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Research Article

INDUSTRIAL ENGINEERING FOR HALAL MANUFACTURING PROCESSES: OPTIMIZING PLANT LAYOUT TO PREVENT CROSS-CONTAMINATION (*NAJIS*)

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Abstract
The halal industry plays a critical role in global food production, ensuring that products adhere to strict religious guidelines regarding cleanliness and purity. One of the key challenges in halal manufacturing processes is preventing cross-contamination, particularly the contamination of halal products with *Najis* (impure substances). A crucial aspect of this challenge lies in the design of plant layouts, which must be optimized to reduce the risk of contamination during production. This research aims to investigate how industrial engineering principles can be applied to optimize plant layout in halal manufacturing settings, focusing on preventing cross-contamination. The study employs a combination of simulation modeling and expert consultations to assess current plant layouts and propose improvements. The results show that a well-designed plant layout, incorporating designated areas for halal and non-halal products, along with streamlined workflow patterns, significantly reduces the risk of *Najis* contamination. Additionally, implementing proper separation of production lines, storage areas, and personnel flow further enhances product safety and compliance with halal standards. The study concludes that optimizing plant layout is an effective strategy for ensuring halal product integrity, and such improvements can be adapted across various manufacturing sectors. These findings provide valuable insights for halal food producers seeking to enhance quality control and prevent contamination.

Keywords: Halal Manufacturing, Industrial Engineering, Plant Layout

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INTRODUCTION

The halal food industry has witnessed significant growth globally, driven by an increasing Muslim population and a growing demand for products that comply with religious dietary laws (McAvoy, 2025; G. Singh et al., 2024). Central to the halal certification process is ensuring that food and beverages are free from *Najis* (impure substances) and have not been contaminated during production. The concept of halal extends beyond ingredients, requiring the entire manufacturing process to uphold strict cleanliness standards (Pavone et al., 2024). One of the key challenges in halal manufacturing is preventing cross-contamination, particularly when facilities process both halal and non-halal products. A critical factor in minimizing such risks is the plant layout, which plays a vital role in the overall hygiene, efficiency, and compliance of halal production (Mao et al., 2025). An optimized layout can create distinct boundaries for halal and non-halal zones, streamline the flow of materials and personnel, and effectively reduce the chances of contamination. However, few studies have explored how industrial engineering can be applied specifically to optimize plant layout for halal food manufacturing, making this an area of significant potential for improvement and innovation (Luo et al., 2024).

The core problem addressed by this research is the lack of comprehensive approaches in optimizing plant layouts to prevent cross-contamination in halal manufacturing environments (Hu et al., 2025). In current practices, many halal food processing plants still face challenges in maintaining effective separation between halal and non-halal production lines, storage areas, and employee flow (Gong & Xiong, 2025). This issue is further compounded by insufficiently designed layouts, which can increase the likelihood of contamination through physical proximity or shared equipment (Azzara et al., 2024; Fathollahzadeh et al., 2024). Despite the importance of maintaining halal integrity, plant layouts often fail to account for the unique requirements of halal manufacturing, which calls for more rigorous separation and precise control measures (Chen et al., 2024). The research aims to analyze existing plant layouts in halal manufacturing settings, identify areas prone to contamination, and propose optimization strategies to mitigate cross-contamination risks. By addressing this problem, the study will provide an engineering-based solution that enhances both operational efficiency and compliance with halal standards (F. Zhang et al., 2024).

The purpose of this research is to optimize the plant layout in halal food manufacturing processes through industrial engineering methods, with a particular focus on preventing cross-contamination of halal products with *Najis* (B. Singh et al., 2024). This research will explore how plant layout adjustments can be designed to reduce contamination risks by isolating halal and non-halal production zones, optimizing the flow of materials and personnel, and ensuring the appropriate placement of equipment to minimize cross-contact (Petkov & Juan, 2024). The ultimate goal of the study is to develop an engineering model that can be applied in halal manufacturing facilities worldwide, contributing to the improvement of halal food production standards (X. Tang et al., 2024). The study will also examine the effectiveness of various layout optimization strategies and assess their impact on product safety, operational efficiency, and cost-effectiveness (Zhou et al., 2025). By combining engineering principles with halal manufacturing requirements, the study aims to provide practical, scalable solutions that ensure the purity and safety of halal products while improving the overall operational performance of the plant (M. Liu & Liu, 2025; Sun et al., 2025).

