JOURNAL OF TECHNOLOGY AND OPERATIONS MANAGEMENT

https://e-journal.uum.edu.my/index.php/jtom

How to cite this article:
Tuan Sharifuddin, T. N. A. Q., Mahmood, S., & Sukadarin, E. H. (2026). Improvement of facility layout for manuring process in an oil palm plantation: A simulation-based study, *Journal of Technology and Operations Management, 21 (2), 94-112*. https://doi.org/10.32890/jtom2026.21.2.7

IMPROVEMENT OF FACILITY LAYOUT FOR MANURING PROCESS IN AN OIL PALM PLANTATION: A SIMULATION-BASED STUDY

[1]Tuan Nur Aisya Qistina Tuan Sharifuddin, [2]Salwa Mahmood & [3]Ezrin Hani Sukadarin

[1]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh, Johor Malaysia

[2]Corresponding author: msalwa@uthm.edu.my

Received: 22/1/2026 Revised: 8/6/2026 Accepted: 30/6/2026 Published: 30/7/2026

ABSTRACT

Facility layout plays a crucial role in operational efficiency by influencing material flow, labor utilization, and productivity. Although layout optimization has been widely applied in manufacturing, its implementation in plantation operations, particularly in oil palm manuring, remains limited. This study evaluates the existing facility layout for the manuring process from the workshop to the field, which relies heavily on manual material handling, resulting in prolonged handling time, potential worker idle time, and inefficient use of labor and equipment. The main objective of this paper is to assess the current layout and develop an improved facility layout that enhances operational efficiency and safety, with its performance verified through simulation analysis. On-site observations and time-study data were collected from workers involved in the manuring process to represent actual operating conditions. The existing and proposed layouts were developed using SketchUp and evaluated through discrete-event simulation in FlexSim to analyze worker movement, cycle time, and labor utilization. The proposed layout integrates the Hasrul Fertilizer Lift (HFL), a mechanized system designed to reduce manual fertilizer handling. Simulation results indicate improved operational performance through increased worker utilization and reduced operational cycle time. These findings demonstrate that the proposed layout improves workflow efficiency, reduces manual handling, and enhances labor utilization. This study provides practical guidance for plantation managers and demonstrates the value of simulation-based facility layout optimization for improving oil palm manuring operations.

Keywords: Facility layout, plantation operation, layout improvement, manuring process, simulation

INTRODUCTION

Facility layout is defined as the systematic arrangement and integration of departments, workstations, machinery, equipment, and materials within an existing or proposed industrial facility to achieve efficient operational flow and resource utilization (Naik & Kallurkar, 2016). As demand and production volumes grow, the facility layout may need to change to ensure an efficient workflow in terms of material handling, space utilization, and cost-effectiveness (Pérez-Gosende et al., 2021). Even minor adjustments to the positioning of machines and equipment within the manufacturing plant can significantly influence material flow, thereby affecting production costs and the overall efficiency of the manufacturing process (Okpala et al., 2016). Based on research by Kikolski & Ko (2018), facility layout planning is commonly applied in manufacturing environments. However, its relevance is equally important in plantation-based operations, where material handling and field activities form a significant part of daily operations. In plantation operations, particularly in manuring activities, efficiency is closely linked to how materials are prepared, transported, and applied in the field. In oil palm production, manuring or fertilization process inputs have been reported to account for a large proportion of the total production cost, highlighting the high-cost burden of nutrient management in plantations (Goh et al., 1999).

This study focuses on the facility layout in the plantation sector, specifically on the manuring process in oil palm plantation. This process involves multiple stages that begin at the workshop area and end at the field area. Despite the importance of this process, the current layout has not been systematically evaluated to ensure that it supports efficient operations. Therefore, a detailed study is necessary to examine the current facility layout and identify opportunities for improvement that can enhance productivity and operational safety. The current manuring process at this plantation relies heavily on manual material handling, particularly during fertilizer loading and field application. This practice has resulted in high worker idle time, long material handling durations, and inefficient utilization of manpower and equipment.

While many studies have focused on facility layout optimization in manufacturing and shop-floor environments, there is limited research that addresses facility layout planning in plantation operations (Hu et al., 2025), especially for the manure-handling process. If these inefficiencies are not addressed, operational performance may continue to decline, leading to increased labour costs, longer operational cycles, and reduced productivity. This gap highlights the need for a systematic facility layout evaluation tailored to plantation-based activities. The main objectives of this study are to analyze the existing facility layout of the manuring process in the oil palm plantation, to propose an improved facility layout design that enhances efficiency and safety, and to verify the effectiveness of the proposed layout through simulation analysis using FlexSim software.

This study applied computer-aided design (CAD) software, specifically SketchUp and FlexSim software, to analyze the facility layout of the company. SketchUp software was used solely to create the visual models of the current and proposed layouts, providing a clear spatial representation to ensure better understanding of the configurations. FlexSim software was used to simulate operational activities, including worker movement, transportation, loading and unloading processes, and material flow within the facility. This simulation provided quantitative analysis of operational performance. Additionally, it facilitated the analysis of the proposed layout design to verify its superiority over the existing layout.

LITERATURE REVIEW

This section presents a review of the relevant literature related to facility layout planning and its application in improving operational efficiency. This review focuses on the key concepts of facility layout, the role of simulation in layout evaluation, and previous studies related to layout improvement.

Facility Layout Planning

Systematic facility layout planning involves the systematic arrangement of equipment, workers, and material flow to ensure efficient operations in terms of time, cost, and space utilization (Pérez-Gosende et al., 2021). An effective facility layout minimizes unnecessary movement, reduces bottlenecks, and improves labor utilization, while a poor layout often leads to excessive material handling, idle resources, and increased operational costs (Pearly Saira et al., 2019). As production demand and operational complexity increase, the facility layout must be reviewed and adapted to maintain workflow efficiency and flexibility (Varinder Khurana, 2015).

In plantation-based operations, facility layout planning is equally important but often more challenging due to dispersed work areas, long transportation distances, and heavy reliance on manual labor (Ahn et al., 2018; Wang et al., 2025). Previous research by Vahdanjoo & Sorensen (2021) indicated that the manuring process requires coordinated layout planning to reduce non-value-added movement and delays. Moreover, Wang et al. (2025) highlighted that plantation or agricultural facility layouts are influenced by terrain and geographic conditions, such as elevation, slope, and proximity to infrastructure, which contrast with standardized manufacturing environments. As a result, inefficient layouts in the plantation manuring process can lead to high labor idle time, increased material handling effort, and higher operational costs.

