

Impact of Plant Layout on Material Flow: Saudi Industrial Case Studies

Ahmad Alkhaleefah

Assistant professor

Prince Sultan University

Riyadh, Saudi Arabia

a.alkhaleefah@psu.edu.sa

Abstract

Efficient material flow is a fundamental requirement for operational performance in manufacturing facilities, yet it is frequently compromised by plant layouts that are developed without sufficient consideration of operational sequencing and movement patterns. This study examines the impact of plant layout decisions on material flow efficiency through a set of Saudi industrial case studies. The research is based on primary empirical data collected through supervised field observations and measurements conducted by students across multiple manufacturing facilities. Simple spatial and movement-related indicators such as distances between sequential operations, movement frequency, and handling-related time were analyzed using descriptive statistical methods. The analysis compares existing layouts with proposed alternative configurations to assess the magnitude and consistency of material flow inefficiencies. The findings reveal that existing plant layouts are associated with relatively long and inconsistent distances between sequential operations, leading to increased motion waste and fragmented material flow. In contrast, layout alternatives that better align spatial arrangement with process sequence demonstrate substantial reductions in average distances, movement variability, and handling effort. The results indicate that material flow inefficiencies are not isolated anomalies but reflect systemic layout-related issues across the examined cases. This study underscores that plant layout is not merely a physical arrangement decision but a strategic operational determinant with direct implications for material flow performance. By employing simple empirical measures and a multi-case perspective, the study provides practical evidence highlighting the critical role of layout planning in supporting efficient manufacturing operations, particularly within industrial environments characterized by limited data availability.

Keywords

Plant Layout, Material Flow Efficiency, Facility Planning, Industrial Case Studies, and Saudi Arabia.

1. Introduction

In contemporary manufacturing environments, material flow efficiency has become a critical determinant of operational performance, cost control, and responsiveness to market demand. As production systems grow more complex and product variety increases, the movement of materials across facilities often represents a significant portion of non-value-adding activities. Within this context, plant layout planning plays a central role in shaping how materials, workers, and information interact across the production system.

Despite this importance, many industrial facilities continue to operate with layouts that have evolved incrementally over time, influenced by space availability, organizational constraints, or short-term operational decisions rather than systematic layout planning principles. Such layouts often result in excessive travel distances, repeated handling, intersecting movement paths, and congestion, all of which negatively affect material flow efficiency and contribute to motion waste.

The existing literature has extensively emphasized the importance of facility layout in improving material flow and reducing operational inefficiencies. However, much of this literature either focuses on single-case optimization, simulation-based redesigns, or assumes the availability of detailed quantitative data and advanced analytical tools. Less attention has been given to how simple, field-based empirical observations across multiple facilities can reveal consistent patterns linking plant layout characteristics to material flow inefficiencies, particularly in real industrial contexts where data availability is limited.

Accordingly, this study aims to examine the impact of plant layout on material flow efficiency using primary empirical data collected from multiple industrial case studies in Saudi Arabia. By applying descriptive and comparative analysis to spatial and movement-related data, the study provides practical insights into how layout-related decisions influence material flow performance. The findings contribute to a better understanding of plant layout as a foundational managerial and engineering decision, rather than a purely physical or schematic exercise.

2. Literature Review

Previous studies converge on the view that motion waste is a direct outcome of inadequate plant layout and poor alignment between operational sequencing and material flow logic. Jessani et al. (2019) explicitly identified unnecessary motion as one of the most influential forms of waste in Lean environments, emphasizing that its reduction is essential for improving operational efficiency, albeit without providing detailed spatial measurements between sequential operations. This perspective aligns with the findings of Szabó et al. (2020), who demonstrated that visual tracking of movement paths reveals excessive travel distances and unnecessary intersections, often resulting from layouts that do not reflect actual process flow requirements. Their work highlighted that even simple reconsideration of movement paths can expose substantial improvement opportunities.

Similarly, Mendoza-Ortega et al. (2020) showed through Systematic Layout Planning (SLP) based redesign that bringing sequential operations closer leads to significant reductions in material handling distances and improvements in material flow performance. This conclusion was reinforced by Henni (4), who reported that rearranging functionally adjacent departments resulted in lower internal transport distances and handling costs. Firmansyah et al. (7) further supported this logic by demonstrating that reductions in total transport distances positively affect overall operational performance, implicitly assuming a direct causal relationship between distance, time, and cost.

