

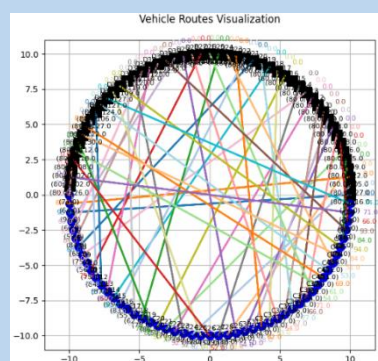
Development of Decision Support System for Halal Meat Distribution System

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Abstract: Amid the growing demand for Industry 4.0 adoption in the business world, the halal supply chain must also integrate these technologies. A roadmap is needed to build a halal supply chain 4.0. The distribution of halal products in this case halal meat from halal-certified slaughterhouses is still very limited, while the demand for halal meat is high. Therefore, if the distribution of halal meat is not planned properly (optimally), there will be a shortage of supply, excess stock, and soaring transportation costs. For that, application development as one of the initiatives towards the halal supply chain 4.0 is very necessary. The method used in this study is to develop a desktop-based application based on Python and VS Code using Linear programming to minimize the total distance and total distribution cost, where the distribution cost is a function of the sum of transportation costs, oversupply costs and shortage costs. The application successfully provides an optimal solution to the Multi-Depot Vehicle Routing Problem (MDVRP), effectively solving the complex logistics scenario. Based on the result of this study, the Halal Meat Distribution System (HMDS) application has demonstrated its capability to determine optimal distribution plans for halal meat. Therefore, the study proposes application which is named as HMDS, which can become the decision support system to help the decision maker determines the optimized halal meat distribution strategy. As part of the broader halal supply chain ecosystem 4.0, this study serves as an early step toward the digital transformation of halal logistics.



Keywords: Halal Supply Chain 4.0; Halal Meat Distribution; Halal Logistics; Linear Programming; MDVRP; Optimization; Decision Support System.

Introduction

The halal industry is a rapidly expanding sector on a global scale, driven by a substantial and growing Muslim population [1], [2]. This development suggests that the halal industry is not merely a domestic market but also a strategic opportunity for international exports and investments [3]. In view of the escalating complexity of the industrial sector, coupled with the exponential growth of data, the contemporary industrial landscape necessitates the adoption of Industry 4.0 methodologies to achieve operational excellence [4].

In recent years, there have also been issues regarding the awareness and interest of millennials in the halal supply chain [5]. Halal supply chain has a vital role in halal industry, since it can ensure the halal integrity of the halal product from the farm to the fork, in halal supply chain, it is not recommended to produce, distribute, store, and serve the halal product in some facilities with non-halal product. Because it can make the cross-contamination which halal product can move become non-halal product. With this rigid requirement, digitalization and integration of information and material flow will become important. Otherwise, many decisions making regarding halal supply chain operation will not be optimized, if the decision making is done

partially or manually and not use any digitalization. In line with the finding from [6], which mentioned that implementation of Artificial Intelligence (AI) and Industry 4.0 technologies will be very beneficial and improve the implementation of halal supply chain.

Along with the demands to adopt Industry 4.0 in the business world, as has been mentioned before the halal supply chain also needs to adopt Industry 4.0 technology. As the demand for halal products increases [7], there is also a growing need to ensure that halal supply chains remain efficient, transparent, and reliable [8]. Responding to these challenges requires not only regulatory compliance but also technological transformation [9]. In practice, majority of halal industries still lack to adopt 4.0 technologies. This is also the finding of study by Kurniawati and Cakravastia (2023). The lack of adopting digitalization in halal supply chain, of course will make the implementation of halal supply chain become more difficult and not optimized. So, the lackness of adopting digitalization and 4.0 technologies will make decision making related with it become difficult to be optimized. Adding AI could provide records that more secure,

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transparent and cannot be changed, this also would increase trust between companies and consumers even further [10].

In this regard, the integration of digital technologies aligned with Industry 4.0 is considered a strategic approach to modernizing and enhancing the performance of halal supply chains [11]. Industry 4.0 involves the application of cyber-physical technologies to revolutionize automation, monitoring, and supply chain analysis [12]. It emphasizes connectivity and real-time data analytics. Key technology pillars of Industry 4.0, such as Internet of Things (IoT) for sensors and connectivity and advanced data analytics [13], are highly relevant for logistics that need to adapt quickly to rapidly changing customer demands and expectations and improve the ability to predict and mitigate potential problems through real-time data analytics. In the context of halal logistics, the ability to continuously monitor conditions (e.g., temperature, location) and analyze this data instantly is fundamental [14]. AI technology is increasingly recognized for its potential in addressing key challenges in the halal food industry [15].