Manuring Process

Manuring, commonly known as fertilizer application, is a fundamental agronomic practice in oil palm plantations because it directly supports soil fertility and long-term crop productivity (Prajapati et al., 2023). As fresh fruit bunches are harvested continuously, significant amounts of essential nutrients are removed from the soil (Mahey et al., 2024). Without proper and timely nutrient replacement, palm health and yields can gradually decline (Khambalkar et al., 2025). To address this, large-scale commercial plantations should implement carefully planned and standardized fertilizer programs to maintain balanced nutrient levels throughout the production cycle. Fertilizer selection and application rates are determined by plant nutritional needs and soil conditions, which makes efficient fertilizer handling an important operational consideration (Raj & Dawar, 2023). In this oil palm plantation, five main fertilizer types are routinely used: rock phosphate, kieserite, ammonium sulphate, muriate of potash, and NK compact. Each fertilizer type fulfils a specific role in supporting oil palm growth and the company’s sustainability objectives.

Simulation-Based Facility Layout Evaluation

Simulation is widely recognized as an effective approach for evaluating and improving facility layouts. Discrete-event simulation provides an effective way to analyze system performance, detect operational bottlenecks, and assess different layout alternatives without affecting actual production activities (Nooranizam et al., 2024). It allows organizations to evaluate critical performance measures, including cycle time, throughput, and resource utilization, through quantitative analysis, thereby supporting better planning and operational decision-making (Surianshah et al., 2022). Among the available simulation tools, FlexSim is frequently used due to its ability to model worker environments, equipment interactions, and time-based processes in three-dimensional (3D) environment (Aliyu & Mokhtar, 2021). FlexSim is one of the most powerful discrete-event simulation software tools that supports engineers and decision-makers in analyzing, designing, and improving system operations. It combines simulation modeling with artificial intelligence, 3D visualization, and data processing capabilities, enabling users to gain deeper insights into system behavior and performance (Aliyu & Mokhtar, 2021). Furthermore, FlexSim provides a comprehensive environment for the development, execution, and evaluation of simulation models, making it a valuable tool for optimizing complex industrial and manufacturing processes. Previous studies, as shown in Table 1, have demonstrated that simulation-based layout evaluation can lead to reductions in process times, improved labor utilization, and better decision-making in facility planning.

Visualization Tools in Facility Layout Planning

Visualization tools, such as SketchUp software, are commonly used to support facility layout planning by providing clear 3D representations of layout arrangements. SketchUp is a powerful and versatile 3D modeling software application used for various design fields, including architecture, interior design, and engineering (Vanstappen, 2019). The software was initially introduced by Google in 2006 to simplify the creation of buildings for 3D city visualization on Google's satellite imagery (Vanstappen, 2019). SketchUp allows users to visualize spatial relationships, workflow sequences, and equipment positioning, which enhances the understanding of layout designs (Nooranizam et al., 2024). Although SketchUp lacks advanced analytical capabilities, it is highly effective as a supporting visualization tool when integrated with discrete-event simulation software. Table 1 presents a summary of previous studies that applied SketchUp software as a visualization tool in facility layout planning.

Previous Research

Several studies have investigated facility layout improvement using simulation and visualization tools, as summarized in Table 1 with respect to their optimization objectives and corresponding software applications.

Table 1
Summary of Previous Research on Facility Layout Optimization

No.	Author	Sector	Software Used	Key Findings
1	Karim et al. (2022)	Food manufacturing	SketchUp, FlexSim	The proposed layout reduced material handling distances and eliminated bottlenecks, resulting in smoother workflow and improved system efficiency.
2	Surianshah et al. (2022)	Food manufacturing	SketchUp, FlexSim	Simulation results showed a reduction in total cycle time and improved resource labor utilization after layout redesign.

Table 1
Continued

No.	Author	Sector	Software Used	Key Findings
3	Nooranizam et al. (2024)	Food processing	FlexSim	The optimized layout increased labor utilization and reduced idle time, leading to improved production efficiency.
4	Ramlan et al. (2024)	Palm oil industry	ARENA	The redesigned layout achieved 5.89% reduction in overall process time and improved workstation balance.
5	Nurudeen et al. (2024)	Mineral processing	SLP, FlexSim	Layout optimization increased throughput and improved equipment utilization without increasing resource requirements.
6	Wu & An (2024)	Warehouse (fertilizer products)	SLP, FlexSim	Optimized warehouse functional zones, reduced material congestion, shortened forklift travel distances, and improved process flow efficiency through simulation-based validation.
7	Wang & Feng (2024)	Manufacturing workshop	SLP, FlexSim	The proposed layout significantly reduced transportation distances and logistics costs while improving production efficiency, demonstrating the effectiveness of simulation-supported layout redesign.
8	Liu et al. (2020)	Manufacturing plant	SLP, Timed Petri Net, FlexSim	The integration of SLP and FlexSim simulation reduced equipment idle time, minimized cross-routing, and improved overall production efficiency by validating layout alternatives through simulation.

As shown in Table 1, previous studies have demonstrated that simulation-based layout optimization can improve operational efficiency by reducing travel distances, minimizing idle time, and making better use of available resources. However, most of these studies were carried out in manufacturing plants, processing facilities, or warehouses where work processes are more structured and predictable. Unlike previous manufacturing-focused studies, this research addresses a plantation context characterized by long-distance transport and manual field operations, requiring different layout considerations.

Overall, the literature demonstrates that simulation-based facility layout planning is one of the most effective methods for improving operational performance, particularly in manufacturing environments. FlexSim software is the most frequently used tool, highlighting its reliability for layout evaluation. However, limited research has focused on the plantation-based manuring process, highlighting a gap that this study aims to address.

METHODOLOGY

This study employed a systematic approach to evaluate the existing facility layout and identify opportunities for improving the efficiency of the manuring process. The approach combined on-site observations, layout visualization, and simulation analysis to ensure that the proposed improvements were practical and data-driven. The methodology began with a site visit to the plantation for data collection and to understand the actual workflow, followed by the development of the current and proposed layout models. Finally, discrete-event simulation software was used to evaluate and compare the performance of both layouts in terms of efficiency and resource utilization. Figure 1 shows the methodology flowchart for this study.