In a partially related context, Maniezzo et al. (2018) focused on congestion in receiving areas, showing that capacity constraints and synchronized truck arrivals generate operational bottlenecks. However, their analysis remained confined to the receiving function itself and did not trace how such congestion propagates into internal material movement and downstream flow inefficiencies. Despite differences in analytical tools and methodological rigor, studies share the assumption of direct relationship between distance, motion, and time without broad comparative validation; reliance on single or very limited case studies; and emphasis on solution deployment rather than systematic diagnosis of recurring layout-related inefficiencies.

A. What Literature Has Overlooked

Although prior research strongly emphasizes the importance of reducing motion waste and improving plant layout, most studies do not explicitly address the diagnostic phase preceding layout intervention. The majority assume that inefficiencies are already well-defined and proceed directly to applying redesign tools, optimization models, or Lean techniques. Limited attention has been given to how simple operational data, such as distances between sequential operations, movement frequency, and daily handling activities, can be used to detect recurring patterns of inefficiency and estimate their magnitude before engaging in complex redesign efforts.

Furthermore, few studies discuss how non-standardized field observations can generate valid improvement hypotheses, or how such observations can be unified across multiple cases to form a comparable analytical framework. As a result, a gap remains in linking early-stage operational observation with structured comparative analysis that precedes formal layout redesign.

B. Limitations of Existing Studies

Despite their scientific and practical contributions, studies exhibit several methodological limitations that restrict the generalizability of their findings. Most rely on single-case analyses or highly contextualized industrial settings, making it difficult to extract patterns applicable across diverse manufacturing environments. Additionally, many studies

prioritize final improvement outcomes, such as optimized layouts or Lean implementations, without explicitly linking the existing layout configuration to the specific type of material flow inefficiency observed. Several contributions also depend on advanced analytical models or simulation techniques that require detailed time-based data, which are often unavailable in small- and medium-sized manufacturing facilities. Finally, studies addressing congestion or receiving-related issues tend to treat these functions in isolation, rather than embedding them within an integrated view of internal material flow.

C. Research Gap

The present study is grounded in the same conceptual foundation as earlier works (1) – (7), recognizing plant layout as a fundamental determinant of material flow efficiency. However, it differs in analytical focus and methodological intent. Instead of assuming predefined inefficiencies and directly proposing optimization solutions, this research emphasizes the diagnostic stage of layout-related analysis. It demonstrates how primary empirical data, collected through supervised field observations, specifically spatial distances, movement frequency, and handling activities, can reveal recurring patterns of material flow inefficiency across multiple industrial cases.

By adopting a multi-case comparative approach, the study moves beyond isolated contextual findings and identifies common layout-related inefficiencies observable across different Saudi manufacturing facilities. Moreover, it introduces a lightweight analytical framework that links existing layout characteristics to observed motion waste without relying on simulation models or extensive time measurements. Finally, by incorporating receiving-area congestion as a supporting operational case, the study addresses a limitation in prior research by integrating entry-point constraints into a broader internal material flow perspective.

In doing so, the present work positions itself as a bridge between descriptive field observation and layout-driven improvement, offering a practical and defensible empirical foundation upon which more advanced redesign or optimization studies may subsequently build.

D. Purpose of the Study

The purpose of this study is to examine how material flow bottlenecks and motion waste emerge as a result of non-optimized plant layouts, using simple primary empirical data related to spatial distances and movement activities collected from multiple industrial cases. The study aims to provide a comparative diagnostic perspective that highlights patterns of material flow inefficiencies and reveals potential improvement opportunities without proposing or implementing specific layout redesign solutions.

E. Research Questions

The research questions are formulated to operationalize and examine the purpose of the study through descriptive and comparative analysis:

RQ1: How do spatial distances between sequential operations reflect material flow inefficiencies in existing plant layouts?

RQ2: To what extent do observed movement frequency and handling activities indicate the presence of motion waste associated with the current layout configuration?

RQ3: What comparative patterns of potential material flow improvement can be identified across multiple industrial cases based on spatial and movement-related empirical data?

F. Research Objectives

O1: To examine how spatial distances between sequential operations in existing plant layouts reflect material flow inefficiencies and potential bottlenecks, using field-based empirical distance measurements.

O2: To assess the extent to which observed movement frequency and handling time indicate motion waste under current layout configurations, based on simple movement-related indicators collected from industrial cases.

O3: To identify recurring, cross-case patterns of potential material flow improvement by comparing existing layouts with proposed alternative configurations across multiple Saudi industrial case studies, using descriptive and comparative analysis.

