Jurnal Ilmiah Teknik Elektro Komputer dan Informatika (JITEKI)
Vol. 10, No. 3, September 2024, pp. 625-638
ISSN: 2338-3070, DOI: 10.26555/jiteki.v10i3.29686

Optimizing Disaster Response: A Systematic Review of Time-Dependent Cumulative Vehicle Routing in Humanitarian Logistics

Dedy Hartama[1], Wanayumini[2], Irfan Sudahri Damanik[1]
[1]Study Program of Information Systems, STIKOM Tunas Bangsa, Pematangsiantar, Indonesia
[2]Study Program of Informatics Engineering, Universitas Asahan, Indonesia

ARTICLE INFO

Article history:

Received July 28, 2021
Revised August 28, 2021
Published September 28, 2021

Keywords:

Time-Dependent Cumulative Vehicle Routing Problem (TDCVRP;
Humanitarian logistics;
Disaster response;
Optimization models;
Vehicle Routing Problems (VRP)

ABSTRACT

Effective delivery of aid during disasters is crucial for mitigating impacts and ensuring well-being. A major challenge in humanitarian logistics is optimizing vehicle routing to maximize efficiency and minimize delivery times. which included 50 studies published between 2012 and 2022. We used the prism method to guide the process of choosing a study, which started from 200 Abstract which is identified and ends with 50 appropriate studies for in - depth analysis. This systematic literature review (SLR) examines the Time-Dependent Cumulative Vehicle Routing Problem (TDCVRP) in humanitarian logistics, identifying VRP variants, their applications, and effectiveness in disaster scenarios. Using a comprehensive search and PRISMA guidelines, the review highlights the importance of optimization models and advanced algorithms. Applications include aid delivery, evacuation management, and facility location optimization, though challenges like computational complexity and reliance on real-time data persist. The review identifies research gaps and suggests future research should focus on integrating advanced methods and improving practical applicability in disaster responses.

Corresponding Author:

Dedy Hartama, Study Program of Information Systems, STIKOM Tunas Bangsa, Pematangsiantar, Indonesia
Email: dedyhartama@amiktunasbangsa.ac.id

1. INTRODUCTION

In the realm of humanitarian logistics, effective disaster response is a crucial aspect that can significantly impact the lives of those affected by emergencies [1], [2], [3], [4]. Timely and efficient delivery of aid and resources is essential for mitigating the adverse effects of disasters and ensuring the well-being of survivors [5], [6]. One of the critical challenges in humanitarian logistics is the optimization of vehicle routing, which involves the strategic planning of routes to maximize efficiency and minimize delivery times [7], [8], [9]. The Vehicle Routing Problem (VRP) has been extensively studied in various contexts, including commercial logistics and transportation [10], [11]. However, the unique conditions and constraints of disaster response scenarios necessitate specialized approaches. In particular, the Cumulative Vehicle Routing Problem (CVRP) and its time-dependent variants have gained attention for their potential to address the dynamic and unpredictable nature of disaster environments [12], [13], [14], [15]. Several studies have investigated the applications of VRP in disaster response logistics.

For instance, the study by Ma *et al.* (2023) proposes a Time-Dependent Vehicle Routing Problem (TDVRP) model that optimizes departure time and speed for shared autonomous electric vehicle services. The model aims to minimize travel time and reduce energy consumption by considering dynamic traffic conditions. Using a genetic algorithm, the study successfully finds optimal solutions, demonstrating that this approach effectively reduces travel time and energy consumption compared to traditional methods. The included case study validates the model's effectiveness in real-world situations, making a significant contribution to the literature on electric vehicles and autonomous technology in logistics. However, the lack of field validation means the simulation results may not fully apply to real-world scenarios. The computational complexity of the genetic algorithm also poses challenges, particularly in large-scale or highly dynamic conditions. The model relies on assumptions about traffic conditions that may not always be accurate. Additionally, the focus on shared autonomous electric vehicles limits the model's applicability to other types of vehicles or logistics scenarios [16], [17], [18], [19].