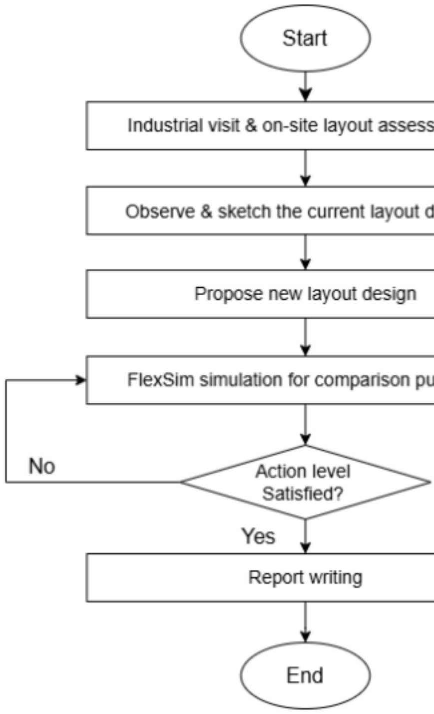

Figure 1
Research Methodology Flowchart

Site Visit and On-site Layout Assessment

A site visit was conducted at the oil palm plantation to understand the actual operational environment and the existing facility layout, with a focus on plantation upkeep activities, particularly the manuring process flow from the workshop area to the manuring area. Direct observations were carried out on the workflow, material handling activities, and worker movements, which were supported by on-site photographs and layout sketches. To capture the complete operational sequence, the researcher followed the workers from early morning until midday, covering fertilizer preparation, transportation, and field application. Discussions with the manuring process executive were also conducted to obtain detailed information on fertilizer types, application rates, daily targets, and operational practices. Additionally, the time taken for each activity was recorded to analyze the process duration and identify idle times, delays, and inefficiencies.

Observe and Sketch Current Layout Design

The information collected during the field assessment served as the primary reference for developing the facility layout model. Based on on-site observations, the current layout was sketched and visualized using SketchUp software to illustrate the spatial arrangement of the facility. Due to the unavailability of official blueprints, the workshop layout was developed using on-site photographs and visual observations without precise dimensional scaling. In addition, the travel route between the workshop and the manuring area was mapped using the Avenza Maps application, which indicated an approximate travel distance of 4 km. This measured distance was documented to provide contextual information regarding the operational route between the workshop and the manuring area; however, these data were not directly incorporated into the SketchUp model or the FlexSim simulation. Instead, the simulation model was constructed using the specific cycle time data collected during the field observations. Overall, the SketchUp model provided a clear visualization that supported a better understanding of the existing layout conditions.

Manuring Process for the Current Layout

Figure 2 shows the block diagram of the current layout system, which relies heavily on manual handling and conventional transport methods. Fertilizer is initially collected from the storage area and manually loaded onto a trailer. The loaded trailer is then transported to the field using a tractor. Upon arrival at the field, the fertilizer is manually transferred from the trailer into the Mobile Tractor Fertilizer Applicator (MTFA) unit. The MTFA subsequently distributes the fertilizer to the oil palm trees according to operational requirements. This process is repeated in cycles until the total requirement of 110 fertilizer bags is met. After completing the distribution task, the equipment and personnel return to the workshop area. Overall, the current layout involves multiple manual handling stages, which contribute to higher labor dependency and reduced operational efficiency.

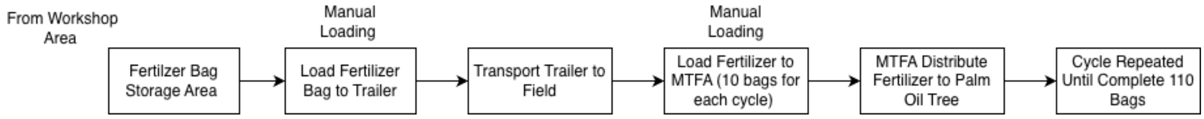

Figure 2
Block Diagram of Manuring Process for the Current Layout

Proposed New Layout Design

A comprehensive literature review was conducted to understand facility layout design principles and techniques as well as limitations, serving as the foundation for developing an improved layout for the oil palm plantation. The current facility layout was modeled in FlexSim software using the data collected during the site visit, including process sequences, resource usages, and operational times. The simulation was configured based on cycle times rather than actual travel distances. This baseline model was analyzed to identify operational inefficiencies, including delays, unnecessary movements, and workflow disruptions. Based on these findings, an improved facility layout design was developed. This proposed layout incorporated the fertilizer lift, which was first visualized using SketchUp and subsequently modeled and evaluated through FlexSim simulation to verify its performance against the existing layout.

Manuring Process for the Proposed Layout

Figure 3 shows the block diagram for the proposed layout, which features an improved fertilizer distribution system incorporating the lift mechanism and partial automation to enhance operational efficiency. Fertilizer is initially collected from the storage area and manually loaded into a fertilizer lift system. The lift is then transported to the field using a tractor. At the field location, the fertilizer is transferred from the lift into the MTFA unit through an assisted feeding mechanism. The MTFA then distributes the fertilizer to the oil palm trees in a similar operational sequence to the current system. This process is repeated until the required fertilizer quantity is fully distributed. Upon completion, the system and operators return to the workshop area. Compared to the current layout, the proposed system reduces direct manual handling at the field site and improves material handling efficiency through the integration of a lift-assisted transfer process.

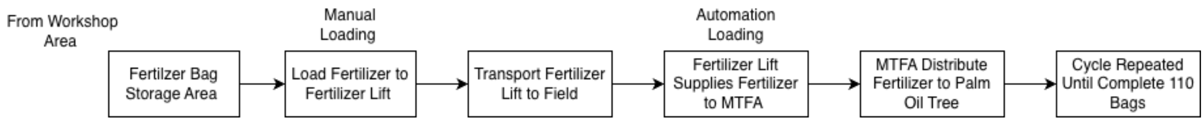

Figure 3
Block Diagram of Manuring Process for the Proposed Layout

Fertilizer Lift

The fertilizer lift is a mechanized fertilizer handling system used in plantation operations to improve material flow efficiency between storage, transport, and field application. Its main purpose is to reduce repetitive manual handling of fertilizer bags by allowing workers to load the fertilizer directly into a lifting and transport unit. Once loaded, the fertilizer lift system securely carries the fertilizer to the field, where it is transferred directly into the MTFA for distribution. This system reduces physical workloads and streamlines the logistics of fertilizer movement. In contrast, the baseline manual fertilizer handling involves several stages. Workers must first load fertilizer bags from the storage area onto a trailer at the workshop area. The trailer is then transported to the field, where the fertilizer is manually unloaded and reloaded into the MTFA unit. During this process, additional manpower is required, and workers often experience idle time while waiting for the MTFA to complete its application cycle. Consequently, these repetitive loading and unloading activities create operational inefficiencies, exacerbate worker fatigue, and bottleneck the overall workflow.

Introducing the fertilizer lift system significantly improves both the facility layout and operational workflow. Instead of undergoing multiple handling stages, fertilizer is loaded a single time into the fertilizer lift at the storage area and transported directly to the field by the tractor. Upon arrival, the fertilizer lift serves as the fertilizer supply unit for the MTFA, allowing fertilizer to be transferred without intermediate unloading and reloading activities. As the fertilizer lift can be operated independently by the MTFA operator, the need for additional workers to handle fertilizer in the field is eliminated. Consequently, the proposed system reduces manpower requirements, minimizes non-value-added handling activities, and enhances the overall efficiency of the manuring operation. Compared to the current system, the integrated MTFA and Hasrul Fertilizer Lift (HFL) layout minimizes non-value-added activities, such as repeated handling and unnecessary movements, while improving operational continuity, reducing idle time, and increasing overall productivity in fertilizer application.