3. Methods

This study adopts a practical empirical methodology aimed at diagnosing material flow inefficiencies and motion waste associated with plant layout configurations in industrial facilities. The methodological approach emphasizes simplicity, field relevance, and comparative insight, rather than optimization or inferential modeling, thereby aligning with the exploratory and diagnostic nature of the research.

A. Research Design

The research follows an applied empirical research design with a descriptive–comparative orientation. It focuses on identifying recurring patterns of material flow inefficiencies arising from existing plant layouts across multiple industrial cases. The study does not seek to develop optimal layout solutions or to test statistical hypotheses; instead, it aims to examine observable layout-related conditions and their implications for material flow performance using basic empirical indicators.

B. Data Source and Nature

The study is based on primary empirical data collected through supervised industrial case studies conducted by students under the direct methodological guidance of the author. The data were collected specifically for the purpose of this research and have not been previously published. Data collection involved direct field observation within operating facilities, including measurement of spatial distances between sequential operations, documentation of material handling activities, and estimation of movement-related characteristics within real industrial environments.

C. Description of the Studied Cases

The analyzed cases represent industrial facilities that differ in product type, operational characteristics, layout configuration, and process complexity. The cases were intentionally selected to support comparative analysis, enabling the identification of common layout-related patterns rather than statistical generalization. The objective of including multiple cases is to extract recurring tendencies in material flow behavior associated with layout decisions.

D. Data Classification

To support structured analysis, the empirical data were organized into four main categories:

- Quantitative spatial data, including measured distances between sequential operations in the existing layout and in a proposed alternative arrangement.
- Movement and frequency data, capturing the number of handling trips, movement repetitions, and estimated movement times associated with material flow.
- Improvement indicators, reflecting potential reductions in distances and movement derived from the proposed layout rearrangements.
- Supporting categorical data, used to relate material flow inefficiencies to receiving area congestion as a complementary operational case.

This classification facilitated systematic comparison across cases while maintaining analytical clarity.

E. Analytical Approach

A descriptive statistical analysis was applied to the empirical data. The analysis included before–after layout comparisons, calculation of averages and percentage changes, and examination of trends across the studied cases. The purpose of the analysis was to estimate the magnitude of potential material flow improvement opportunities and to highlight consistent patterns of motion waste, rather than to establish causal relationships through inferential statistics.

F. Role of the Receiving Area in the Analysis

Receiving area congestion was incorporated as a supporting operational case to illustrate how constraints at the facility entrance may propagate into internal material flow inefficiencies. The receiving area was not treated as an independent statistical focus, but rather as a contextual element that reinforces the linkage between layout decisions and internal movement behavior.

G. Methodological Limitations

Given the reliance on field-based case data and a limited number of industrial facilities, the findings are interpreted within a comparative diagnostic framework. The proposed layout-related improvements represent potential opportunities rather than verified implementation outcomes. Accordingly, the results are intended to support practical understanding and early-stage diagnosis of material flow inefficiencies, while recognizing that more detailed optimization or simulation-based studies may be required in subsequent research phases.

4. Empirical Data

The four datasets presented in this study fully represent the available empirical evidence derived from the analyzed student case reports and constitute the complete basis for the descriptive and comparative analysis conducted.

Table 1. Spatial Distances Between Sequential Operations Before and After Proposed Layout

Case	First Operation	Second Operation	Distance Before Layout (m)	Distance After Layout (m)
C1	Cutting	Assembly	32	8
C2	Drilling	Grinding	28	10
C3	Welding	Inspection	25	12
Mean	—	—	28.3	10.0
Minimum	—	—	25	8
Maximum	—	—	32	12
Range	—	—	7	4

The Table 1 presents the core spatial data extracted from the student case reports, which serve as the starting point for analyzing motion waste and material flow performance. These data were collected through direct field observation, where students measured the distances between sequential operations within each facility under the existing layout conditions. The observed distances were then compared with distances derived from a proposed alternative layout developed by the students, in which functionally related operations were repositioned to better reflect the actual flow of materials. The table is used for relative comparison between the current and proposed layouts in order to illustrate the potential magnitude of material flow improvement, without implying that the proposed configurations were implemented in practice. In this context, distances under the current layout represent the observed operational reality during site visits, while distances under the proposed layout reflect analytically derived outcomes from layout reconfiguration aimed at improving process sequence alignment and reducing unnecessary movement. This structured comparison provides a transparent empirical basis for subsequent descriptive statistical analysis, including mean values, ranges, and relative improvement indicators.

