressed as:

$$V(\widetilde{M}_1 \geq \widetilde{M}_2) = hgt(\widetilde{M}_1 \cap \widetilde{M}_2(d) = \begin{Bmatrix} 1 \quad if\ m_2 \geq m_1 \\ 0 \quad if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \quad otherwise \end{Bmatrix} \quad (3)$$

2.2.3 Calculating the priority vector

The fuzzy weights $\widetilde{W}$ for the criteria are computed by comparing the fuzzy numbers obtained in the previous steps. The result of this process yields a priority ranking of criteria and alternatives.

3. Materials and methods

The research process was divided into three parts. First, we studied the business process and layout requirements, following the SLP; next, we selected assessment criteria based on the SCOR model and GMP; and finally, we assessed the weights of the criteria and the options for each criterion to analyse the selective outcome by employing the FAHP.

3.1 Developing alternative layouts according to SLP principles

The procedure for layout planning was divided into 11 stages, as follows. The first stage involved the accumulation of past data and interview questions regarding the basic information of the business operators, along with a survey of the packing house utilizing sorting systems similar to the case study, to support the analysis of PQRST terms (Product, Quantity, Routing, Supporting Services, and Time). In the second stage, a process flow diagram of the movement of produce between the departments was analysed based on the routes. The third stage consisted of an evaluation of this relationship, starting with the primary activities and support activities. In the fourth stage, we developed a relationship diagram based on the data from the relationship, starting with paired activities that showed the most intense flow. In the fifth stage, we reviewed the required and specific conditions, and in the sixth stage, we studied the empty space in order to determine the actual used area and the possible production rate. The seventh stage involved designing a diagram of the relationships from the area identified in the fourth stage. In the eighth, ninth and tenth stages, we determined the practicality limitations and conditions of the working space. The final stage consisted of assessing the criteria and layout based on the FAHP [33].