Similarly, the study by Kritikos, Metzidakis, and Ioannou (2024) addresses the Cumulative Vehicle Routing Problem (CVRP) with arc time windows, presenting a model that incorporates specific time constraints for each arc or segment of the route. This approach aims to enhance the precision of vehicle routing by ensuring that vehicles adhere to predefined time windows, thus optimizing delivery schedules and improving overall efficiency. The researchers employ advanced algorithms to solve this complex problem, demonstrating that their model can significantly improve routing performance under time constraints. However, the model's reliance on strict time windows for each arc may limit its flexibility in real-world applications where conditions are often unpredictable. Additionally, while the proposed algorithms show promise, their computational demands can be high, particularly for large-scale problems with numerous variables. The study primarily uses simulated data for validation, which may not fully capture the complexities of real-world scenarios [20].

Furthermore, the study by Liu *et al*. (2020) addresses the Time-Dependent Vehicle Routing Problem (TDVRP) with time windows in the context of city logistics, incorporating a congestion avoidance approach. The proposed model aims to optimize vehicle routes by considering both time windows and traffic congestion, thereby improving delivery efficiency and reducing travel time. The researchers utilize advanced algorithms to tackle this complex problem, demonstrating that their model can effectively navigate congested urban environments and adhere to delivery time windows, leading to enhanced logistics performance. However, while the model effectively incorporates congestion avoidance, it relies heavily on accurate traffic data, which may not always be available or reliable in real-world scenarios. The computational complexity of the algorithms used can also pose challenges, particularly for large-scale applications with numerous vehicles and delivery points [21].

Additionally, the study by Wu *et al*. (2023) examines the Time-Dependent Vehicle Routing Problem (TDVRP) for fresh agricultural products, taking customer value into account. The proposed model focuses on optimizing delivery routes for fresh products to ensure their freshness and customer satisfaction. By incorporating customer value into the model, the study aims to enhance distribution efficiency and maximize the perceived value for customers. The researchers employ advanced algorithms to tackle this problem, demonstrating that their model can effectively reduce delivery times and maintain the quality of fresh agricultural products. However, the model's reliance on accurate and up-to-date customer value data may pose a challenge, as customer preferences and values can fluctuate. Additionally, the computational complexity of the algorithms used presents a limitation, especially in large-scale applications with numerous delivery points and customer variables [22].

Lastly, the study by Guo *et al*. (2022) explores an industrial information integration method for vehicle routing optimization using the grey target decision model. The research aims to enhance vehicle routing efficiency by integrating various industrial information sources and applying the grey target decision model to optimize routing decisions. The proposed method effectively addresses the complexity of routing problems in industrial settings, demonstrating improved decision-making capabilities and route optimization. However, the reliance on accurate and comprehensive industrial data can be challenging, as data quality and availability may vary. Additionally, the computational complexity of the grey target decision model can pose difficulties, especially in large-scale industrial applications with numerous variables and constraints. Further research is needed to validate this model in practical industrial environments, streamline the computational processes, and ensure the robustness of the model under diverse real-world conditions [23].

