Journal of Social Research

P-ISSN: 2827-9832
E-ISSN: 2828-335x
http://ijsr.internationaljournallabs.com/index.php/ijsr

Development of a Vehicle Routing Problem Model to Reduce Service Delays in Pickup and Delivery Operations

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ABSTRACT

The rapid growth of the e-commerce sector in Indonesia has increased the demand for reliable and timely logistics services. However, challenges such as delayed pickups and deliveries continue to occur, leading to the accumulation of operational penalties. This study aims to develop a mathematical model based on the Vehicle Routing Problem (VRP) that addresses the complexities of modern logistics distribution. The proposed model, named HFMTVRPDPTW (Heterogeneous Fleet Multi-Trip Vehicle Routing Problem with Delivery and Pickup and Time Windows), incorporates five key elements: vehicle capacity, fleet heterogeneity, service time windows, simultaneous pickup and delivery, and multi-trip operations within a single working period. A systematic literature review of twenty-one prior studies was conducted to identify research gaps and inform the model's development. The model is formulated using an integer linear programming (ILP) approach and aims to optimize service time accuracy while minimizing delays. The findings suggest that this model provides a more comprehensive and realistic approach to distribution challenges and offers an original contribution to the development of adaptive and efficient VRP models for logistics operations.

Keywords: *vehicle routing problem, pickup and delivery, time windows, heterogeneous fleet, multi-trip*

INTRODUCTION

The advancement of digital technology has brought about fundamental changes in the way people live and think in the modern era. This digital transformation has driven a major shift in economic activities from conventional systems to *online*-based systems. One of the most prominent manifestations of this change is the growth of *e-commerce*, which enables people to obtain goods and services quickly, easily, and efficiently through digital platforms. This phenomenon has led to a surge in digital transaction activities, as reflected in data from the Ministry of Trade, which shows an increase in transaction value during the *National Online Shopping Day*—from IDR 16.8 trillion in 2021 to an estimated IDR 40 trillion in 2024. This growth has directly impacted the rising demand for fast and reliable logistics services. In addition, data from Bank Indonesia shows that the number of logistics service consumers increased by 51%, and the number of *online* business actors grew by 38.3% (Adianti & Trimarjono, 2023).

As demand continues to grow, the national logistics sector faces increasing challenges in ensuring smooth distribution of goods, particularly in terms of on-time delivery and pickup. Modern logistics services are required to complete the distribution process with high accuracy in order to maintain customer satisfaction and cost efficiency. On the other hand, failure to meet operational targets can result in significant financial consequences. For example, a logistics service outlet in *West Java* reported total fines of IDR 3,431,320,000 due to late deliveries, and IDR 76,240,000 due to late pickups during 2024. These penalties were incurred because service outlets are required to achieve a minimum pickup timeliness rate of 90% and a minimum delivery timeliness rate of 86%. If these targets are not met, late shipments are penalized in accordance with company policy.

As a mitigation effort, several operational strategies have been implemented, including a mapping procedure for grouping packages by destination area and a failed pickup procedure to avoid missed pickups due to sender unavailability. However, despite the contributions of these strategies to operational efficiency, delays still occur and have led to a significant accumulation of fines. This indicates that existing strategies are not yet fully optimal, and therefore a more systemic, optimization-based approach is needed to improve the performance of logistics distribution, particularly in the *last-mile* delivery phase.

Various studies have explored and developed *Vehicle Routing Problem* (VRP) models as solutions to complex distribution routing challenges. Some relevant approaches include the *Vehicle Routing Problem with Simultaneous Pickup and Delivery and Parcel Lockers* (*VRPSPDPL*), which aims to minimize travel costs (Yu et al., 2022); the *Heterogeneous Fleet VRP with Time Windows* (*HFVRP-TW*), which has been shown to reduce operational costs by more than 50% (Ayu & Nahry, 2020); as well as other models such as the *Multi-Depot VRP*, *Two-Echelon VRP*, and *Selective Pickup and Delivery with Transfers*, which are designed to optimize the efficiency of multi-level distribution systems under various real-world constraints (Moreno et al., 2024; Bi et al., 2023).