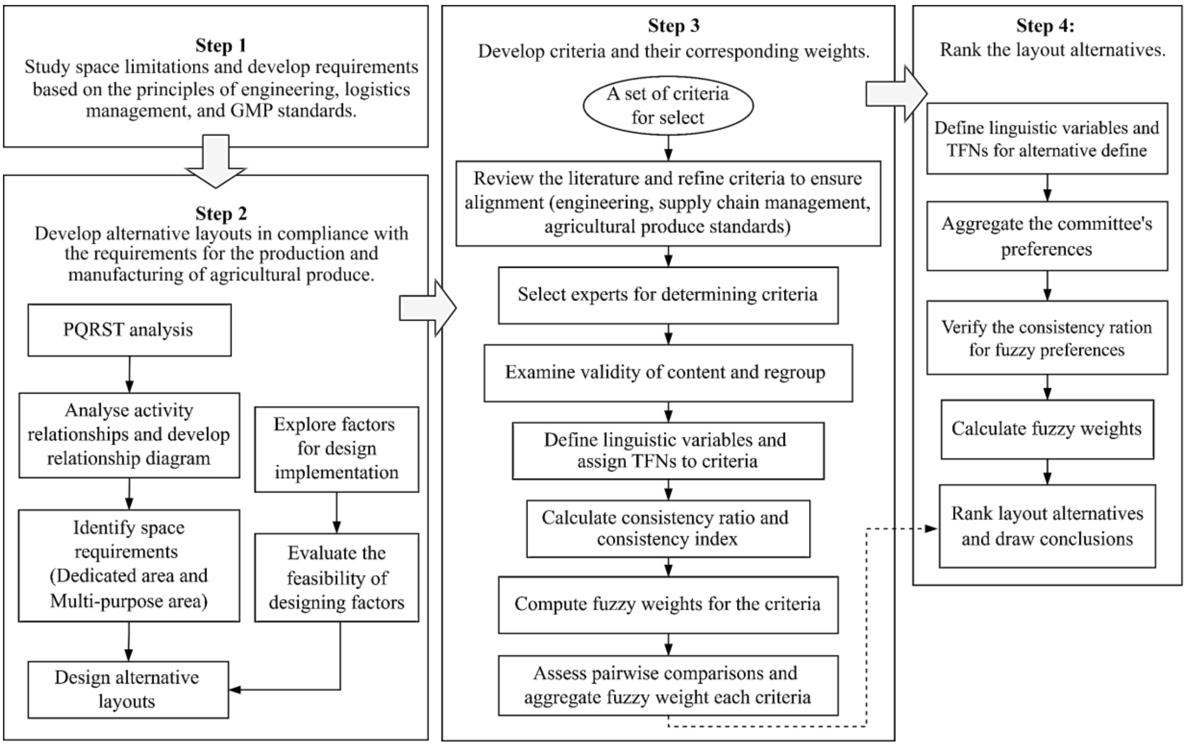

Figure 1 Framework of the proposed integrated approach for facility layout optimisation

The process follows each step in Figure 1, and involves studying the space limitations and developing requirements based on the principles of engineering, supply chain management, and the GMP standard.

3.2 Selection of criteria according to SCOR model principles

To establish a robust framework for evaluating the criteria and prioritising alternatives, indicators were developed to integrate multiple dimensions, including supply chain management, agricultural manufacturing standards, and engineering principles. These criteria were carefully constructed to provide a comprehensive approach to determining the relative importance of evaluation factors. This integration process was based on the following concepts. (i) The GMP standard serves as a cornerstone for ensuring the quality and safety of agricultural products intended for export. This internationally recognised standard, which is often mandated by importing countries, facilitates traceability to the production source, and applies to products exported directly or sold through auction systems. Key considerations within this framework include prevention of contamination, adherence to hygiene standards, and the suitability of the working environment to ensure compliance with export regulations and food safety protocols. (ii) The SCOR model provides a structured approach for analysing, standardising, and improving supply chain performance, and is widely used to define specific activities and develop systematic policies to guide strategic and operational decision-making. The performance attributes derived from the SCOR model, such as operational flexibility, ease of workflow and maintenance, and cost efficiency, were adapted to form the basis of the selection criteria for service providers and strategic options. These attributes ensure alignment with supply chain optimisation goals and operational excellence. (iii) Engineering principles emphasise operational efficiency within the facility layout. These criteria incorporate considerations such as optimising material flow systems, ensuring accessibility to allow for equipment maintenance, and positioning machinery to enhance ergonomic efficiency. These elements aim to minimise operational disruptions, reduce physical strain on workers, and improve overall productivity.

Following this, the criteria for assessing the agricultural process layout were developed based on consultations with related businesses and evaluations of content validity from five experts, including industrial engineers and supply chain management professors, who had experience in researching and teaching about industrial plant layout planning, fresh fruit exporters and cold storage operators, and representatives from an industrial automation installer business [34, 35].

An assessment of the content validity index (CVI) shows that the results for the content validity for item (I-CVI) and content validity index for scale (S-CVI) were lower than 0.70 and 0.9, respectively. The final criteria set with the S-CVI 0.975 consisted of four global criteria and eight local criteria: safety (SF), with three local criteria [36-38]; agility (AG), with one local criterion [39]; convenience (CV), with two local criteria [40, 41]; and cost (CT), with two local criteria [42, 43]. The details were as follows: (i) *SF1: Working space and environment* was related to whether the ventilation and lights were sufficient, following the GMP: (ii) *SF2: GMP standard* was related to GMP sanitation, and aimed to reduce the contamination from the outside environment; (iii) *SF3: Ergonomics* was related to the positions of equipment placement, to help reduce exhaustion and occupational injuries; (iv*) AG1: Movement and maintenance* was related to the movement of produce by equipment and the flexibility to allow for maintenance; (v) *CV1: Working area* was related to the convenience of work and movement, and included the width of the walkway and the positions of equipment; (vi) *CV2: Future schematics* was related to the convenience of layout adaptation, future improvements in terms of automation, and cold storage; (vii) *CT1: Space utilisation* was related to the overall usefulness of space in each process and the effective utilisation of other equipment; (viii) *CT2: Distance and direction* was related to the distance and direction in movement, and aimed to reduce the utilisation of resources and avoid repetition in movement.