The results of the integrated table indicate that distances between sequential operations in the existing layouts range from 25 to 32 meters, with an average of approximately 28.3 meters. In contrast, the proposed layouts reduce these distances to a range of 8 to 12 meters, with an average of about 10 meters, reflecting a clear and systematic difference between the current and alternative layouts across all analyzed cases. The minimum and maximum values further show that even the shortest distance in the existing layouts remains longer than most distances observed in the proposed layouts, while the maximum distances before redesign are substantially higher than those after redesign. This highlights a weak alignment between the existing layouts and the actual sequence of operations when compared to the proposed arrangements. Moreover, the reduction in range from 7 meters in the current layouts to 4 meters in the proposed layouts indicates that the improvement is not limited to distance reduction alone but is also associated with greater spatial consistency across cases. From a facilities planning perspective, this increased consistency is an important indicator, as it reflects more stable material flow patterns and reduced operational variability.

Table 2. Movement Frequency and Time-Related Data Under Existing Layout Conditions

Case	Daily Trips Between Operations	Average Trip Time (sec)	Total Wasted Time per Shift (min)
C1	30	35	17.5
C2	24	30	12.0
C3	20	40	13.3
Mean	24.7	35.0	14.3
Minimum	20	30	12.0
Maximum	30	40	17.5
Range	10	10	5.5

The Table 2 presents movement and frequency data related to material flow across the analyzed cases. These data capture the number of material or worker transfers between sequential operations, along with the approximate time required for each trip, as reported in the student case studies or directly inferred from field observations. The table is used to estimate the magnitude of motion waste associated with the existing facility layouts and to establish a simple quantitative basis for comparative analysis across cases. The reported time and idle-time values represent operational estimates derived from observed movement frequencies rather than precise time-motion measurements, and are therefore employed for descriptive and relative comparison purposes. By linking spatial distance (Table 1) to movement frequency and time impact, this dataset enables the extraction of summary statistics, case ranking, and preliminary assessment of layout-related improvement potential.

The Table shows that the number of daily trips between sequential operations ranges from 20 to 30 trips per shift, with an average of approximately 24.7 trips, indicating a consistently high frequency of material handling movements across all studied cases. In addition, the duration of a single trip ranges between 30 and 40 seconds, with an average of 35 seconds, a duration that occurs frequently enough to translate into a tangible amount of operational time loss over the course of a shift. The observed range in total wasted time, reaching up to 5.5 minutes across cases, reflects operational variability resulting from differences in process sequencing and movement paths. This variation supports the use of movement frequency and associated time as direct quantitative indicators of motion waste linked to the existing facility layout.

Table 3. Improvement Indicators Derived from Proposed Layout Configurations

Case	Distance Reduction (%)	Movement Reduction (%)
C1	75%	70%
C2	64%	60%
C3	52%	45%
Mean	63.7%	58.3%
Minimum	52%	45%
Maximum	75%	70%
Range	23%	25%

The Table 3 presents improvement indicators derived from the comparison between the existing facility layouts and the proposed layout configurations across the analyzed cases. These indicators quantify the potential reduction in spatial distances and motion-related activities that could be achieved if the suggested layout rearrangements were adopted, thereby illustrating the magnitude of improvement opportunities in material flow performance and motion waste reduction in a clear and comparable manner. It should be noted that the reported improvement percentages represent theoretical improvement potential based on layout redesign scenarios and do not reflect results from actual implementation within the facilities. By consolidating observations, comparative analysis, and improvement indicators, this table completes the analytical progression from empirical observation to structured comparison and

performance interpretation, providing a coherent basis for descriptive statistical analysis and subsequent discussion of layout-related material flow inefficiencies.

The table shows that the proposed layout is associated with clear potential for reducing both distances and material handling activities across all studied cases, with an average distance reduction of approximately 63.7% and an average reduction in handling movement of 58.3%. The minimum and maximum values indicate that all cases—including those with the least improvement—exhibit tangible reductions, suggesting that the effect of the proposed layout is not limited to a single case. Moreover, the relatively narrow range of improvement reflects that, although the magnitude of improvement varies among cases, the pattern remains consistent, reinforcing the view that layout improvement represents a systematic and effective mechanism for reducing motion waste in industrial facilities.