Based on the complexity of the current problem and the review of previous literature, this study proposes a model called the *Heterogeneous Fleet Multi-Trip Vehicle Routing Problem with Delivery and Pickup and Time Windows* (*HFMTVRPDPTW*). This model takes into account the diversity of vehicle types, the capability of vehicles to perform multiple trips per day (*multi-trip*), simultaneous pickup and delivery services, and time window constraints at each service point. The main objective of this model is to minimize the total travel time and the number of late shipments, both in the pickup and delivery phases. As a result, operational fines due to delays can be reduced, and the overall efficiency of the distribution system can be improved.

This model is expected to provide a practical and relevant approach to distribution challenges in today's digital era. Simulations using real operational data will also demonstrate the extent to which this model can be implemented to enhance service time accuracy and reduce financial risks caused by late pickups and deliveries.

METHOD

This study employs a systematic literature review approach to identify and analyze the development of previous research related to the *Vehicle Routing Problem* (*VRP*), with a specific focus on five key elements: vehicle capacity, heterogeneous fleet composition, time windows, simultaneous pickup and delivery services, and *multi-trip* operations within a single working period. The literature search was conducted using leading academic databases such as Scopus, ScienceDirect, SpringerLink, and Google Scholar. Search keywords were formulated in various combinations, including "*vehicle routing problem*," "*time windows*," "*multi-trip routing*," "*heterogeneous fleet VRP*," and "*simultaneous pickup and delivery*." Selected articles were peer-reviewed publications from the past fifteen years to ensure relevance with recent advancements. Additionally, classical literature such as the seminal work of Dantzig and Ramser (1959) was included to provide a historical framework.

After collecting the literature, content analysis was carried out to examine the main objectives of each study, the mathematical models or algorithms used, the types of constraints considered, and the solution methods applied. These studies were then classified based on the integration of constraints and compared using a synthesized research matrix. An evaluation of the strengths and limitations of each approach was conducted to identify gaps in the literature that have yet to be thoroughly explored. These gaps serve as a foundation for designing a new model that is comprehensive, realistic, and applicable to the current challenges of logistics distribution systems.

RESULT AND DISCUSSION

A review of twenty-one previous studies in the field of Vehicle Routing Problem (VRP) reveals that the approaches to vehicle distribution problems have undergone dynamic developments in terms of model formulation, optimization objectives, and solution methods. These studies were analyzed based on five key constraint categories: vehicle capacity limitations (capacity), service time windows, fleet heterogeneity (heterogeneous fleet), pickup and delivery systems, and the ability of vehicles to make multiple trips within a single working period (multi-trip). Additionally, aspects such as the objective function and the solution methods used in each study were evaluated to gain a more holistic understanding.

In general, it was found that most studies adopted only two to three of the five constraint elements, and few have integrated all of them simultaneously. For example, the study by Adebayo et al. (2019) combined capacity and time window constraints in a multi-depot setting, with a focus on minimizing cost and travel time. Meanwhile, Ayough et al. (2020) included only capacity and time window constraints, aiming to minimize cost and the number of vehicles. The classic study by Dantzig and Ramser (1959) considered only vehicle capacity, with the objective of minimizing total travel cost. Some studies have begun to incorporate fleet heterogeneity, such as those by Aktas et al. (2021), Lubis and Mawengkang (2020), and Ramos et al. (2020). However, these models generally have not fully integrated the pickup and delivery or multi-trip components. On the other hand, studies that focus on pickup and delivery aspects typically combine them only with capacity or time window constraints, as shown in the works of Bouanane et al. (2019), Guo and Wang (2023), Ma and Li (2024), and Yu et al. (2022).