The imbalance between supply and demand in the distribution system for halal products, particularly halal beef in Indonesia, is a significant operational challenge. Although demand for halal meat is very high, distribution of products, especially from halal-certified slaughterhouses, is still very limited. More research highlights are needed on animal welfare, including humane slaughtering procedures, animal handling and transport [16]. For example, data shows that in the Special Region of Yogyakarta, several districts such as Kulon Progo and Gunungkidul do not have halal-certified slaughterhouses, resulting in a direct supply shortage. Meanwhile, other districts such as Bantul and Sleman have certified RPHs with production capacities ranging from 307.25 kg to 258.86 kg per unit, and the city of Yogyakarta has one RPH with a larger capacity of 514.82 kg [17].

According to Aisyah and Kurniawati (2019), the city of Yogyakarta itself has one halal-certified slaughterhouse with a larger production capacity of 514.82 kg. On the other hand, the Kulon Progo and Gunungkidul regions do not have halal-certified slaughterhouses, so they are unable to directly supply the markets in their areas. On the other hand, market demand also varies. Some markets report high demand, such as Pleret Market (491.10 kg) and Bantul Market (360.72 kg), while others show lower but still significant figures, such as Pakem Market (140.91 kg) or Kota Gedhe Market (188.44 kg) respectively. This imbalance causes some regions to experience surplus supplies that are not efficiently absorbed, while other regions face shortages due to the absence of direct supply sources.

This phenomenon highlights the need for a more adaptive and integrated distribution system across regions. Without restructuring distribution patterns, excess supplies in one region will go to waste, while shortages in other regions will impact consumer satisfaction and rights regarding halal products. A strategy that accounts for production capacity, actual market demand, and logistical efficiency is essential to achieve a sustainable and equitable distribution of halal beef throughout the region. The benefits of adopting a halal supply chain are not only relative advantages felt by producers, but there is also compatibility felt by perceived complexity, religious beliefs, and awareness [18].

The models developed in previous studies [17], [19] has provided a strong theoretical foundation for halal meat logistics optimization, but HMDS goes further by overcoming applicability barriers and explicitly becoming a strategic initiative towards Halal Supply Chain 4.0 (Halal SC 4.0). Thus, previous models serve as mathematical validation of what needs to be done for

efficient distribution. However, HMDS represents a much more important transformation: as an answer to the question of how to do it in a disruptive operational environment. HMDS takes this theoretical foundation and complements it with Artificial Intelligence and the necessary software framework, transforming optimization from an academic concept into a ready-to-use and measurable managerial tool, as well as a catalyst for Halal Supply Chain 4.0.

In view of the aforementioned points, there is an urgent need for research on halal supply chains that leverage Artificial Intelligence (AI) and move toward Industry 4.0. Kurniawati and Cakravastia (2023) [6] and Kurniawati et al. (2024) [20]. This synergy has profound implications for increasing transparency and trust among stakeholders (producers, distributors, retailers, and consumers). This is supported by the fact that in recent years, there has been increased consumer demand for halal-certified products and a greater need for transparency in the food supply chain [21].

In HSC, the main challenge often lies in the lack of trust due to unclear processes. Such research is necessary to ensure halal integrity and to build a halal supply chain 4.0 to bridge the gap between theory and practice in the application of halal technology. [22], [23]. The significance of this study is to provide a solution to the existing gap related to the halal supply chain 4.0, which is currently not well-developed, especially related to the optimization of the halal supply chain [6], [20]. By proposing a Python-based application and VS Code, the proposed solution can be a solution to determine the distribution of halal meat with minimal distribution costs.

Materials and Methods

The method used in this study is to develop a desktop-based application based on Python and VS Code using linear programming to minimize the total distance and total distribution cost, where the distribution cost is a function of the sum of transportation costs, oversupply costs and shortage costs.

The algorithm developed in this application is designed to optimize supply distribution from suppliers to retailers by minimizing total operational costs, which consist of three key components: oversupply costs, shortage costs, and transportation costs. Beyond determining the most efficient distribution routes, the system generates optimal visitation sequences and provides route visualizations, offering a comprehensive solution to logistical challenges. This integrated approach not only ensures cost efficiency but also enhances distribution planning accuracy through clear visual representations of delivery routes. The application developed in this study is the Halal Meat Distribution System (HMDS) v.1 application.