FlexSim Simulation for Comparison Purposes

Discrete-event simulation was used to verify the effectiveness of the proposed facility layout, as it allows operational issues to be analyzed without disrupting actual plantation activities. In this study, FlexSim software was applied to model and simulate both the current and proposed layouts to identify inefficiencies and compare operational performance. The simulation generated detailed performance data, including worker states, machine and tractor utilization, throughput, and overall process durations. The data generated by FlexSim were analyzed and compared between the current and proposed layouts to identify efficiency improvements, time analysis, and utilization percentages, which served as the main indicators of performance. The comparative results were then interpreted to evaluate the effectiveness of the proposed layout in improving operational efficiency and reducing manual handling during the fertilization process. Overall, FlexSim software provided a cost-effective and risk-free approach for evaluating layout alternatives prior to real-world implementation.

RESULTS AND DISCUSSIONS

This section presents the results and analysis obtained from the FlexSim simulation of the manuring process, specifically tracing the workflow from the workshop area to Field 10F. The simulation results were used to assess the performance of the current facility layout and to identify operational constraints contributing to inefficiencies within the manuring process. Based on these findings, a comparative analysis between the current and proposed layouts was conducted to assess the effectiveness of the proposed improvements. Ultimately, the simulation data provided a clear performance comparison between the current and proposed facility layout configurations for the manuring process.

Assessment of Current and Proposed Layouts

The current facility layout supports the manuring process from the workshop area to the manuring area by combining both manual and mechanized activities. The fertilizer bags are stored at the workshop before being manually loaded into the trailer and transported to the field. At the field, additional manual handling is required, as workers must reload the fertilizer bags into the MTFA before application can begin. This arrangement involves four workers, consisting of two workers assigned to fertilizer loading and unloading, one MTFA operator, and one tractor driver supporting both the workshop and field locations. This configuration results in an uneven task distribution, particularly during field operations, as the loading workers experience extended idle times while waiting for the MTFA operator to complete the application process.

The proposed facility layout maintains the same physical configuration of the workshop and field, but introduces a functional improvement through the integration of the HFL. In this layout, all fertilizer loading activities are centralized at the workshop, where the fertilizer bags are loaded directly into the HFL prior to transportation. Upon arrival at the field, the tractor assists with positioning and setting up the HFL before leaving the unit stationed at the site. The HFL automatically dispenses fertilizer into the MTFA, thereby eliminating the need for manual loading and reducing labour dependency. As a result, field operations can be carried out by a single MTFA operator, while the loading workers are reassigned to productive tasks either at the workshop or within other fields. This redesigned workflow improves labour utilization, reduces idle time, and streamlines the overall manuring process. The subsequent increase in MTFA utilization is modest because the travel distance between the workshop and field remains unchanged, and the application process is constrained by the MTFA’s fixed operating capacity.

SketchUp Software Design

SketchUp software was used in this study as a visualization tool to develop 3D representations of the current and proposed facility layouts at the oil palm plantation. The simulation models were developed using data collected through on-site observations and photographic documentation to accurately represent the arrangement of the workshop area, transportation paths, and field operations. Although the models were not developed using exact dimensional scaling due to the unavailability of official layout drawings, they effectively represent the spatial relationships between resources and the sequence of activities within the manuring process. The SketchUp models provide a clear visual reference that supports the development and interpretation of the subsequent FlexSim simulation models, allowing for a better understanding of both layouts. Figure 4 presents the top view layout of the workshop area, while Figure 5 illustrates the overall layout extending from the workshop to the plantation area.

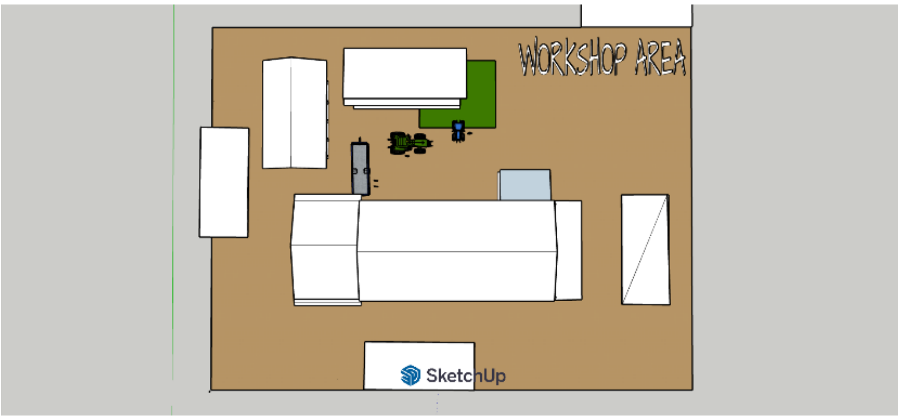

Figure 4
Top View of Workshop Area in Current Layout

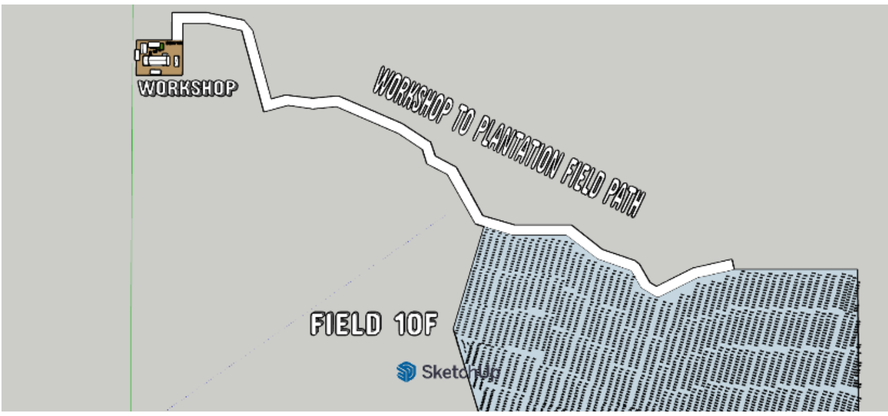

Figure 5
Top View of Workshop to Plantation in Current Layout

The proposed facility layout was also developed using SketchUp software, with the overall physical arrangement of the workshop and field remaining unchanged. The key difference in this model was the functional modification introduced by integrating the fertilizer lift, which replaced the conventional trailer previously used to load fertilizer bags. In this layout, fertilizer bag loading was centralized at the workshop, and fertilizer dispensing at the field was automated through the fertilizer lift, thereby reducing manual handling and labor dependency.