3.3 Evaluation of alternative layouts based on FAHP principles

The pairwise comparison technique was applied to evaluate the relative importance of the criteria pairs and alternatives under each criterion, using a scale ranging from one to nine, as presented in Table 1. The evaluation was conducted by three executives from the case study organisation, with representatives from the accounting, marketing, and production departments. To ensure a clear understanding of the evaluation process, the criteria, and the designed alternatives, a focus group discussion was organised. The evaluators' pairwise comparisons were converted into triangular fuzzy numbers for analysis using the fuzzy pairwise comparison method and the EAM technique; to address potential inconsistencies in the evaluators' judgments, a consistency analysis was performed using the consistency ratio (CR) and consistency index (CI) [33, 44], and any inconsistencies identified were revisited with the evaluators, accompanied by a review of the reasoning behind their assessments. The aggregated judgments were calculated using the geometric mean. The weights of the criteria and their respective alternatives were then determined through a weighted scoring method, followed by normalisation to facilitate a systematic ranking of the alternatives.

Table 1 Fuzzy scale of relative importance [31]

Intensity of importance	Linguistics scale	Triangular fuzzy numbers (TFNs)	Reciprocal TFNs
1	Equally important (EQ)	(1, 1, 3)	(1/3, 1, 1)
3	Weakly important (WE)	(1, 3, 5)	(1/5, 1/3, 1)
5	Strongly more important (ST)	(3, 5, 7)	(1/7, 1/5, 1/3)
7	Very strongly important (VS)	(5, 7, 9)	(1/9, 1/7, 1/5)
9	Extremely important (EX)	(7, 9, 9)	(1/9, 1/9, 1/7)

4. Results

4.1 Operational process for exports and auction system

The production process started with the receipt of raw material from members and the agricultural group network in Eastern Thailand, which had already been sorted by weight and quality. The group then examined the quality again, packed the produce in baskets based on six grades, and waited for the auction with the domestic merchants and exporters. To increase the value of the product, it was packed and loaded into the containers to be ready for export. Figure 2 shows that the main production process is divided into three stages, which are categorised by distribution channel as follows. (1) Export process: This process is significant for future development but requires substantial space due to the need for machinery, equipment, and personnel. (2) Auction process: This is the primary process currently in operation. It involves fewer activities as no product transformation occurs, relying mainly on labor for sorting and transportation tasks. (3) Retail process: This process has a few steps and space requirements, as it primarily focuses on repackaging pre-sorted products for retail sale.