The development of the HMDS application is based on the application of linear programming to solve the Multi-Depot Vehicle Routing Problem (MDVRP). The use of LP is justified because the main objective of the model is to minimize total distribution costs, which are the sum of transportation costs, excess stock costs, and stock shortage costs. All of these are represented as linear objective functions. LP is a standard approach in Operations Research that is highly effective for optimization problems with linear capacity, demand, and non-negative constraints, enabling the determination of the most efficient supply allocation and delivery routes.

The application is developed user-friendly so that it can be used by decision makers. The HMDS application is an application created to facilitate halal slaughterhouses in optimizing the distribution of halal products for each Halal Market. This application is created using VS Code software with

the Python programming language to write the program code. In this application, users can utilize the graphical interface or Graphical User Interface (GUI) designed using the Tkinter, Matplotlib, Numpy, Pandas, and PuLP libraries for processing and calculating data directly through interactive tables.

Users will easily enter halal slaughterhouse and Halal Market information data according to user needs, such as halal slaughterhouse and/or Halal Market name, halal slaughterhouse production capacity (supply), Halal Market demand (demand), product price (per kg), gasoline cost (per kilometer), oversupply cost, and distance between halal slaughterhouse and Halal Market through interactive tables. After entering the data, the application will process the data and optimize the distribution using the Simplex algorithm from the PuLP library. With the Simplex algorithm, this application will calculate the optimal distribution solution from the halal slaughterhouse to the Halal Market. This application can display the results of the minimum transportation cost based on the distance from halal slaughterhouse to Halal Market and fuel costs. If there is an imbalance between supply and demand, this application has a feature that can overcome this problem by adding a dummy row or column to ensure the optimization process remains valid. The results of calculations with the Simplex algorithm will be displayed in a separate window, including optimal halal meat distribution, total distribution costs, and analysis of excess supply products (oversupply) or lack of demand fulfilment (shortage), if any.

The simple GUI application makes it easy for users from various backgrounds to operate it without special technical skills. With flexibility for various distribution scenarios, this application helps logistics companies or other businesses manage their goods delivery more efficiently and cost-effectively. Potential for further development includes map integration for automatic distance calculation, data storage for in-depth analysis, and graphic visualization to present distribution results more attractively. The use of VS Code and Python makes this application easy to develop further and utilizes the Python ecosystem, which is rich in libraries and development tools. The development of this application can be adjusted to the needs of users in operating the information system. The flowchart of the program developed in this study is presented in Figure 1.

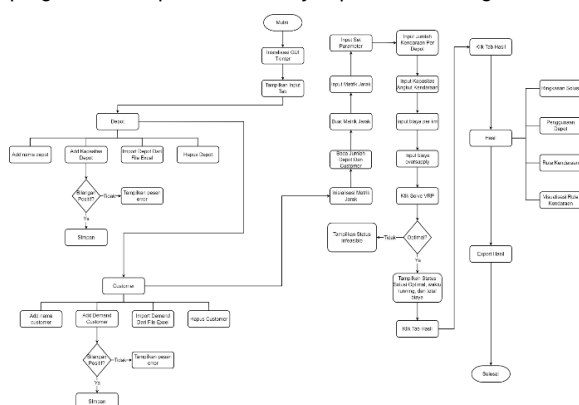


Figure (1): Research Methodology.

This study is a continuation of Kurniawati (2018) and Aisyah and Kurniawati (2019), where in this study is the development of an application-based decision-making system by minimizing transportation costs, shortage costs and excess stock costs. Transportation costs are defined as the distance from the supplier to the retailer or from the halal slaughterhouse to the market.

The current HMDS model, although optimal in the specified parameters, has several limitations that require future

expansion. The current model operates based on deterministic input data (fixed capacity and demand). This limitation ignores real operational uncertainties, such as sudden fluctuations in demand (stochastic demand) or unexpected changes in supply capacity. Future model expansion could include incorporating stochastic optimization techniques or simulation models to address the dynamic nature of the halal meat market. Although the application was developed as a Halal 4.0 initiative, the main optimization calculation (MDVRP) still relies on manual input or CSV import. A critical expansion is the integration of real-time data (real-time data processing) from IoT sensors (temperature, location) and mapping systems for automatic distance calculations. This integration will transform HMDS into a truly adaptive DSS.