Table 4. Receiving Area Congestion as a Supporting Operational Case

Case	Problem Location	Type of Constraint	Impact on Material Flow
C1	Receiving Area	Receiving congestion	Increased internal movement and route interference
C2	Receiving Area	Waiting and unloading delays	Additional internal handling activities
C3	Receiving Area	Limited space	Forced detours and extra handling time

The Table 4 links internal material flow inefficiencies with congestion in the receiving area, presented as a supporting applied case within the study. It illustrates that constraints at the receiving area—such as truck congestion, unloading delays, or limited space—do not remain confined to the plant entrance, but propagate into internal operations, affecting movement patterns and material flow continuity. This connection reinforces the central premise of the study that motion waste and flow inefficiencies should be examined across the entire facility system rather than in isolated functional zones. From a methodological perspective, the receiving area is incorporated as a supporting operational case to demonstrate how upstream constraints translate into downstream material handling inefficiencies, without positioning receiving congestion as an independent research focus. By doing so, this table completes the logical progression established across the empirical datasets, highlights the interdependence between receiving operations and internal material flow, and strengthens the overall analytical framework of the study in a coherent and defensible manner. Due to the categorical nature of the data, Table 4 is analyzed using descriptive qualitative statistics to identify recurring patterns in receiving-related issues and their consistent impact on internal material flow.

The table indicates that all studied cases exhibit operational constraints in the receiving area, although the nature of the issue varies between congestion, waiting, and limited space. These constraints are reflected in increased internal movement, route interference, or additional temporary handling activities. The findings are presented as supporting operational observations that complement the analysis of internal material flow.

5. Results and Discussion

The empirical analysis reveals that the spatial distances between sequential operations in the existing layouts are relatively large and consistently clustered around a high average. This pattern does not indicate isolated design flaws or exceptional cases; rather, it reflects a broader layout tendency characterized by weak functional adjacency between operations that should, by material flow logic, be positioned close to one another. From a facility planning perspective, such distance patterns typically emerge when layouts are driven by structural constraints, historical expansions, or traditional functional separation, rather than by the actual sequence of operations and flow requirements.

In contrast, the proposed layout scenarios demonstrate a substantial reduction in average distances alongside a noticeable narrowing of variability across cases. This suggests that meaningful improvements can be achieved through spatial realignment alone, without altering processes, resources, or production volumes. Such findings reinforce a fundamental principle of facility planning: inefficiencies in material flow often stem not from insufficient space or capacity, but from how functions are arranged within the available space. The increased spatial consistency observed after realignment is particularly important, as stable and predictable distances contribute to smoother flow and reduced operational variability, an aspect frequently overlooked in incrementally evolved layouts.

The movement-related findings further support this interpretation. The observed number of daily trips between operations indicates that material handling is not an occasional activity, but a repetitive and integral part of daily operations. When such high-frequency movement is combined with non-essential distances, the resulting motion waste is amplified through repetition. Although the time required for a single trip may appear modest in isolation, its cumulative effect over multiple trips per shift translates into a measurable loss of productive time. This highlights a common weakness in non-optimized layouts, where small movement times are underestimated while their aggregate operational impact is overlooked.

Importantly, the time lost due to repeated handling activities should not be interpreted as a consequence of worker inefficiency or individual performance. Rather, it reflects a structural outcome of how operations and paths are spatially arranged. From a facility planning standpoint, this distinction is critical: addressing motion waste in such contexts does not require behavioral interventions or additional resources, but a reconsideration of route logic and the spatial sequencing of operations. While some level of movement may be justified by process requirements, the consistency of movement patterns across cases suggests that the existing layouts were not designed with systematic minimization of repeated handling in mind.

The comparative improvement indicators show that substantial reductions in distance and motion are achievable across all cases, with relatively consistent improvement levels. This consistency implies that the observed inefficiencies are not unique to a specific plant or product type but are instead linked to common layout-related decision patterns. The absence of extreme improvement values also adds credibility to the findings, indicating that the proposed changes respect operational and regulatory constraints rather than assuming radical or impractical redesigns. From a planning perspective, this balance between improvement magnitude and realism strengthens the applicability of the results.

The analysis also highlights the role of the receiving area as a contributing factor to internal flow inefficiencies. Although the nature of receiving-related problems varies—ranging from truck congestion and unloading delays to space limitations—their downstream effects are remarkably similar. In all cases, receiving constraints propagate into the internal system in the form of additional movement, temporary transfers, or intersecting paths. This reinforces the view that receiving should not be treated as an isolated logistical function, but as an integral entry point of the internal material flow system.

When receiving areas are designed primarily around unloading capacity without adequate consideration of internal flow continuity, bottlenecks tend to shift rather than disappear. Facility planning principles emphasize that front-end constraints often amplify downstream motion waste if transitional mechanisms—such as clear exit paths, staging zones, or flow-aligned buffers—are not incorporated. The recurring internal impacts observed across cases suggest that such integrative planning considerations were insufficiently addressed in the existing layouts.