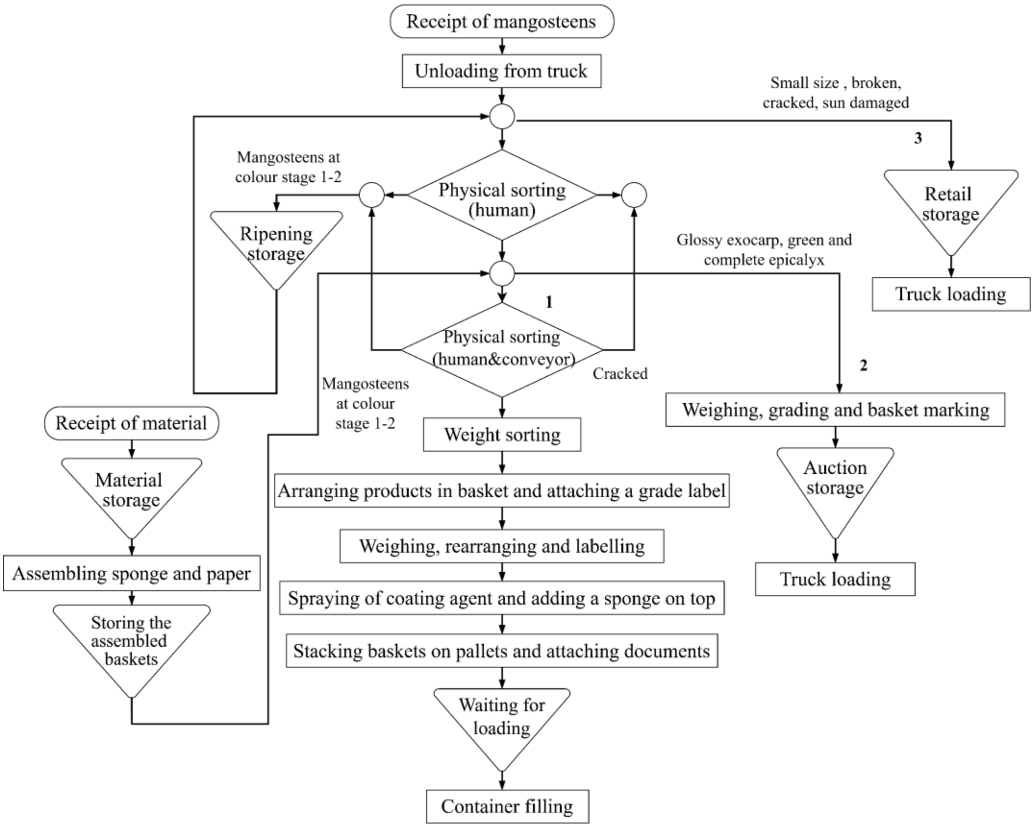

Figure 2 Process flow chart for the export and auction procedure

4.2 Relationship analysis and layout design

This stage began with an analysis of the activities requiring space for production or storage, specifically for products distributed through auction systems and containerized export systems, encompassing a total of 17 activities. The evaluation of the relationship between each pair of activities was presented in the relationship chart, which includes both the rating score and corresponding reasons, as illustrated in Figure 3. The rating scores were used to define and prioritise each activity and area involved in the process; for example, the receiving and weighing area is located near the visual inspection area in order to minimise the travel distance and to support process continuity, and these were categorised as Level A due to their critical importance to the overall system.

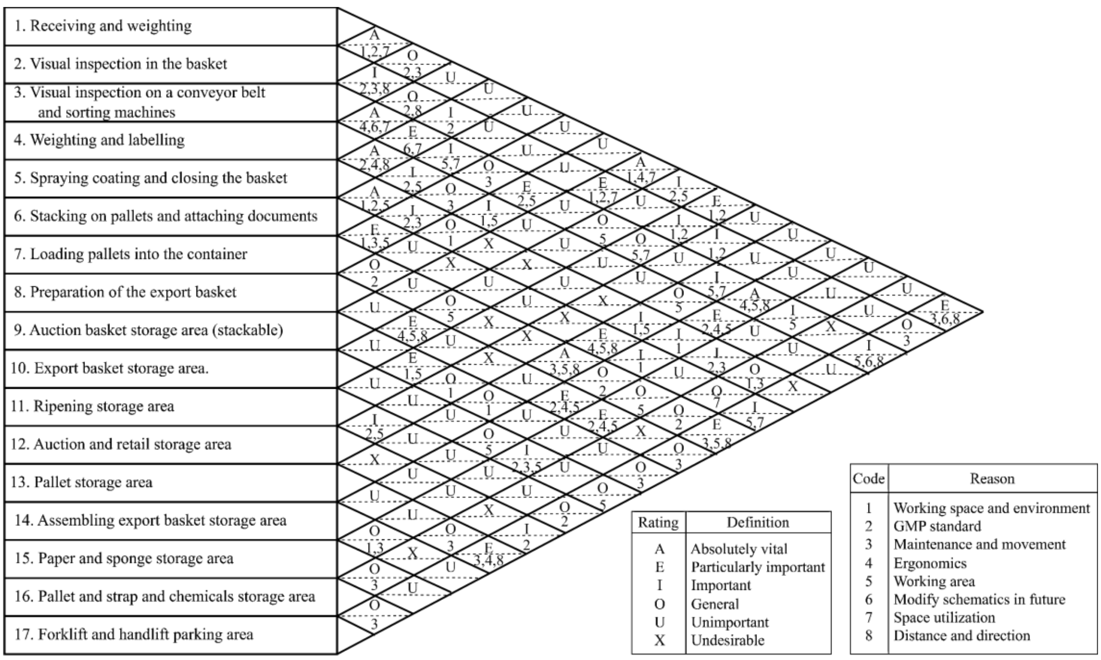

Figure 3 Relationship chart

From an analysis of the space relationships, three key factors related to workflow design and workspace layout were identified for development, as follows: (i) the number of physical sorting steps; (ii) the placement position of the sorting machine; and (iii) the direction of raw material entry.