System Design and Development

Development of Applications and Research Results

The application will be developed and used to simulate large-scale data on halal meat distribution with multi-warehouse and multi-customer distribution issues.

The artificial data used for the numerical experiment included 50 halal-certified slaughterhouses (depots) and 50 customer markets with varying production capacities and demand levels. To maintain clarity in presentation, only the key characteristics of the dataset are summarized in Table 1, while the complete data can be found in Appendix A. The detailed distance matrix used in the numerical experiment is provided in Appendix B. The range of distances between depots and customers varies from 35 km to 95 km.

Table (1): Artificial Data for Numerical Experiment (Depot capacity and customer demand).

Parameter	Description	Value
Number of Depots	Halal-certified slaughterhouses	50
Number of Customers	Halal markets	50
Total Supply Capacity	Combined depot capacity	5,838 units
Total Customer Demand	Combined market demand	3,510 units

Demonstration of the Halal Distribution Application

Application Optimization Distribution Halal meat is an application created to facilitate the Slaughterhouse (Halal Slaughterhouse) in optimizing distribution of halal products for every Halal Market. Application This made use VS Code software with the Python programming language to write code the program. In the application, the user can utilize an interface graphic or Graphical User Interface (GUI) designed using the Tkinter, Numpy, Pandas, Matplotlib and PuLP libraries to process and perform data calculations directly

Users will with easy Entering halal slaughterhouse and Halal Market information data accordingly with need users, such as name of halal slaughterhouse and /or Halal Market, capacity halal slaughterhouse production (supply), Halal Market demand (demand), number of vehicles per depot, cost gasoline (per kilometer), vehicle capacity, cost oversupply (per unit) and distance location between halal slaughterhouse and Halal Market through table interactive.

The display presents the minimum total distance, total cost distribution, total real demand served, total shortage, and total oversupply cost as part of the overall solution summary. It also provides detailed information on depot usage, showing how much supply is utilized and the level of oversupply at each depot. In addition, the vehicle route sequences are listed, and a visual representation of the vehicle routing is shown, illustrating the product distribution from multiple depots to customers. This combination of numerical data and route visualization offers a

comprehensive overview of the distribution performance in solving the MDVRP.

The graphical user interface (GUI) developed for this application offers several notable advantages in terms of usability and functionality. Built using Tkinter, the GUI features an intuitive design with a structured layout that separates data input and result visualization into distinct tabs, facilitating seamless user navigation. Its flexible data input capabilities—supporting both manual form entry and CSV file import—enhance efficiency when handling large-scale datasets. Additionally, the interface provides an interactive distance matrix editor with scroll functionality for visual data modification. Optimization results are presented comprehensively through a dual-panel display, combining numerical summaries with Matplotlib-based graphical visualizations to enable spatial analysis of outcomes. Real-time feedback through error messages and solution status updates further enriches the user experience by minimizing ambiguity. Another key strength lies in its minimal external dependencies, relying solely on standard Python libraries such as PuLP and NumPy, which simplifies installation and deployment. Overall, this interface adheres well to user-centered design principles, making it a robust tool for addressing Multi-Depot Vehicle Routing Problems (MDVRP) in both academic and practical contexts.

Figure in the Appendix C presents the coding Program of HMDS Application. The input for coding program of HMDS application is presented in Figure in Appendix D. Appendix D presents the input interface of the HMDS application which allowing users to enter supply, demand, vehicle capacity, and cost parameters through an interactive table. This layout supports both manual and CSV data entry for flexible use.

The output of HMDS application is presented in the Figure of Appendix E and F. Figure of output program HMDS application for depot usage in Appendix E presents the output interface which displays the optimal solution summary, including total distribution cost, total travel distance, fulfilled demand, shortage, oversupply cost, and depot utilization, thereby providing decision makers with actionable insights. In addition, the graphical visualization illustrates the optimized vehicle routing paths between multiple depots and customers. Appendix F shows the output interface which displays the optimal solution summary, including total travel distance, fulfilled demand, and shortage, thereby providing decision makers with actionable insights. In addition, the graphical visualization illustrates the optimized vehicle routing paths between multiple depots and customers. Table 2 presents the output interface which displaying the optimal solution summary generated by the solver. It includes total distribution cost, total travel distance, fulfilled demand, total shortage, and total oversupply cost, providing decision makers with actionable insight.

Table (2): Solution Summary for total cost and distance.