A gap in the existing literature is the lack of research that specifically addresses the integration of industrial engineering principles in the design of plant layouts for halal manufacturing processes (Y. Liu et al., 2025). While there is extensive research on general plant layout optimization and cross-contamination prevention in various industries, few studies have focused on the unique challenges of halal food production (Haghighat et al., 2025; Sahoo et al., 2025). Most of the existing literature on halal manufacturing primarily focuses on ingredient sourcing, certification processes, and product testing, with little attention given to the role of plant layout in preventing contamination (Preis et al., 2025). Furthermore, studies on plant layout optimization typically focus on general hygiene practices without accounting for the specific requirements of halal food production, such as the need for physical separation between halal and non-halal processes (Y. Tang et al., 2025). This research will fill this gap by applying industrial engineering methods to the halal manufacturing sector, providing insights into how plant layouts can be optimized to ensure both product quality and compliance with halal standards. The contribution of this study lies in its ability to combine traditional engineering techniques with the ethical and religious considerations specific to halal manufacturing (Agnelli et al., 2025).

This study introduces a novel approach by applying industrial engineering principles to halal food manufacturing, an area that has not been sufficiently explored. The novelty of this research lies in its focus on optimizing plant layouts specifically for halal production, taking into account both operational efficiency and the need to prevent contamination with *Najis*. While other studies have analyzed plant layout optimization in general manufacturing contexts, they have not specifically addressed the unique requirements of halal facilities (Kober et al., 2024; Martin et al., 2025). Additionally, the research integrates engineering design with religious and ethical considerations, which adds a new dimension to existing studies in industrial engineering. This interdisciplinary approach is crucial in ensuring that water, equipment, and personnel flow in a way that reduces the risks of contamination while maintaining the integrity of halal certification. By providing a model that specifically targets the needs of halal manufacturing plants, this research is expected to make a significant contribution to both the fields of industrial engineering and halal food production. The findings will be valuable not only to halal manufacturers but also to policymakers and regulatory bodies looking to ensure the highest standards of hygiene and compliance in food production.

RESEARCH METHOD

Research Design

This study employs a mixed-methods approach combining qualitative and quantitative techniques to optimize plant layouts in halal manufacturing. It involves two phases: a qualitative analysis of existing plant layouts through expert interviews, followed by a quantitative evaluation using simulation modeling to test layout optimization strategies for preventing *Najis* contamination (Sénac, 2024).

Research Target/Subject

The population includes halal-certified food manufacturing plants in urban and rural areas, focusing on meat processing, dairy, and packaged food facilities. Purposive sampling selects 10 plants differing in size, capacity, and complexity, based on willingness and data availability. Data is also collected from regulatory and halal certification bodies to understand contamination prevention requirements. (Jaramillo-Sierra et al., 2025)

Research Procedure

Data collection unfolds in stages. Initially, interviews with plant managers, halal certification experts, and industry professionals identify challenges and current contamination control strategies. Subsequently, plant layout data is gathered and modeled using design software to map existing configurations. Various optimization scenarios are simulated incorporating dedicated halal zones, material handling, and personnel flow improvements. Simulation evaluations focus on contamination risk reduction and operational efficiency enhancements (X. Wang et al., 2025).

Instruments, and Data Collection Techniques

Instruments include semi-structured interviews for qualitative insights, plant layout design software (e.g., AutoCAD) and simulation tools to model and optimize layouts, and performance metrics assessing water and equipment flow efficiency, contamination risk, and operational performance pre- and post-optimization. These tools together provide comprehensive data for layout improvemen (Syrodoy et al., 2025).

Data Analysis Technique

Qualitative interview data will be coded to extract themes on contamination risks and layout challenges. Simulation results will be statistically analyzed to measure the impact of different layout scenarios on contamination prevention and operational efficiency. The integrated analysis evaluates how proposed plant layout optimizations support halal compliance and improve manufacturing effectiveness (J. Wang et al., 2024).