FlexSim Simulation Analysis

The FlexSim simulation model was developed under controlled conditions to focus on time-based performance evaluation. To facilitate a clearer analysis of resource utilization and task sequencing, the simulation was divided into two distinct models: one representing worker movements and the other representing transporter movements (tractor and MTFA). The process flow was modeled based on cycle time data obtained from on-site observations, while actual travel distances were omitted from the simulation logic. Furthermore, the simulation was designed to represent a single operational cycle of the manuring process, focusing on the workflow sequence and resource interactions under standardized operating conditions. In the model, the initial fertilizer loading process from storage to the trailer was represented as a full batch of 110 bags, reflecting the total quantity required for one complete fertilizing operation. However, at the field level, the MTFA operated in smaller loading cycles of 10 bags per application. Therefore, the simulation model replicated one field application cycle of 10 bags transferred from the trailer to the MTFA, a sequence that is repeated in actual practice until the full 110-bag requirement is met. This boundary approach allows the model to capture detailed operational behavior at the field level while maintaining a simplified and manageable simulation structure. While repeated field cycles and long-term operational variations were not included in the model, the simulation successfully captured key performance indicators (KPIs), including worker utilization, idle time, stay time, and total process durations. These indicators provided a reliable basis for evaluating and comparing the operational performance of the current and proposed layouts.

Current Layout Time Analysis

The simulation analysis provided a quantitative assessment of the baseline manuring process, focusing on operational efficiency, labor utilization, and processing time. The results from the current layout model indicated that although the manuring workflow followed a structured sequence, it was constrained by inefficiencies related to manual fertilizer handling in the field. Specifically, the two workers assigned to fertilizer bag loading experienced prolonged idle time once the MTFA began the spraying operation. The simulation results showed an overall worker utilization of approximately 70.78%, with a total process cycle time of 170.97 minutes. These results suggest opportunities for further improvement in operational efficiency and resource allocation. This imbalance occurred because the spraying process took an average of 20.33 minutes per cycle, which significantly exceeded the loading duration of approximately 10.66 minutes. This resulted in extended waiting times for the loading workers when the MTFA began the spraying process. Figures 6 and 7 show the model and data of worker movement in the current layout, respectively.

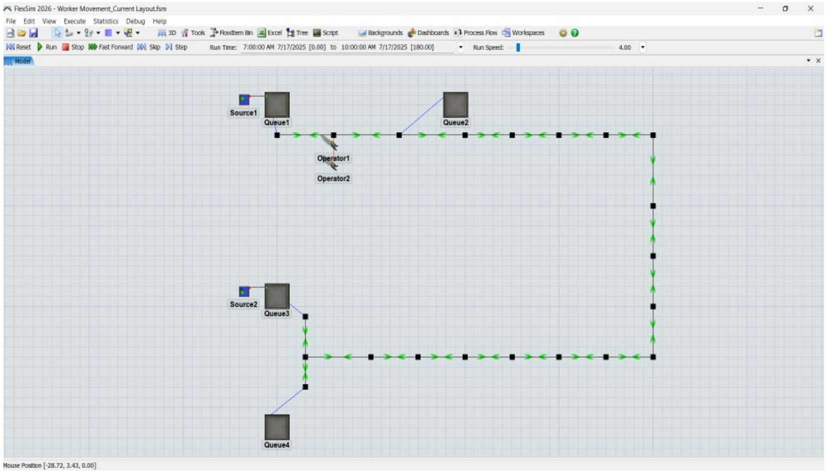

Figure 6
Model of Worker Movement in Current Layout

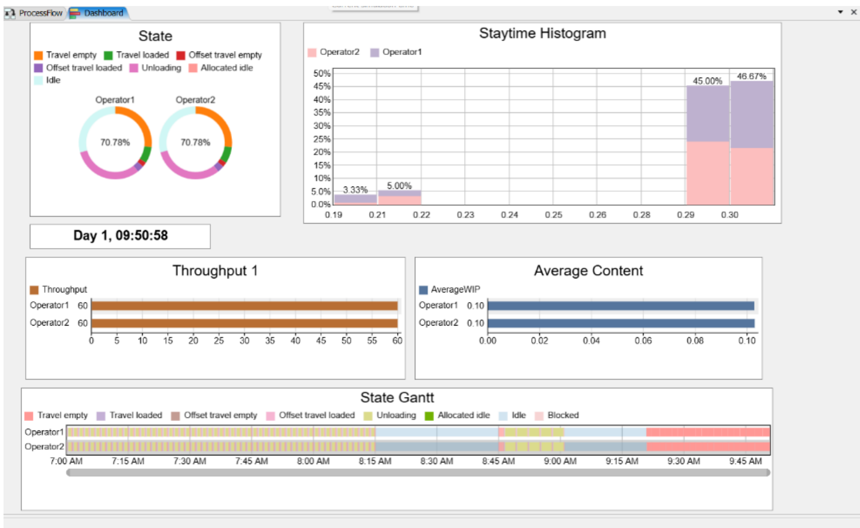

Figure 7
Data of Worker Movement in Current Layout

Moreover, the analysis of the transporter performance in the current layout further highlighted inefficiencies in material handling. The MTFA required approximately 180 minutes to complete one full operational cycle, with an overall utilization of approximately 52.22%. A substantial portion of this time was spent in non-value-added states, such as waiting and traveling, largely due to dependence on manual fertilizer bag loading at the field. These results confirmed that the existing layout did not fully support continuous and balanced operations between labour and machinery. Figures 8 and 9 show the model and data of transporter movement in the current layout, respectively.