Performance Metrics	Values
Status	Optimal
Total Distance	4105.00 km
Total Cost	Rp 37.915.000,00
Total Real Demand Served	3383.0
Total Shortage	156.0 units
Total Oversupply Cost	Rp 9.590.000,00

The optimization results present an optimal solution for the Multi-Depot Vehicle Routing Problem (MDVRP), confirming the system's capability to effectively handle complex halal meat distribution scenarios. The solver produced a total travel distance of 4,105.00 km with associated transportation costs of Rp 37,915,000.00. The optimized plan successfully fulfilled 3,383.0 units of customer demand, while a remaining 156.0 units were unserved due to vehicle capacity and routing limitations.

Additionally, the total oversupply cost reached Rp 9,590,000.00, reflecting the economic impact of unutilized depot resources. While the proposed model achieved an "optimal" status, the presence of both shortages and oversupplies indicates that the optimization process prioritizes total cost minimization over perfect demand fulfilment. The remaining shortage primarily occurs in high-demand markets that are geographically distant from high-capacity depots, illustrating a trade-off between service level and cost efficiency. Conversely, oversupply at certain depots reflects underutilized capacity that results from route balancing constraints and vehicle capacity limitations. The presence of both shortage and oversupply costs suggests opportunities for further optimization through parameter tuning or capacity adjustments in future iterations.

The study has similar objective and result with Salman and Al-Sahili (2025) [24] in terms of proposing new strategy to minimize the cost. In addition, the study performed by Salman and Al-Sahili (2025) is not just minimizing the cost, but also minimizing the emission of CO2 which the object of study is Nablus urban shared-taxis. In their study, minimizing the cost is indicated by the increasing of financial saving.

Results and Discussion

To validate the effectiveness of HMDS, a series of comparative experiments and stress tests were designed. The primary experiment entailed a comparison of the performance of the Manual Distribution Method (hereafter referred to as the "Baseline/Status Quo," which reflects current practices in DIY that result in imbalances) and the Optimal Solution generated by HMDS. The baseline scenario will be calculated by assuming that the distribution follows historical patterns that are uncoordinated or based solely on geographical proximity. This will result in inefficient overstocking and supply shortages in certain areas.

Furthermore, stress test scenarios will be conducted to assess the resilience of the model. For instance, the model can be used to simulate a 50% increase in demand at Pleret Market or a 30% decrease in capacity at the Yogyakarta City Slaughterhouse due to operational issues. The ability of HMDS to generate optimal solutions under extreme conditions is crucial to prove its readiness to face a disruptive 4.0 environment.

A thorough analysis of the optimization results is expected to demonstrate a substantial reduction in total distribution costs, attributable to two key factors: transportation cost savings and reduced penalties for excess or insufficient stock. Utilizing an advanced optimization model, HMDS determines the most efficient supply allocation, thereby avoiding logistical waste caused by suboptimal routes or unnecessary storage costs.

A significant contribution of the HMDS optimal solution is its capacity to address distribution inequities experienced by deficit regions. In a manual scenario, regions without certified RPHs (such as Kulon Progo and Gunungkidul) tend to experience stockouts or have to pay high logistics premiums due to the lack of centralized planning.

The HMDS solution, which functions by reducing penalties for supply shortages across all regions, will explicitly allocate supplies from surplus RPHs (such as Yogyakarta City) to markets in deficit regions. This ensures that consumers' rights to obtain halal products are fulfilled and strategically reduces the region's dependence on unverified or non-certified sources of supply. Consequently, HMDS optimization not only enhances economic efficiency but also fortifies the potential for sharia compliance across the regional distribution network.

For perishable products, such as meat, optimal decisions must be made expeditiously. A subsequent computational

performance analysis will verify that the HMDS algorithm's run time is within acceptable limits for operational decision-making. The rapid completion of optimization models, facilitated by Python's efficiency and advanced solver algorithms, ensures that HMDS can satisfy the real-time decision-making requirements that are imperative in the 4.0 supply chain. The capacity to perform real-time feasibility analysis distinguishes research-based mathematical models from applied DSS.

Implications and Future Research

This research successfully bridges the significant gap between logistics optimization theory and the practical operational needs of the halal supply chain. The development of the Halal Meat Distribution System (HMDS) provides an applicable, scalable, and user-friendly tool that directly addresses the issue of regional halal meat distribution inefficiency, characterized by a critical imbalance between slaughterhouse capacity and market demand. The HMDS is a system that transforms a validated linear programming model into a decision support system that logistics managers can implement and that provides prescriptive solutions that can be measured. The primary contribution of the system is its capacity to concurrently minimize distribution expenses, oversee excess inventory, and curtail supply shortages, while adhering to rigorous Halal SC stipulations.