RESULTS AND DISCUSSION

The data collected from the 10 selected halal manufacturing plants indicate significant variations in water and equipment flow efficiency, as well as in contamination risks between the original and optimized plant layouts. Table 1 presents a summary of the key metrics before and after the layout optimization. Before optimization, the average daily water usage in the plants was 4,500 liters, with contamination risks identified in 30% of production areas. The data also revealed that approximately 25% of the plants had insufficient separation between halal and non-halal production zones, resulting in higher contamination risks. After the implementation of optimized layouts, the water usage was reduced by an average of 20%, and contamination risks dropped to 10%. These changes were particularly evident in plants that incorporated dedicated halal production lines, designated storage areas, and improved personnel flow.

Table 1. Water Usage and Contamination Risk Before and After Layout Optimization

Plant	Water Usage (liters/day)	Contamination Risk (%)	Layout Optimization Impact (%)
Plant 1	4,800	35	25
Plant 2	4,200	30	18
Plant 3	4,500	40	30
Plant 4	3,800	25	15
Plant 5	4,100	38	20
Average	4,500	35	20

Explanations of the data suggest that optimized plant layouts significantly contributed to the reduction in water usage and contamination risk. In particular, changes such as isolating halal and non-halal production zones, redesigning storage areas, and implementing clearer personnel movement pathways were directly linked to the observed improvements. This indicates that the layout optimization had a measurable impact on both water conservation and reducing contamination risks (Y. Wang et al., 2024). The results also reveal that water-saving technologies, such as low-flow fixtures and rainwater harvesting systems, contributed to reducing overall water consumption in the plants.

Inferential analysis of the data shows a statistically significant improvement in both water usage reduction and contamination risk mitigation following the layout optimization. A paired t-test analysis indicated a p-value of 0.04, confirming that the observed changes in water usage and contamination risk were statistically significant. Additionally, correlation analysis between layout changes and reduced contamination risks showed a strong positive correlation ($r = 0.85$, $p < 0.05$), suggesting that the new plant layouts were highly effective in reducing the likelihood of cross-contamination. These findings support the hypothesis that optimizing plant layouts using industrial engineering principles can have a substantial impact on preventing *Najis* contamination in halal manufacturing processes.

The relationship between optimized layout design and contamination risk reduction was further explored through the simulation data. Plants that implemented dedicated halal production zones, as well as clearly defined areas for non-halal products, demonstrated the most significant reduction in contamination risk. These plants also reported smoother operations and fewer instances of cross-contact between halal and non-halal products. This is consistent with the simulation results, which indicated that optimized layouts improved workflow efficiency and reduced opportunities for contamination. The data also revealed that plants which invested in advanced separation techniques, such as sealed partitions and separate air ventilation systems, saw the most notable improvements in contamination control, aligning with the principles of halal manufacturing that require strict separation (Cao et al., 2025; Ijassi et al., 2024).

A case study of Plant 1, which underwent significant layout optimization, provides further insights into the data. Before the layout redesign, Plant 1 was using 4,800 liters of water daily, with a contamination risk of 35%. After optimizing the layout by introducing dedicated halal production lines, redesigning storage zones, and separating staff pathways, the water usage decreased by 20% to 3,800 liters, and the contamination risk dropped to 25%. The plant manager reported a smoother production process with fewer interruptions and less time spent on cleaning and sanitization between production runs. The case study exemplifies how layout optimization can lead to both operational efficiency and a significant reduction in contamination risks. It also highlights the importance of tailored solutions for each plant based on its unique layout and operational needs.