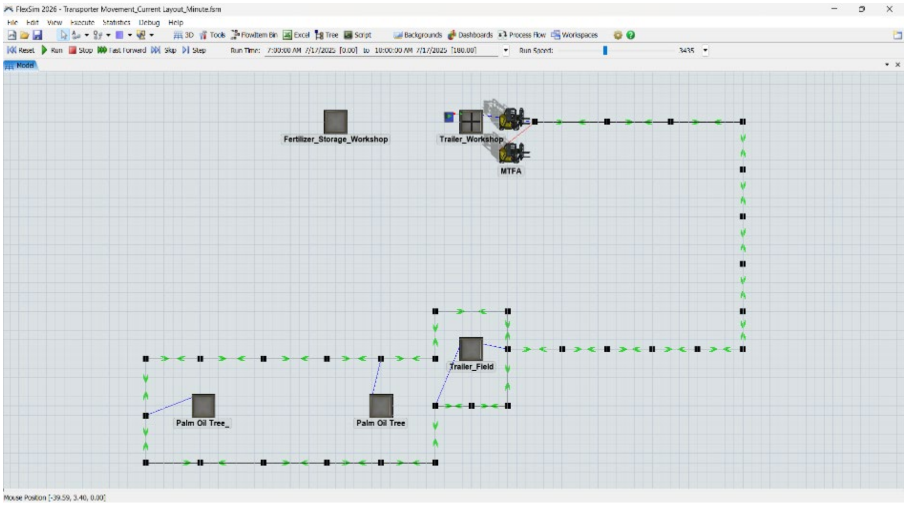

Figure 8
Model of Transporter Movement in Current Layout

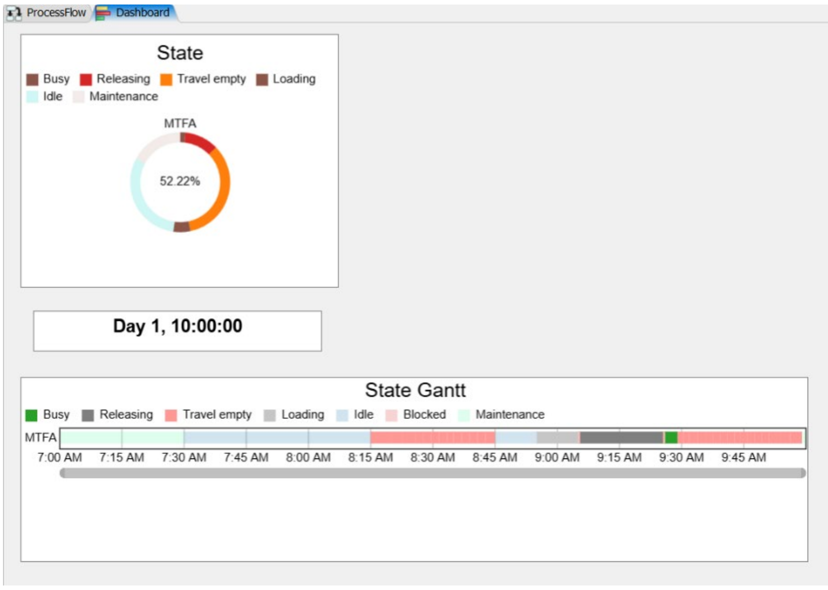

Figure 9
Data of Transporter Movement in Current Layout

Proposed Layout Time Analysis

Following the introduction of the proposed layout incorporating the fertilizer lift, significant improvements in labor performance were recorded. By relocating all fertilizer bag loading activities to the workshop area and automating fertilizer dispensing at the field, worker involvement in field operations was eliminated. As a result, worker utilization increased substantially to approximately 88.89%, indicating a shift toward more productive and continuous work. The workers' activities were concentrated within the early phase of the operation, after which they remained available for reassignment to other productive tasks. The reduced variability in task duration and the elimination of field-related waiting time produced a more compact and predictable work pattern, with idle time minimized across the operational cycle. Figures 10 and 11 show the model and data of worker movement in the proposed layout extracted from the FlexSim simulation software, respectively.

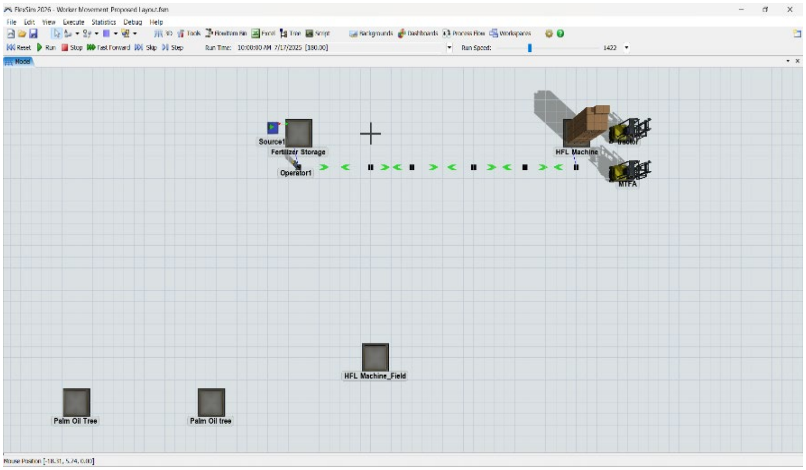

Figure 10
Model of Worker Movement in Proposed Layout

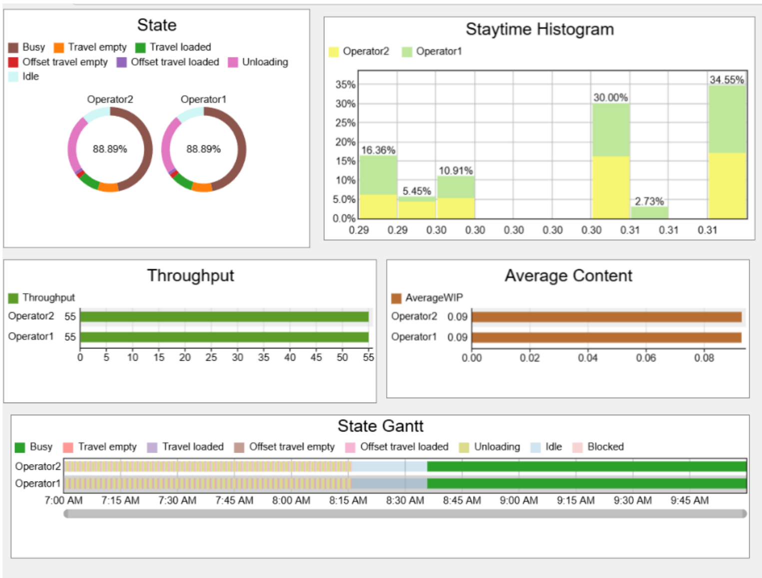

Figure 11
Data of Worker Movement in Proposed Layout

Improvements were also recorded in transporter performance under the proposed layout. The MTFA completed one operational cycle in approximately 166.79 minutes, representing a reduction of about 13.21 minutes compared to the current layout. This corresponded to 7.3% improvement in time efficiency for transporter movement. Although MTFA utilization increased only moderately to 54.45%, the reduction in loading-related delays and waiting time resulted in smoother and more consistent operations throughout the cycle. Figures 12 and 13 show the model and data of transporter movement in the proposed layout. Overall, the findings demonstrated that the proposed layout provides better quantitative integration between labor and equipment by reducing the dependency on manual material handling for the manuring process at the field. The introduction of the HFL effectively increases worker utilization, reduces total cycle time, and improves workflow consistency. The simulation results confirmed that the proposed layout successfully addressed the main inefficiencies identified in the current system. The improved arrangement enhances operational performance and provides a more efficient and sustainable approach to plantation manuring operations.