Based on various prior studies, several key gaps still need to be bridged to enhance the efficiency and effectiveness of practical applications of the Time-Dependent Vehicle Routing Problem (TDVRP) [24], [25], [26]. Many research models use simulated data to test their effectiveness, which may not fully reflect real-world conditions, indicating a need for broader field validation. Additionally, the reliance on accurate and real-time traffic data suggests the need for further development in more comprehensive and adaptive real-time data integration. The computational complexity of the algorithms used in these models also presents a significant challenge, particularly in large-scale applications, highlighting the necessity for the development of more efficient algorithms. Existing models often depend on certain assumptions about traffic conditions and customer values, which can reduce their flexibility in handling the variability and uncertainty of real-world conditions. Furthermore, many models face scalability issues when applied to large-scale scenarios with numerous variables and constraints. Therefore, further research is needed to address these scalability challenges, as well as to improve the flexibility and efficiency of the models in practical applications. This systematic literature review (SLR) [27], [28], aims to fill this gap by providing a thorough analysis of current approaches, techniques, and applications of TDCVRP in disaster response logistics [29], [30], [31]. The objectives of this review are threefold: to identify and categorize the various methods and algorithms used in TDCVRP research within the context of humanitarian logistics; to evaluate the effectiveness and limitations of these approaches through a comparative analysis; and to highlight key findings, gaps in the literature, and provide recommendations for future research directions [32], [33], [34]. To achieve these objectives, we formulated several research questions that guided our review:

1) RQ1: What are the different variants of VRP and how are they applied in humanitarian logistics?
2) RQ2: What distinguishes CVRP from other VRP variants and what methods are used in TDCVRP research?
3) RQ3: How do temporal factors influence vehicle routing in disaster response, and what approaches address these challenges?
4) RQ4: What are the current applications of TDCVRP in real-world disaster scenarios, and what are the main challenges and limitations encountered?
5) RQ5: How do the various approaches compare in terms of performance, and what are the key findings from the literature?
6) RQ6: What gaps exist in the current research, and what directions should future studies take to address these gaps?

By synthesizing findings from existing studies, this SLR aims to provide valuable insights and practical implications for researchers and practitioners involved in humanitarian logistics and disaster response[35], [36], [37]. In the following sections, we detail the methodology employed in our review, present the results and discussion of our findings, and conclude with implications for practice and directions for future research [38], [39], [40].

2. METHODS

To conduct a thorough and systematic literature review (SLR) on Time-Dependent Vehicle Routing Problem (TDVRP) methodologies, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were meticulously followed [41], [42] (Fig. 1).

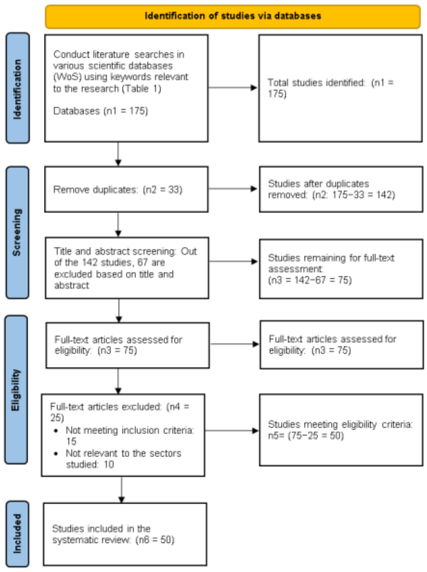


Fig. 1. Study selection process using the PRISMA framework

The Methodology section details the search strategy, including the databases used such as Google Web of Science and the search terms employed “Time-Dependent” AND “Vehicle Routing Problem” AND “Disaster” AND “Humanitarian” AND “Logistics” OR “Humanitarian Logistics” OR “TDVRP”. Inclusion criteria for the review include peer-reviewed articles, relevance to TDVRP, and publications within the last ten years. Exclusion criteria involve non-English articles and unrelated topics. The study selection process outlines the steps from initial search results to detailed review and final selection of studies.

To ensure that this systematic literature review includes relevant and high-quality studies, we established clear inclusion and exclusion criteria. These criteria are designed to filter the literature to include the most pertinent studies focusing on the optimization of time-dependent cumulative vehicle routing in the context of humanitarian logistics for disaster response. The following table summarizes the inclusion and exclusion criteria applied in this study. Article criteria using the PICOS framework shown in Table 1.