Table 1. Summary of Research Related to Vehicle Routing Problem (VRP)

Author	Comprehensive Explanation
Adebayo et al. (2019)	This study developed a VRP model considering time window constraints and customer service priority levels. It focuses on scheduling services based on the urgency of customer requests to minimize delays for high-priority clients.
Aktas, Bourlakis, & Zissis (2021)	This study discusses the use of heterogeneous vehicles and time windows in retail logistics distribution. It emphasizes the importance of

Author	Comprehensive Explanation
	selecting appropriate vehicle types suited to the characteristics of each route and service schedule.
Ayough et al. (2020)	The research developed a VRP model integrating vehicle capacity and time window constraints for urban distribution. It proposes a mathematical approach to determine optimal routes under tight delivery timeframes.
Ayu & Nahry (2021)	This study models VRP with heterogeneous vehicles of varying sizes and capacities while considering customer time windows. It is particularly relevant for inter-city distribution in Indonesia with diverse vehicle and demand characteristics.
Bouanane, Benadada, & Bencheikh (2019)	This study formulated a VRP model with simultaneous delivery and pickup constraints, reflecting real-world courier operations. The problem is solved using a heuristic approach.
Dantzig & Ramser (1959)	This foundational study introduced the Vehicle Routing Problem for the first time, incorporating vehicle capacity constraints. It laid the groundwork for all subsequent developments in VRP research.
Ghannadpour (2019)	This study designed a VRP model that accounts for customer service priority based on delivery urgency. Emphasis is placed on time-window-based delivery strategies for high-priority shipments.
Guezouli & Abdelhamid (2018)	This model integrates VRP with a multi-depot structure and heterogeneous vehicles, although it does not include pickup and delivery features. It is applicable to multi-source distribution networks.
Guo & Wang (2023)	This research introduces a multi-trip constraint into VRP, allowing vehicles to complete more than one route per period. It also considers heterogeneous vehicles and time windows for operational efficiency.
Guo, Hu & Xue (2024)	This comprehensive model combines multiple constraints: multi-trip, simultaneous delivery & pickup, and time windows. It represents the complexity of modern logistics distribution in high-efficiency courier services.
Liu et al. (2023)	This model tackles pickup and delivery VRP with strict time windows, optimizing total service time. It is applied in fast-moving consumer goods (FMCG) distribution where speed and timeliness are critical.
Lubis & Mawengkang (2020)	The study uses a mixed-integer programming approach to model VRP with heterogeneous vehicles. It considers differences in capacity and

Author	Comprehensive Explanation
	travel time, reflecting logistical conditions in areas with varied infrastructure.
Ma & Li (2024)	This research focuses on the integration of pickup and delivery in a single trip for individual customers. The model represents scenarios where both services are required concurrently, with emphasis on travel time efficiency.
Molina et al. (2020)	This study develops a VRP model with heterogeneous vehicles and time window constraints for distributing medical supplies and equipment. It aims to ensure timely and efficient delivery in the healthcare sector.
Ramos, Gomes & Povoa (2020)	This study addresses multi-depot distribution using heterogeneous vehicles for deliveries to remote areas. It is relevant in geographically dispersed regions with limited access to a central depot.
Sitompul & Horas (2021)	The model developed addresses VRP with vehicle capacity and time window constraints. It employs a mathematical approach tailored for urban delivery settings in Indonesia with dense customer demand.
Tirkolaee et al. (2019)	The study considers a combination of vehicle capacity and customer time window constraints. It contributes to time-based solution strategies for large-scale goods distribution problems.
Wang et al. (2020)	The study focuses on VRP with a multi-depot structure and heterogeneous fleet. It proposes efficient vehicle allocation strategies in multi-origin distribution systems.
Wang et al. (2015)	This study examines VRP with pickup and delivery along with time window constraints. The objective is to minimize total delivery time and improve overall logistics service.
Yu et al. (2022)	This research addresses VRP with pickup and delivery in the context of e-commerce. It adapts to the high-demand dynamics and tight time constraints in modern online distribution systems.

Most models in the VRP literature tend to optimize cost and travel time functions. However, studies such as Ghannadpour et al. (2019) expanded the focus to include energy efficiency, while Wang et al. (2015) emphasized the service aspect by maximizing the number of customers served. In terms of solution methods, heuristic and metaheuristic approaches dominate, as the VRP is a complex combinatorial problem. Genetic algorithms, tabu search, and ant colony optimization are among the most popular methods, as applied in studies by Aktas et al. (2021), Liu et al. (2023), and Guo and Wang (2023). Nevertheless, very few studies have successfully integrated all five constraint elements into a single comprehensive model.