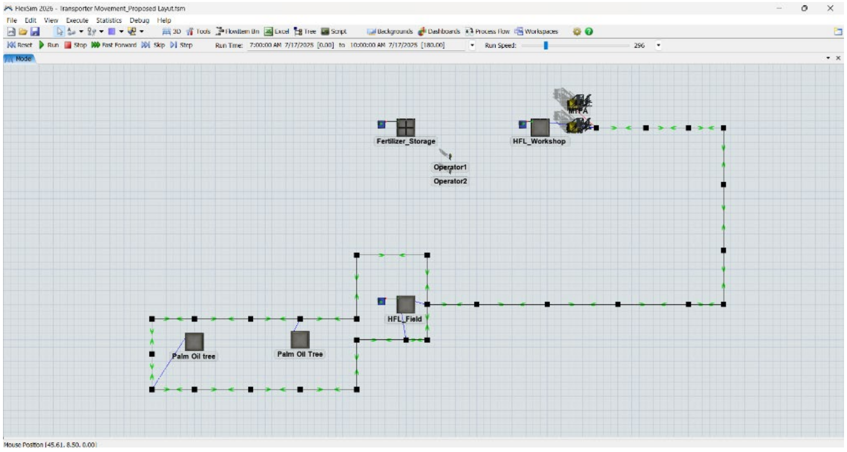

Figure 12
Model of Transporter Movement in Proposed Layout

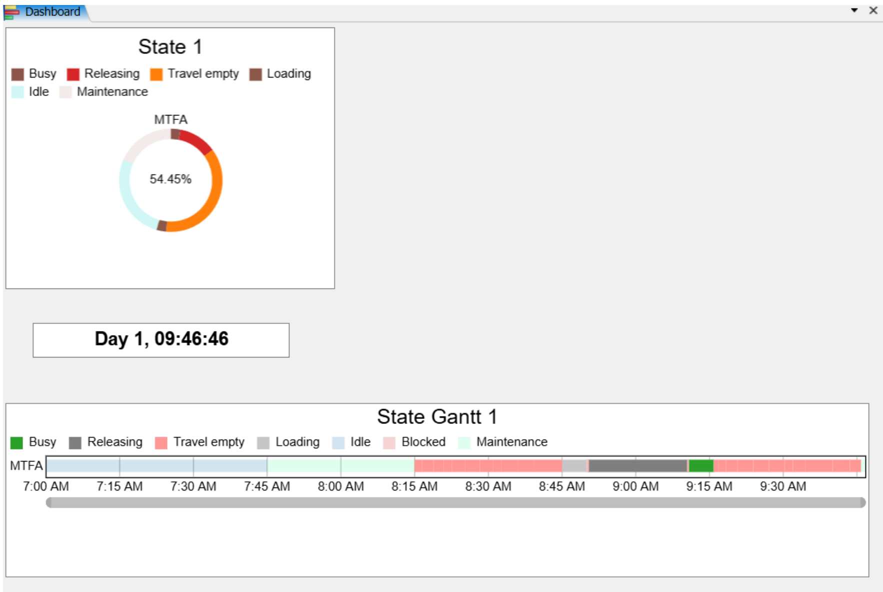

Figure 13
Data of Transporter Movement in Proposed Layout

LIMITATIONS AND RECOMMENDATIONS

Despite the valuable insights obtained from this study, several limitations should be acknowledged, as they may affect the extent to which the findings can be generalized and applied to other plantation environments or operational settings. First, the simulation model developed using the FlexSim software focused primarily on operational time analysis and worker utilization, without incorporating detailed cost evaluation or economic feasibility analysis. As a result, the financial implications of implementing the proposed layout and mechanized system were not quantitatively assessed. In addition, the facility layout model for the workshop area was developed based on on-site observations and photographs rather than precise dimensional drawings, due to the unavailability of official layout plans. This may limit the accuracy of spatial representation, although it does not affect the validity of the process flow and time-based analysis. Furthermore, the scope of this study was limited to the fertilization process within the manuring area and may not fully represent variations in terrain, field size, or operational practices across other plantation areas.

In addition, the applicability of the proposed HFL system to other oil palm plantations is influenced by variations in terrain and soil conditions. In steeper or terraced areas with moderate to high slope gradients, system performance may be affected by reduced stability, limited maneuverability, and an increased risk of tipping or inefficient material transport. Similarly, wetter or softer soil conditions may reduce ground bearing capacity and increase wheel slippage, which can negatively affect traction and overall energy efficiency, particularly during repeated loading and unloading operations. These factors indicate that the system's performance is closely dependent on site-specific environmental conditions, particularly those related to slope and soil strength.

Moreover, future studies are recommended to expand the scope of analysis to include multiple plantation fields and different fertilizer types to improve the generalizability of the findings. Incorporating cost-benefit analysis, maintenance requirements, and long-term labor impact would provide a more comprehensive evaluation of the proposed mechanized layout. In addition, future research could integrate more detailed spatial data and consider environmental factors, such as terrain conditions and weather variability, to enhance simulation accuracy. Further development of the simulation model to include complete operational cycles and alternative process flows would also support more robust decision-making and continuous improvement in plantation facility layout planning.

CONCLUSION

In conclusion, the improvement to the current facility layout for the manuring process at the oil palm plantation summarized the key findings obtained through simulation analysis. The conclusion highlights the effectiveness of the proposed layout in addressing operational inefficiencies and reflects on the contribution of simulation-based analysis in decision making for plantation-based facility planning.

This study successfully analyzed the current manuring process and identified key inefficiencies related to manual material handling, worker idle time, and unbalanced task allocation. Through the development of the proposed layout incorporating the fertilizer lift, a significant improvement was achieved in worker utilization and process efficiency. The simulation results showed an increase in worker utilization from approximately 70.78% to 88.89%, along with a reduction in total operation cycle time from 180 minutes to 166.79 minutes, which represented 7.3% improvement in transporter movement efficiency. These findings confirm that centralizing fertilizer bag loading at the workshop and automating dispensing at the field can effectively streamline the manuring process without altering the current physical layout of the facility. Thus, the proposed HFL integration is recommended for plantations with similar operational characteristics, particularly those involving long manuring distances of more than 4 km and manual loading bottlenecks.

For future research, it is recommended that the simulation be extended to include multiple operational cycles and additional plantation fields to better represent long-term operational performance. Additionally, future studies may incorporate the actual travel distances and cost-benefit analysis to generate more comprehensive evaluation of the proposed layout. In addition, the impact of mechanization on workforce deployment, maintenance requirements, and system reliability could be examined to support larger-scale implementation. This extension would enhance the overall reliability and comprehensiveness of the findings, thereby providing stronger justification and more effective support for decision making in plantation facility layout planning and future operational improvements.