Table 1. Article criteria using the PICOS framework

Criterion	Inclusion Criteria	Exclusion Criteria
Population	Studies focusing on humanitarian logistics in disaster response	Studies not related to humanitarian logistics or disaster response
Intervention	Research involving time-dependent cumulative vehicle routing problems	Research that does not involve time-dependent or cumulative VRP
Comparators	Studies comparing different VRP approaches	Studies without any comparison of different approaches
Outcomes	Studies reporting on efficiency, delivery time, or optimization	Studies that do not report relevant outcomes
Study Design	Empirical studies, case studies, simulation studies	Opinion papers, editorials, or non-empirical studies
Publication Type	Peer-reviewed journal articles, conference papers	Non-peer-reviewed articles, theses, dissertations, book chapters
Time Frame	Studies published from 2008 to present	Studies published before 2008
Language	Studies published in English	Studies published in languages other than English

3. RESULTS AND DISCUSSION

3.1. Variants of VRP and Their Application in Humanitarian Logistics

The keyword co-occurrence analysis (Fig. 2) provides significant insights into the different variants of the Vehicle Routing Problem (VRP) and their applications in humanitarian logistics. The central keywords, such as "optimization," "model," "algorithm," "vehicle routing problem," and "logistics," indicate the core focus areas in the literature. These keywords are connected to various terms, demonstrating their broad applicability and relevance in the context of humanitarian logistics

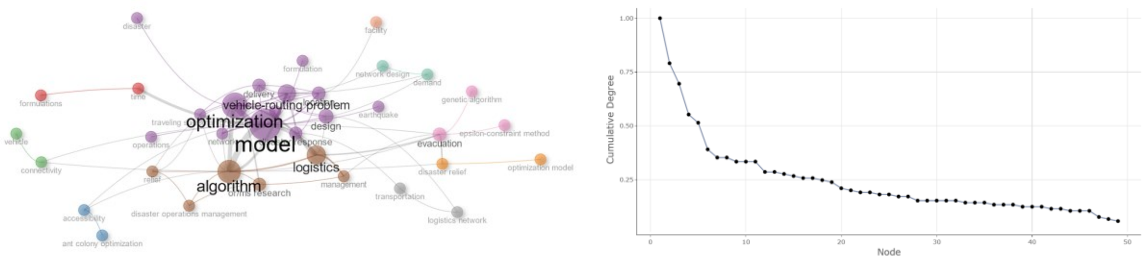


Fig. 2. Keyword Co-occurrence

Several VRP variants are identified through keywords like "delivery," "evacuation," "disaster relief," and "response." These terms highlight specific applications of VRP in humanitarian settings, such as optimizing routes for aid delivery, managing evacuations, and coordinating disaster relief efforts. Additionally, the presence of methodological terms like "genetic algorithm," "epsilon-constraint method," and "ant colony optimization" suggests different approaches used to address VRP challenges in disaster response scenarios.

The cumulative degree plot further emphasizes the prominence of certain keywords within the literature. Keywords with higher cumulative degrees, such as those related to optimization and logistics, are more frequently studied and cited, indicating their central role in the field. The steep initial decline in the plot followed by a more gradual decrease shows that while a few core concepts dominate the research, a broad range of other topics are also explored, though less frequently.

The two diagrams based on Author's Keywords and Keywords Plus offer insights into research trends and focus areas within the field of Vehicle Routing Problems (VRP) and their applications in humanitarian logistics (Fig. 3).

The analysis of Author's Keywords (Fig. 3a) shows that Logistics and Optimization are central themes with consistent research interest from 2015 to 2023. These topics are foundational in VRP research, essential for developing efficient routing strategies. Vehicle Routing Problem (VRP) and Algorithm also show continuous interest, indicating ongoing efforts to improve computational methods and models. Emerging topics such as Disaster Response and Evacuation have gained significant attention since 2018 and 2019, respectively. These keywords reflect a growing focus on applying VRP in humanitarian scenarios, particularly for optimizing emergency response and evacuation logistics. Delivery has been a key topic since 2018, emphasizing the importance of timely and efficient delivery systems in disaster logistics. Specialized areas like Network and Location indicate a focus on optimizing resource placement and connectivity, crucial for effective disaster management.