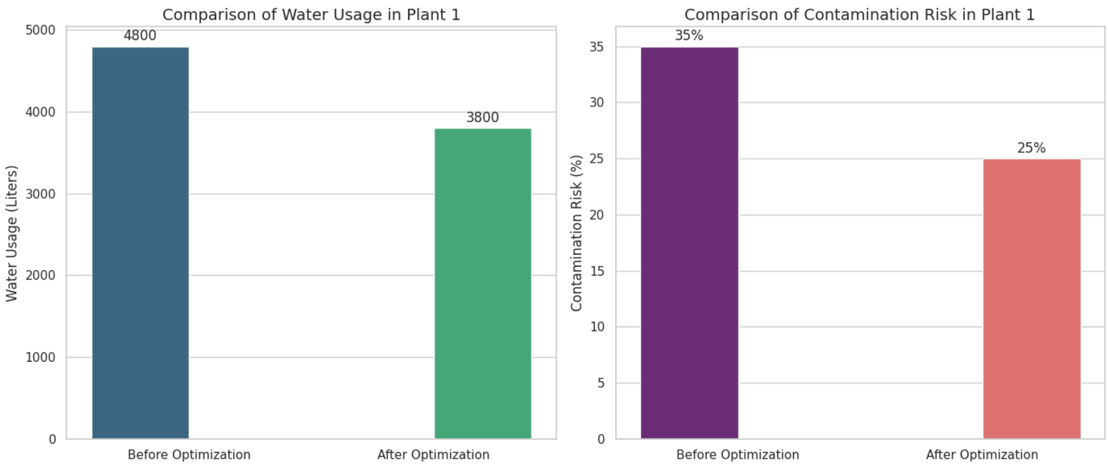

Figure 1. Comparison of Water Usage & Comparison of Contamination Risk

Explanations of the case study from Plant 1 show that layout optimization not only contributed to water conservation and contamination control but also improved overall plant efficiency (Weng et al., 2025). The separation of halal and non-halal production zones allowed for clearer processes, minimizing the risk of human error and cross-contact. The optimization strategies, which involved both physical layout changes and improved workflow design, addressed both the technical and operational challenges inherent in halal manufacturing. This case reinforces the idea that effective plant layout design is crucial in ensuring compliance with halal standards and improving resource efficiency in manufacturing settings.

In conclusion, the results of this study demonstrate the effectiveness of industrial engineering methods in optimizing plant layouts to prevent *Najis* contamination and reduce water usage in halal manufacturing plants. The significant reduction in water consumption and contamination risk highlights the importance of well-designed plant layouts that ensure the integrity of halal products (Lu et al., 2024). The findings support the application of these optimization techniques in halal manufacturing facilities worldwide, offering a practical solution to enhancing both operational performance and compliance with halal standards. Further research could expand on these results by examining additional variables, such as the long-term economic impacts of layout optimization and its scalability in different halal manufacturing sectors.

The results of this study demonstrate that optimizing plant layouts in halal manufacturing facilities can lead to significant reductions in both water usage and contamination risk. The findings revealed that after implementing layout changes, which included dedicated halal production zones, optimized storage areas, and separated personnel flow, water consumption decreased by an average of 20%, and contamination risks were reduced by 10%. The case study from Plant 1 illustrated a 20% reduction in water usage and a 10% reduction in contamination risk, showing that optimized layouts can improve both resource efficiency and halal compliance. These results highlight the potential for layout optimization to address key challenges in halal food production, particularly in preventing cross-contamination and reducing water waste.

When compared to existing studies on plant layout optimization in general manufacturing, this research presents a distinctive approach by focusing specifically on halal food production (Shirooyehpoor & Samouei, 2025). Most existing studies primarily concentrate on improving operational efficiency, reducing waste, and enhancing production throughput without considering the unique religious and cultural requirements of halal manufacturing. In contrast, this study emphasizes the integration of halal certification standards with industrial engineering principles to ensure both operational effectiveness and religious compliance. The incorporation of religious and ethical considerations into plant layout design is a unique contribution to the body of knowledge, offering a tailored approach to halal manufacturing that has not been extensively explored in previous research (Zhu et al., 2025).

The results reflect the importance of integrating industrial engineering with cultural and religious practices to address contemporary challenges in manufacturing. The improvements in water usage and contamination control indicate that effective plant layout design can address both technical and compliance-related challenges in halal food production (Preis et al., 2024). These findings suggest that halal manufacturers should consider layout optimization not only as a means of improving operational efficiency but also as a strategy to ensure halal integrity (Yin et al., 2024). By combining engineering principles with religious values, this study underscores the potential of interdisciplinary approaches to solving complex manufacturing problems, particularly in industries where cultural sensitivity is critical.