REFERENCES

Ahn, H. S., Dayoub, F., Popović, M., MacDonald, B. A., Siegwart, R., & Sa, I. (2018). *An overview of perception methods for horticultural robots: From pollination to harvest*. arXiv. https://arxiv.org/abs/1807.03124

Aliyu, R., & Mokhtar, A. A. (2021). Research Advances in the Application of FlexSim: A Perspective on Machine Reliability, Availability, and Maintainability Optimization. *Journal of Hunan University Natural Science, 48*(9), 518-563.

Goh, K. J., Teo, C. B., Chew, P. S., & Chiu, S. B. (1999). Fertiliser Management in Oil Palm: Agronomic Principles and Field Practices. *Fertilizer Management for Oil Palm Plantations, 20,* 21

Hu, F., Wang, C., & Wu, X. (2025). Generative Artificial Intelligence-Enabled Facility Layout Design Paradigm. *Applied Sciences (Switzerland)*, *15*(10), 5697. https://doi.org/10.3390/app15105697

Karim, N.N.A., Tajurahim, N.A.N., Mahmood, S., & Samat, M. K. (2022). Facility Layout Improvement for Erul Food Industry: A Simulation and Comparison. *3rd Asia Pacific International Conference on Industrial Engineering and Operations Management.* https://doi.org/10.46254/AP03.20220030.

Khambalkar, P. A., Agrawal, S., Dhaliwal, S. S., Yadav, S. S., Sadawarti, M. J., Singh, A., Yadav, I. R., Yadav, K., Shivansh, Prasad, D., Singh, A., & Afreen, N. (2025). Sustainable nutrient management balancing soil health and food security for future generations. In *Applied Food Research, 5*(2), 101087. https://doi.org/10.1016/j.afres.2025.101087

Kikolski, M., & Ko, C. H. (2018). Facility layout design - Review of current research directions. In *Engineering Management in Production and Services, 10*(3), 70-79. De Gruyter Open Ltd. https://doi.org/10.2478/emj-2018-0018

Liu, H., Liu, X., Lin, L., Islam, S. M. N., & Xu, Y. (2020). A study of the layout planning of plant facility based on the timed Petri net and systematic layout planning. *PLoS ONE*, *15*(9), 1-23. https://doi.org/10.1371/journal.pone.0239685

Mahey, H. K., Sharma, K., Singh, A., Rampal, V. K., & Kaushik, P. (2024). Green Manuring Crop Plants: Harnessing Natural Processes to Enhance Soil Health and Promote Sustainable Agricultural Practices, 1-24. *Preprints.* https://doi.org/10.20944/preprints202406.0340.v1

Naik, S. B., & Kallurkar, S. (2016). A Literature Review On Efficient Plant Layout Design. *International Journal Of Industrial Engineering Research And Development*, *7*(2), 28-35. https://doi.org/10.34218/ijierd.7.2.2016.005

Nurudeen, A., Dagwa, I., Ugheoke, I., & Muhammad, I. (2024). Facility layout design, simulation, and optimization for kaolin beneficiation plant using Flexsim. *Mechanical Technology and Engineering Insights, 1*(1), 15-27.

Nooranizam, N. F. F., & Mahmood, S. (2024). Proposed Improvement of Factory Layout for KSF Industry Sdn Bhd using Flexsim Software. *Progress in Engineering Application and Technology*. *5*(2), 377–386. https://doi.org/10.30880/peat.2024.05.02.039

Okpala, C. C., Chukwumuanya, E. O., & Chikwendu, C. (2016). *Plant layouts' analysis and design*. *International Journal of Advanced Engineering Technology, 7*(3), 201–206.

Pearly Saira, C., Gritty Maria, P., & N. Ramanathan, H. (2019). Facility Layout Improvement For Enhancing Productivity: An Application Of Systematic Plant Layout. *International Journal Vallis Aurea*, *5*(2), 5–19. https://doi.org/10.2507/IJVA.5.2.1.62

Pérez-Gosende, P., Mula, J., & Díaz-Madroñero, M. (2021). Facility layout planning. An extended literature review. In *International Journal of Production Research, 59*(12), 3777–3816. https://doi.org/10.1080/00207543.2021.1897176

Prajapati, S. K., Dayal, P., Kumar, V., & Gairola, A. (2023). Green Manuring: A Sustainable Path to Improve Soil Health and Fertility. *AgriSustain-An International Journal*, *2023*(2), 24–33. https://doi.org/10.5281/zenodo.10049824

Raj, A., & Dawar, R. (2023). Chapter-8 Modern Concepts of Fertilizer Application Methods and it's Management to Increase Nutrient use Efficiency. *Advances in Agricultural Engineering, 2*(1), 50-56.

Ramlan, M.I.H., Mamat, T.N.A.R ., & Masrol, S. R. (2024). Comparison of Transfer Process Layout at Company A using Arena Simulation Software. *Progress in Engineering Application and Technology*. *5*(1), 453–461. https://doi.org/10.30880/peat.2024.05.01.049

Suriansah, N. L. S., Mahmood, S., Samat, M. K., & Jiran, N. S. (2022). A Simulation of Facility Layout Improvement at Local Food Industry. *International Journal of Integrated Engineering*, *14*(6), 16–27. https://doi.org/10.30880/ijie.2022.14.06.002

Vahdanjoo, M., & Sorensen, C. G. (2021). Novel Route Planning Method to Improve the Operational Efficiency of Capacitated Operations. Case: Application of Organic Fertilizer. *AgriEngineering*, *3*(3), 458–477. https://doi.org/10.3390/agriengineering3030031

Vanstappen, H. (2019). SketchUp software and file format: exploration of the options for digital preservation. *International Journal of Digital Archives, 6*(2), 112-130.

Varinder Khurana, R. M. (2015). Facility Layout Planning: A Review. *International Journal of Innovative Research in Science, Engineering and Technology*, *4*(3), 976–980. https://doi.org/10.15680/ijirset.2015.0403027

Wang, T., & Feng, Y. (2023, October). *Workshop Layout Optimation and Simulation Analysis Based on SLP: A Case Study*. In 2023 4th International Conference on Management Science and Engineering Management (ICMSEM 2023) (pp. 1443-1453). Atlantis Press. https://doi.org/10.2991/978-94-6463-256-9_146

Wang, Z., Wei, K., Wen, B., You, K., Wang, H., Ye, C., & Ren, F. (2025). Research on the Allocation Level of Land for Agricultural Facilities Based on Green and High-Quality Development: A Case Study of Zhejiang Province. *Land*, *14*(4), 672. https://doi.org/10.3390/land14040672

Wu, T., & An, R. (2024). Study on the Optimization of X Warehouse Layout Based on SLP and Flexsim. *Journal of Engineering System, 2*(4), 1-8. https://doi.org/10.62517/jes.202402401