Studies such as Guo, Hu, and Xue (2024) and Bouanane et al. (2019) only incorporated partial combinations of these elements.

In comparison, the research developed in this study offers a more holistic approach. The proposed model integrates all major elements simultaneously: vehicle capacity, service time windows, heterogeneous fleet, pickup and delivery system, and multi-trip capabilities. Furthermore, the model also optimizes service performance by minimizing delivery and pickup delays. This makes the model more representative of real-world operational conditions in the courier industry, where logistical efficiency and service quality must go hand in hand. This model was developed using an integer linear programming (ILP) formulation and is designed to be solvable using heuristic approaches for large-scale instances, striking a balance between computational accuracy and efficiency. This type of approach is still rarely found in the existing literature, thus offering an original contribution to VRP model development.

Therefore, the results of this review indicate a significant gap in previous research concerning the integration of operational complexities within VRP models. This study attempts to address that gap while also opening opportunities for further development of vehicle routing systems that are flexible, adaptive, and efficient in modern logistics environments. In conclusion, this review highlights a considerable lack of comprehensive integration of the five main constraint elements—capacity, time windows, heterogeneous fleet, pickup and delivery, and multi-trip capabilities—within a single, unified model. This research addresses that gap by developing a model known as HFMTVRPDPTW (Heterogeneous Fleet Multi-Trip Vehicle Routing Problem with Pickup and Delivery and Time Windows). The model not only accommodates all the primary constraints simultaneously but also formulates a service-oriented objective function aimed at minimizing pickup and delivery delays and maximizing the number of demands served. The model was developed using an integer linear programming (ILP) approach and is designed to be applicable with heuristic or metaheuristic methods for large-scale implementations. This approach has been rarely discussed in previous studies, thereby contributing an original perspective to the development of efficient, adaptive, and realistic logistics distribution models that address the current operational challenges of courier service companies.

CONCLUSION

The literature review conducted reveals that the development of *Vehicle Routing Problem* (*VRP*) models continues to evolve in terms of formulation complexity, constraint variations, and solution approaches. This study focuses on five main constraint elements: vehicle capacity, *time windows*, heterogeneous fleet, pickup and delivery systems, and *multi-trip* capabilities within a single working period. The findings show that most previous studies only integrate two or three of these constraint elements into their models. Very few have successfully incorporated all five elements into a unified and comprehensive model. In general, *VRP* models in the literature tend to focus on cost efficiency and travel time minimization. However, some studies have expanded the scope of their objective functions by incorporating energy efficiency and service quality. In terms of solution methods, heuristic and metaheuristic approaches are widely adopted, considering that *VRP* is a highly complex combinatorial problem. Methods such as genetic algorithms, *tabu search*, and *ant colony* *optimization* are commonly used to address large-scale problem instances involving numerous variables and constraints.

To address the gap identified in the literature, this study proposes a more comprehensive model named *HFMTVRPDPTW* (*Heterogeneous Fleet Multi-Trip Vehicle Routing Problem with Pickup and Delivery and Time Windows*). This model is designed to simultaneously accommodate all five key constraint elements, thereby providing a more realistic representation of operational conditions in modern logistics distribution systems. Moreover, the model emphasizes customer service by minimizing delivery and pickup delays and maximizing the number of fulfilled demands. The *HFMTVRPDPTW* model is mathematically formulated using an *Integer Linear Programming* (*ILP*) approach, with a structure that allows for both exact and heuristic/metaheuristic solutions, particularly when applied to large-scale instances. This ensures computational efficiency and adaptability in practical implementation, where diverse and dynamic operational conditions are often encountered. Therefore, the development of the *HFMTVRPDPTW* model in this study offers an original contribution to the *VRP* literature and serves as a potential solution that is both adaptive and efficient for vehicle routing planning in today's increasingly complex and dynamic logistics industry.

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