After presenting these to the administrators to screen the possible layouts, four alternative approaches were obtained in Figure 4. Alternative 1 (S2NF) involved performing sorting twice, in a situation where the sorting machine was in the new building and received the raw materials in front of the existing building. This created more space for work and clearly specified two types of outbound area. In Alternative 2 (S1NF), sorting was conducted only once, and the sorting machine was in the new building, with raw material being received in the existing building. This could increase the work space in the existing building, which could be developed as a cold room in the future. Alternative 3 (S1NS) involved sorting only once, with the sorting machine located in the new building and raw materials received from the side, between the two buildings. This would make the equipment and flow more convenient, and would be a suitable hygienic process. In the last option, Alternative 4 (S1MS), sorting was conducted only once, and the sorting machine was placed between the two buildings, with material received from the side of the building and a combination of the inspection stages. This could reduce the workspace in the new building and minimise the distance required for movement of the material.

Building space zoning by activity type: The zoning of a building space is determined by considering the types of activities that can be performed together and those that must avoid sharing the same space to reduce contamination. The use of colours to indicate the areas of each activity helps to control the spacing of each activity. Within this working area, there are 17 main activities, marked by different colours.

Figure 4 Four alternatives for the packing house layout.

Table 2 Distances and storage areas for auction and export activities

Alternative (code)	Distance per auction basket (m)	Distance per export basket (m)	Storage area (m^2)
1 (S2NF)	18.80	92.44	254.35
2 (S1NF)	19.78	98.48	258.07
3 (S1NS)	33.21	93.85	266.61
4 (S1MS)	17.63	70.50	267.34

The results for the distances of movement for the baskets and the corresponding spaces are shown in Table 2. When considering the four alternative layouts, it was observed that although Alternatives 1, 2, and 4 had the shortest overall distances, these layouts contained overlapping routes, which could negatively impact safety during operations. Alternative 3 had a longer overall distance but offered greater clarity and continuity in terms of the flow directions. Regarding the outbound routes, Alternative 3 also used longer distances overall, but the lack of overlapping paths contributed positively to safety and operational efficiency. Lastly, when comparing storage areas, all alternatives showed similar capabilities in terms of produce storage capacity.

4.3 Evaluation and selection with FAHP

The result of an individual assessment was used to find the fuzzy importance weight for each criterion by the arithmetic mean [45]. The extent of fuzzy synthesis and degrees of possibility were then calculated as shown in Table 3.

Table 3 Priority weights for criteria

Criterion	Degree of possibility for a convex fuzzy number																Min V	W'(%)
SF1	S1≥S1	**1**	S1≥S2	1	S1≥S3	0.73	S1≥S4	0.34	S1≥S5	0.73	S1≥S6	0.82	S1≥S7	0.82	S1≥S8	0.58	0.34	6.85
SF2	S2≥S1	0.69	S2≥S2	**1**	S2≥S3	0.38	S2≥S4	0.05	S2≥S5	0.40	S2≥S6	0.49	S2≥S7	0.02	S2≥S8	0.28	0.02	0.48
SF3	S3≥S1	1	S3≥S2	1	S3≥S3	**1**	S3≥S4	0.62	S3≥S5	1	S3≥S6	0.62	S3≥S7	0.85	S3≥S8	1	0.62	12.37
AG1	S4≥S1	1	S4≥S2	1	S4≥S3	1	S4≥S4	**1**	S4≥S5	1	S4≥S6	1	S4≥S7	1	S4≥S8	1	1.00	20.01
CV1	S5≥S1	1	S5≥S2	1	S5≥S3	1	S5≥S4	0.65	S5≥S5	**1**	S5≥S6	0.65	S5≥S7	0.87	S5≥S8	1	0.65	12.99
CV2	S6≥S1	1	S6≥S2	1	S6≥S3	0.93	S6≥S4	0.56	S6≥S5	0.92	S6≥S6	**1**	S6≥S7	0.79	S6≥S8	1	0.56	11.29
CT1	S7≥S1	1	S7≥S2	1	S7≥S3	1	S7≥S4	1	S7≥S5	1	S7≥S6	1	S7≥S7	**1**	S7≥S8	1	1.00	19.92
CT2	S8≥S1	1	S8≥S2	1	S8≥S3	1	S8≥S4	0.80	S8≥S5	1	S8≥S6	1	S8≥S7	0.81	S8≥S8	**1**	0.80	16.09