The Keywords Plus analysis (Fig. 3b) shows that Humanitarian Logistics and Robust Optimization have been consistent research areas from 2017 to 2023. Their sustained presence highlights their importance in addressing uncertainties and ensuring reliable VRP solutions in humanitarian contexts. Disaster shows significant research activity from 2017 to 2020, reflecting efforts to understand and manage disaster-related challenges. Emerging topics such as Disaster Management, Vehicle Routing, and Facility Location have been key research areas from around 2018 and 2019, continuing to 2023. This indicates a growing emphasis on strategic and operational aspects of disaster response and logistics.

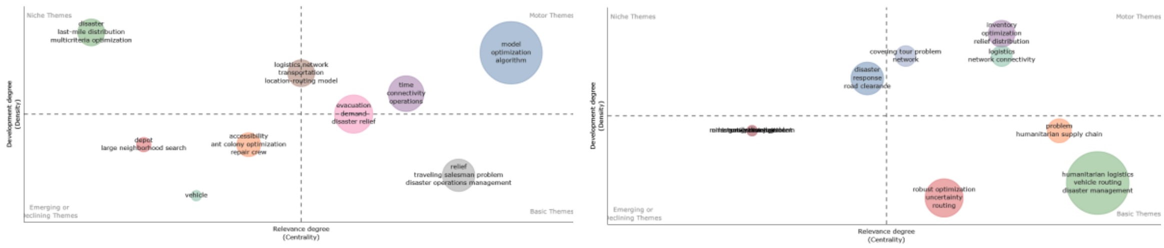
(a) Author's Keywords (b) Keyword's Plus

Fig. 3. Topic Analysis

Linking this analysis to the research questions, both diagrams highlight key variants and methodologies related to VRP. Terms like Vehicle Routing, Optimization, Algorithm, and Robust Optimization indicate various approaches explored in the literature. The focus on Facility Location and Network underscores the importance of spatial and connectivity aspects in VRP research. Applications in humanitarian logistics are emphasized through terms like Disaster Response, Humanitarian Logistics, and Disaster Management, showing the critical role of VRP in optimizing disaster logistics. The presence of terms like Evacuation and Delivery highlights specific applications aimed at managing evacuation logistics and ensuring timely aid delivery.

3.2. Variants of VRP and Their Application in Humanitarian Logistics

The thematic maps based on Keywords Plus and Author's Keywords offer valuable insights into the development and relevance of various research themes within the field of Vehicle Routing Problems (VRP) and their applications in humanitarian logistics (Fig. 4).



(a) Keyword's Plus (b) Author's Keywords

Fig. 4. Thematic Map

The analysis of Keywords Plus (Fig. 4a) reveals several key observations. Model, Optimization, and Algorithm emerge as highly developed and central themes, highlighting the focus on improving computational methods and optimization techniques in VRP research. Additionally, Logistics, Network, and Transportation are identified as important motor themes, indicating their critical role in practical VRP applications. **Niche themes** such as Disaster, Last-Mile Distribution, and Multicriteria Optimization are specialized but crucial for addressing specific aspects of VRP in disaster scenarios. Meanwhile, themes like Vehicle, Large Neighborhood

Search, and Ant Colony Optimization are seen as emerging or possibly declining, suggesting that while these areas are still explored, they may not be the current primary focus. **Basic themes** identified include Evacuation, Demand, and Disaster Relief, which are fundamental to VRP research in humanitarian logistics. These topics emphasize the essential aspects of emergency response and aid distribution.