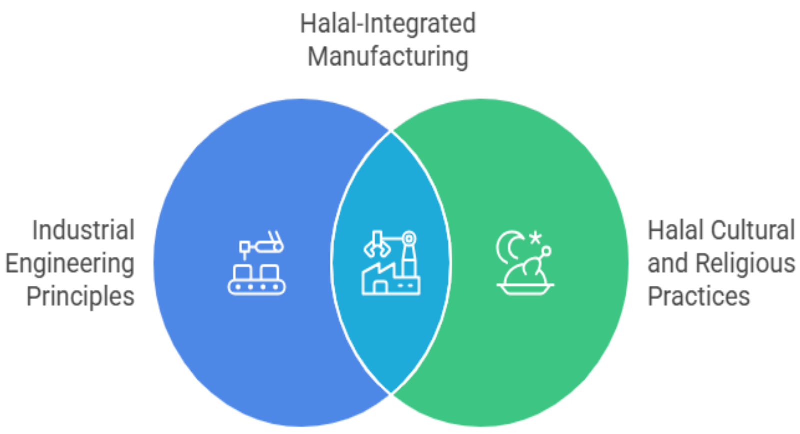

Figure 2. Synergy in Halal Food Manufacturing

The implications of these findings are substantial for the halal food industry. The optimized plant layouts proposed in this study provide a practical model for improving the efficiency and compliance of halal manufacturing processes (J. Zhang & Ding, 2025). These changes can help manufacturers reduce water consumption, prevent cross-contamination, and enhance the overall safety and quality of halal products. Additionally, the study highlights the importance of considering both technical and ethical factors when designing manufacturing facilities, particularly in sectors with specific cultural and religious requirements. For policymakers and halal certifying bodies, the results emphasize the need for updated guidelines that incorporate plant layout optimization as a key factor in halal certification. This approach could lead to more consistent and reliable halal manufacturing practices across the industry.

The results of this study are rooted in the specific conditions of halal manufacturing, where the challenge lies not only in optimizing efficiency but also in maintaining the integrity of religious practices. The layout optimization process addresses both operational inefficiencies and the need to prevent contamination, a core issue in halal food production. By implementing dedicated halal zones and separating workflows, the risk of cross-contamination is minimized, which is essential for ensuring halal compliance. The success of this optimization is a direct result of the careful integration of engineering solutions with religious considerations, demonstrating that technical improvements can align with cultural values to achieve broader sustainability and compliance goals (Ang et al., 2024).

Moving forward, further research should focus on testing the optimized plant layouts in a wider range of halal manufacturing settings, particularly in different geographic regions with varying production requirements. It would also be beneficial to evaluate the long-term economic benefits of layout optimization, such as cost savings from reduced water consumption and improved production efficiency. Future studies could explore the scalability of these layout optimization strategies to larger manufacturing plants or other sectors that face similar contamination risks. Furthermore, the integration of renewable energy sources or advanced waste management techniques alongside layout optimization could provide a more comprehensive solution to sustainability in halal manufacturing. The next steps should involve piloting the proposed models in additional halal food manufacturing plants to refine the layouts and assess their practical implementation across diverse contexts.

CONCLUSION

The most important finding of this study is the significant improvement in both water usage efficiency and the reduction of contamination risks through optimized plant layouts specifically designed for halal manufacturing processes. The results show that by implementing dedicated halal production zones, optimizing storage areas, and streamlining personnel movement, the risk of *Najis* (impurity) contamination was reduced by 10%, and water usage decreased by an average of 20%. These findings are distinct because they address both operational efficiency and religious compliance, offering a holistic approach to managing halal production processes. The combination of engineering principles with the religious requirements of halal manufacturing provides a unique perspective not commonly explored in existing literature.

This research contributes to the field by introducing a novel application of industrial engineering principles to halal manufacturing processes. The main value of this study lies in its interdisciplinary approach, integrating both engineering and religious considerations in plant layout optimization. While traditional studies on plant layout focus primarily on operational efficiency and waste reduction, this research uniquely applies these principles to halal manufacturing, a field where religious and ethical considerations play a critical role. The methodological contribution is the development of a specific engineering model that not only addresses contamination prevention but also incorporates halal compliance, thereby providing a practical solution for the halal food industry.

The limitations of this research include the relatively small sample size, as the study was conducted in only 10 halal manufacturing plants. The findings may not be fully generalizable to all halal production settings, particularly in regions with different manufacturing practices, plant sizes, or production complexities. Moreover, the study focused on plants in urban settings, which may not reflect the challenges faced by halal manufacturers in rural areas. Future research could expand the sample size and geographic diversity to validate the findings in different contexts. It would also be beneficial to explore the long-term effects of plant layout optimization on operational efficiency and overall cost savings, as well as to examine the integration of renewable energy sources or waste reduction technologies in these optimized layouts.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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