Table 3 shows the degree of possibility (V), obtained from a comparison of the fuzzy synthetic extent values (Si) for each criterion (i), as determined by Equation 6. The lowest value V for each criterion was subsequently identified using Equation 5, enabling the computation of the fuzzy weights (W') and their normalisation. This analysis revealed that AG1 achieved the highest fuzzy weight among the criteria. Next, we calculated the score for the fuzzy importance weight of each alternative under the eight assessment criteria and the weight for each alternative of the four layouts, in the same way as for the criteria weights. The results for the weighted scoring method and normalisation are shown in Table 4. It can be seen that the layout with the highest score is Alternative 3 (S1NS), with a composite weight of 30.40%, which is significantly driven by the SF2 GMP standard criterion (weight of 0.53) and the CV1 working area criterion (weight of 0.46). These factors played a crucial role in determining the overall priorities and the final composite weight, making Alternative 3 the most suitable option.

Table 4 Overall priorities and the overall composite weights (percentages) for the layouts

Criterion	Weight	S2NF	S1NF	S1NS	S1MS
1. SF1 GMP Working Space and Environment	6.85	51.60	35.98	12.41	0.00
2. SF2 GMP Standard	0.48	14.12	6.80	53.26	25.82
3. SF3 Ergonomics	12.38	19.44	18.15	29.82	32.59
4. AG1 Movement and Maintenance	20.03	24.20	15.94	39.69	20.16
5. CV1 Working Area	13.00	12.38	18.14	46.42	23.06
6. CV2 Future Schematics	11.24	21.36	22.76	33.28	22.61
7. CT1 Space Utilisation	19.93	31.53	19.48	22.92	26.07
8. CT2 Distance and Direction	16.10	19.92	28.85	21.59	29.65
Total Percentage	100.00	24.60	21.52	30.40	23.48

5. Discussion

This study has presented a framework for sustainable layout design by leveraging the SLP methodology, a widely recognised approach in industrial workflow design. SLP facilitates resource allocation by analysing the interrelationships between activities and addressing resource constraints. A case study was considered, with a focus on expanding production lines and integrating advanced production and material handling technologies, under constraints arising from the inability to establish direct material flow paths. Consequently, the identification of critical design variables was paramount. These variables included the flow direction of raw materials and finished products, the strategic placement of key machinery, and operational sequencing, all of which needed to be implemented in adherence to food production standards relating to spatial allocation, maintenance protocols, and sanitation requirements. To ensure a comprehensive and multidimensional assessment, criteria were developed based on the following key principles. (i) Quality assurance with integrated GMS was required from the outset to ensure compliance with food safety regulations and traceability requirements for export-oriented agricultural products. (ii) Engineering principles were used that emphasised the optimisation of material flow and minimisation of worker fatigue, in view of the extended work hours typical of agricultural production environments. The framework also prioritised ergonomic efficiency in order to mitigate occupational hazards arising from prolonged and intensive tasks. (iii) Supply chain management criteria were derived from the SCOR model, incorporating performance attributes such as cost efficiency, resource utilisation, ease of material handling, and flexibility to accommodate future operational adjustments. This ensured alignment with both current and long-term strategic objectives. The integration of these principles addressed common limitations associated with the MCDM method [31, 46], which often prioritises quantitative metrics over broader contextual considerations. Furthermore, the inclusion of simulation methodologies for agro-industrial processes [14, 47] enhanced the practical relevance and adaptability of the proposed framework. The content validity was rigorously verified by consulting academic experts and industry representatives, to ensure both academic robustness and practical applicability. The next step was the assessment of criteria weights and alternatives, and was conducted using a participatory approach that involved business managers responsible for strategic decision-making across the domains of accounting, marketing, and production. Given the context of the case study, which focused on a small enterprise with clearly defined management strategies, minor discrepancies in evaluation outcomes were observed due to differences in subunit-level priorities. However, these variations were effectively mitigated through the application of fuzzy logic analysis, which addressed ambiguities in the evaluators' judgments and enhanced consistency in the quantitative outcomes.