The thematic map based on Author's Keywords (Fig. 4b) provides additional insights. Inventory Optimization, Relief Distribution, and Logistics are highlighted as highly developed and central themes, essential for the efficient management of resources in disaster response. Network Connectivity and Covering Tour Problem are also important motor themes, reflecting the focus on ensuring effective logistical networks. **Niche themes** such as Robust Optimization, Uncertainty, and Routing indicate specialized research areas addressing specific challenges in VRP under uncertain conditions. Emerging or possibly declining themes include Humanitarian Supply Chain and Problem, which may be gaining or losing prominence based on current research trends. **Basic themes** identified are Humanitarian Logistics, Vehicle Routing, and Disaster Management, which underline the importance of VRP applications in coordinating humanitarian aid and managing disaster logistics.

The co-citation network in Fig. 5 provides a visual representation of how different research works are interconnected through citations. This network helps identify influential studies and the relationships between various research themes in the field of Vehicle Routing Problems (VRP) and their applications in humanitarian logistics.

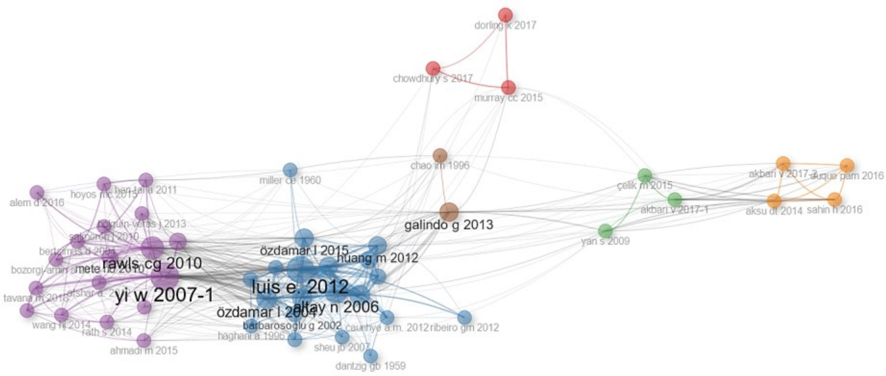


Fig. 5. Co-citation Network

The co-citation network reveals distinct clusters, indicating groups of papers that are frequently cited together. These clusters represent different themes or approaches within VRP research. The Purple Cluster includes works by authors like Yi W (2007) and Tavasszy (2010), focusing on early foundational work in VRP, particularly related to logistics and optimization techniques. The Blue Cluster features prominent works by Luis E. (2012) and Özdamar (2006), highlighting studies central to the development of advanced optimization models and algorithms in VRP. The Green Cluster, containing works by authors like Yan S (2009) and Çelik M (2015), focuses on specific applications of VRP in disaster management and humanitarian logistics. The Orange Cluster includes studies by Akbari N (2017) and Sahin E (2016), suggesting a focus on recent developments and applications in VRP, including vehicle routing and resource allocation in humanitarian settings. Lastly, the Red Cluster features works by authors like Chowdhury S (2017) and Murray CC (2015), indicating a focus on innovative and emerging methods in VRP, possibly including computational techniques and real-world applications.

Central nodes in the network, such as Luis E. (2012) and Özdamar (2006), indicate highly influential studies that are frequently cited and have significantly contributed to the field. These works likely provide key methodologies or theoretical advancements in VRP. The network also shows interconnections between different clusters, indicating that various themes and approaches in VRP research are interrelated. For instance, foundational optimization techniques are linked to advanced models and specific applications in humanitarian logistics.

3.3. Variants of VRP and Their Application in Humanitarian Logistics

Table 2 presents a clustering analysis by coupling, highlighting various thematic groups within research on Vehicle Routing Problems (VRP) and their applications. This analysis is crucial for understanding how different VRP variants are utilized in humanitarian logistics. Clustering by coupling: centrality vs impact shown in Fig. 6.