Overall, the discussion indicates that the observed material flow inefficiencies are structural in nature and closely tied to layout decisions that did not fully prioritize flow logic. The findings collectively support the argument that effective plant layout planning is not a purely spatial or graphical exercise, but a systemic decision-making process that must be grounded in a thorough understanding of material flow behavior, movement repetition, and operational interactions across the facility.

6. Proposed Improvement

The study recommends redefining facility layout planning around recurrent material flow paths, rather than relying solely on departmental boundaries or organizational structures. The findings indicate that excessive distances and motion waste stem largely from weak alignment between layout configurations and actual process sequences. Accordingly, operations with frequent material interactions should be treated as functional clusters during layout redesign, enabling simultaneous reduction in travel distances and handling frequency. This recommendation is non-trivial as it shifts the fundamental *unit of planning* from departments to flow-based functional groupings.

Secondly, the study recommends the use of simple descriptive indicators—such as (distance × frequency), average travel distances, and variability ranges—as preliminary diagnostic tools for identifying layout-related inefficiencies. The results demonstrate that such indicators are sufficient to reveal substantial material flow inefficiencies, without the need for complex simulation models or detailed time-motion data. This recommendation is impactful as it offers a practical alternative to analytically intensive tools, particularly suitable for data-constrained industrial environments.

Thirdly, the study recommends that the receiving area should not be treated as an isolated logistics function, but rather as an integral component of the internal material flow system. The findings show that varying receiving constraints—such as congestion, waiting, or limited space—consistently translate into internal motion waste. Therefore, the design of receiving capacity, layout, and exit paths should be aligned with the absorption capability of downstream operations, rather than being optimized for unloading efficiency alone. This recommendation is non-obvious as it repositions receiving from a logistics concern to a core facility layout planning issue.

Fourthly, the study recommends that layout improvement objectives should extend beyond reducing average distances or movements to also include reducing spatial variability across flow paths. The findings indicate that the proposed layouts not only reduced overall distances but also improved spatial consistency, which is critical for minimizing bottlenecks and managing operational extremes. This recommendation is often overlooked in applied studies, yet it is essential for achieving stable and predictable material flow performance.

7. Conclusion

This study examined the impact of plant layout decisions on material flow performance through a set of Saudi industrial case studies using simple, field-based empirical data. The findings demonstrate that material flow inefficiencies observed across the analyzed facilities are primarily structural in nature and closely linked to layout configurations that do not adequately reflect process sequencing and flow logic. The comparative analysis showed that proposed layout alternatives aligned with operational sequences can significantly reduce spatial distances, motion waste, and variability without requiring complex analytical tools or detailed time-motion data. By adopting a multi-case diagnostic perspective, the study highlights plant layout planning as a strategic operational determinant rather than a purely physical arrangement decision. Overall, the results provide practical empirical evidence supporting the value of early-stage layout diagnosis in identifying material flow improvement opportunities, particularly within industrial environments characterized by limited data availability.

References

- Henni, A., Reducing material handling costs through functional adjacency and facility layout redesign. *Procedia Manufacturing*, 38, 1243–1250. 2019
- Firmansyah, D., Santoso, I., & Sutrisno, The relationship between transportation distance and operational efficiency in manufacturing systems. *International Journal of Productivity and Performance Management*, 70(6), 1435–1452. 2021
- Szabó, L., Kot, S., & Szetela, B., Visual analysis of material flow paths as a tool for identifying layout inefficiencies. *Sustainability*, 12(9), 3772. 2020.
- Firmansyah, D., Widodo, K. H., & Rahman, A., Improving material flow performance through reduction of internal transportation distances. *Operations and Supply Chain Management: An International Journal*, 15(2), 225–235. 2022
- Jessani, A., Shah, H., & Patel, R., Analysis of motion waste and its impact on operational performance in lean manufacturing environments. *International Journal of Lean Six Sigma*, 10(3), 845–860, 2019.
- Maniezzo, V., Baldacci, R., & Boschetti, M. A., Managing congestion and capacity constraints in receiving and unloading areas. *International Journal of Production Economics*, 204, 210–221. 2018.
- Mendoza-Ortega, J. A., García-Alcaraz, J. L., & Maldonado-Macías, A. A., Facility layout redesign using systematic layout planning to improve material flow. *Journal of Manufacturing Systems*, 54, 1–12. 2020