The strategic implications of HMDS extend beyond mere cost efficiency. This initiative constitutes a foundational step in the advancement of the Halal SC 4.0 agenda. The fundamental rationale underlying this assertion is that the halal industry, which predominantly comprises small and medium-sized enterprises (SMEs), frequently encounters substantial impediments in adopting costly and intricate Industry 4.0 technologies, such as digital twins or comprehensive blockchain integration.

It is evident that HMDS employs a more targeted and pragmatic strategy in regard to the digitalization process. The utilization of open-source software, specifically Python, in conjunction with a strategic emphasis on AI/DSS functionalities that expedite operational efficacy, exemplified by the mitigation of logistics expenditures and penalties, ensures a swift return on investment (ROI) for HMDS. These financial savings function as both a motivator and a facilitator for SMEs as they embark on their digital roadmap. By adopting HMDS, these entities initiate the integration of artificial intelligence and data analytics, thereby establishing a robust technological foundation that facilitates seamless integration with other 4.0 technologies, such as IoT data from vehicles or blockchain-based smart contracts, in the future. Therefore, HMDS functions as a catalyst that democratizes the adoption of 4.0 at the operational level of HSC.

While HMDS offers substantial optimization solutions, this research is subject to certain limitations. Presently, the HMDS model functions in accordance with the availability of demand data. Future research endeavours must extend the capabilities of HMDS by incorporating a machine learning module to enhance the precision of demand prediction. This refined prediction will reduce the occurrence of unanticipated stock shortages and facilitate enhanced RPH capacity planning, thereby transitioning from a reactive DSS to a predictive DSS.

Future research endeavours should prioritize the enhancement of Halal SC 4.0 integration. This includes the development of HMDS modularity to communicate directly via API with blockchain systems to automatically verify the halal status of each shipment and record optimization decisions as immutable transactions. Furthermore, the model's expandability extends to encompass Multi-Echelon Halal SC, thereby addressing optimization issues that arise not only at the final

distribution level but also at the procurement and manufacturing echelons.

Conclusion

Based on the result of this study, the HMDS application has demonstrated its capability to determine optimal distribution plans for halal meat by minimizing total costs, including fuel expenses, shortage penalties, and oversupply losses. Through the integration of Python and Visual Studio Code, the developed system enables accurate and efficient decision-making for both small- and large-scale data scenarios in real time.

The use of a user-friendly interface allows the application to be operated by various users without requiring advanced technical skills. By incorporating optimization techniques and supporting interactive data input, the HMDS application provides comprehensive outputs such as distribution allocation, total cost, and analysis of oversupply and shortage conditions. This makes the tool highly applicable for halal meat distribution planners in both operational and strategic contexts.

As part of the broader halal supply chain ecosystem 4.0, this study serves as an early step toward the digital transformation of halal logistics. With further improvements such as integration with map-based distance systems, real-time data processing, or AI-driven recommendations, the HMDS application holds potential to evolve into a robust decision-support system that supports the sustainability and efficiency of halal product distribution.

Strategically, HMDS has implications that go beyond cost efficiency, touching on industry governance, regulation, and consumer trust. For logistics managers, HMDS acts as a tool that reduces cognitive constraints when dealing with semi-structured problems. The system explicitly helps in solving complex MDVRP problems by incorporating halal compliance criteria as hard constraints. The result is optimal distribution decisions (minimum cost) that are inherently halal-aware, mitigating the risk of cross-contamination and cold chain failure.

The development of HMDS and the Halal SC 4.0 initiative offer a solution for certification bodies to verify the Halal Product Process (HPP) in distribution services. This digital system enables the transition from traditional statement-based compliance proof to permanent, verifiable, and real-time digital audit evidence. This significantly improves traceability and trust in halal product assurance.

The HMDS model, particularly data related to supply shortages and surpluses, provides strong empirical data on supply-demand imbalances in the halal meat market. This information is crucial for policymakers to formulate targeted intervention strategies, such as slaughterhouse capacity planning or the development of regional halal logistics infrastructure, to achieve sustainable and equitable halal meat distribution.

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preparation. C. Caroline: literature review, critical review and final manuscript preparation. M.A. Wijayanto: data collection and processing, analysis and interpretation of results. A. Ma'aram: text editing and proofreading. All authors reviewed the results and approved the final version of the manuscript.

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