The findings from the criteria weighting analysis indicated that the ease of material handling and equipment maintenance accounted for over half of the total weight. This result is aligned with the operational flexibility requirements for businesses dealing with the fluctuating nature of agricultural raw materials. A secondary importance was attributed to cost efficiency, driven by the optimal utilisation of space and shorter material flow distances. These factors are aligned with widely accepted international evaluation standards for layout design. The criterion of sanitation received the lowest weighting, reflecting the relatively low enforcement of such standards in real-world operations by regulatory and inspection agencies. However, the significance of this criterion may increase if stricter import regulations are imposed by authorities in the destination markets.

A layout evaluation showed that Alternative 3, which was designed based on engineering principles to eliminate overlapping flow paths between raw materials and finished products, achieved the highest overall score. Its strengths included compliance with GMP standards, with finished products stored in enclosed spaces, and high performance in terms of quantitative metrics, although its effectiveness was less pronounced for auction-based product workflows. To validate these results, an output validation process was conducted with industry experts and real-world testing, and this process identified Alternative 1 as the most suitable for current operations. Although Alternative 1 scored lower on the quantitative evaluation, its design was closely aligned with existing workflows and offered practical advantages, particularly in terms of supporting auction-based distribution channels for finished goods. This study emphasises the critical role of facility and layout design as a strategic decision-making area for organisations. The findings highlight the importance of integrating quantitative assessments with practical considerations to ensure alignment with operational realities and market demands. By balancing theoretical and empirical approaches, this research provides a robust framework for addressing the complex challenges of facility design in agro-industrial contexts.

6. Conclusion

6.1 Theoretical contributions and practical implications

This study contributes to the field of industrial layout design for the fresh fruit export industry by employing the well-established SLP methodology, an approach that incorporates considerations that extend beyond agricultural production requirements to include critical engineering principles. Unlike most facilities, which are designed with open layouts to allow for easy workflow adjustments, the operational areas in this study were not originally designed to support diverse production processes. In addition, the constraints related to the size and orientation of automated machinery necessitated careful collaboration with facility management. These factors make this case study a valuable reference for small and medium-sized enterprises aiming to expand their operations despite spatial constraints and limited engineering expertise. During the development and evaluation of the criteria and their corresponding weights, multiple dimensions were considered in regard to their alignment with business sustainability objectives. These included food safety standards, ergonomics, and supply chain management principles, which focus on enhancing current and future business efficiency. By integrating these diverse perspectives, the proposed criteria serve as a strategic foundation for improving operational practices in agro-industrial enterprises, such as optimising material flow systems and workspace efficiency.

In this study, MCDM techniques were applied, and specifically FAHP, to evaluate and rank the alternatives. This method was chosen to mitigate the ambiguity and hesitancy often faced by evaluators during the decision-making process. Evaluators drawn from different managerial departments within the case study organisation identified the most critical criteria as: (i) flexibility in material handling and equipment maintenance, and (ii) cost-effectiveness of space utilisation alongside the distance and direction of material flow. The highest-ranking option (Alternative 3) contained a single sorting stage, with the sorting system relocated to a newly designated building and raw materials received at the side of the building. This alternative was preferred as it could reduce workflow redundancies, eliminate overlapping material flows, and maximise workspace efficiency. However, to achieve more consistent and objective results in future evaluations, organisations should establish clear operational goals. Anchoring decisions in organisational values and strategic priorities, rather than individual opinions, can ensure better consistency and alignment with long-term objectives.

6.2 Limitations and future work

The primary limitation of this study was a lack of comprehensive quantitative data, such as process times. The data collection process coincided with production and installation preparations, resulting in incomplete labour performance records and the absence of a simulation-based analysis. Furthermore, as the case study enterprise functioned as an agricultural cooperative with a large membership, any modifications to workflows required consensus-building among members, which introduced complexity and potential delays to the decision-making process.

Future research should aim to overcome these limitations by focusing on the development of resource allocation models that optimise labour, machinery, and operational timing. This can be achieved through the development of advanced mathematical models or algorithms that account for a broader range of variables, including the contributions of cooperative members supplying raw materials. In addition, comparative studies of production and distribution scenarios could provide valuable insights for resource planning. These analyses should incorporate historical pricing and production data, along with external factors such as market demand, climatic conditions, and global economic trends, to inform strategies for product distribution and channel management.

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