Table 2. Clustering by Coupling

label	group	freq	centrality	impact
design - conf 33.3% logistics - conf 20% optimization - conf 13.3%	1	5	0.871	1
model - conf 41.2% algorithm - conf 38.5% or/ms research - conf 83.3%	2	18	2.025	1.266
accessibility - conf 75% algorithm - conf 23.1% connectivity - conf 100%	3	5	1.686	1.417
traveling salesman problem - conf 50% accessibility - conf 25% algorithm - conf 7.7%	4	3	3.09	1.25
optimization - conf 46.7% logistics - conf 40% model - conf 23.5%	5	16	2.178	1.25
model - conf 11.8% optimization - conf 13.3% branch-and-price - conf 100%	6	3	2.216	1

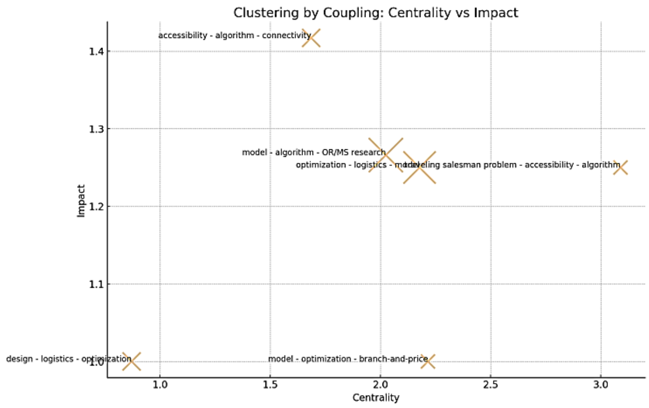


Fig. 6. Clustering by Coupling: Centrality vs Impact

The **first group** focuses on design and logistics, incorporating optimization components. The significant frequency and centrality in this group indicate the importance of design principles in developing VRP models applicable in logistical contexts. The **second group** centers on model and algorithm development within VRP. With the highest frequency and centrality, this group signifies the core focus of VRP research, particularly in creating sophisticated models and algorithms for operational research and management science applications. The **third group** emphasizes the importance of accessibility and connectivity, combined with algorithmic solutions. The high impact of this group reflects the significance of ensuring that VRP solutions are applicable to real-world scenarios, especially in humanitarian logistics where access to affected areas is crucial. The **fourth group** focuses on the Traveling Salesman Problem (TSP), integrating accessibility and algorithmic approaches. The high centrality indicates its pivotal role in the theoretical foundations of VRP, influencing a wide range of applications including disaster response and resource allocation. The **fifth group** highlights the integration of optimization techniques with logistics and modeling. The high frequency and centrality suggest that optimization is a key theme in VRP research, crucial for developing efficient logistical operations in humanitarian contexts. The final group focuses on advanced optimization techniques such as the branch-and-price method. The high centrality underlines its importance in solving complex VRP problems, essential for planning and managing logistical operations in humanitarian logistics.

These clusters reveal key variants and themes within VRP research, such as design, modeling, algorithm development, and specific problems like TSP. Each group represents a different approach or focus area within VRP, indicating the diversity of methodologies used in the field. The relevance of themes like accessibility, connectivity, and optimization highlights the practical applications of VRP in humanitarian logistics. Ensuring access to disaster-affected areas and optimizing logistical operations are critical for effective disaster response and resource allocation. The integration of advanced optimization techniques and algorithmic solutions shows the emphasis on developing robust models that can handle the complexities of real-world humanitarian scenarios.

3.4. Variants of VRP and Their Application in Humanitarian Logistics

Table 3 shows an analysis of keywords clustered based on their dimensions (Dim1 and Dim2) in the research landscape of Vehicle Routing Problems (VRP) and their applications in humanitarian logistics. Each keyword represents an important theme or concept in the field, and this clustering helps in understanding the relationships and relevance of these themes.

Table 3. Word By Cluster

word	Dim1	Dim2	cluster
model	-0.27	-0.25	1
optimization	0.19	-0.04	1
algorithm	0.03	-0.67	1
logistics	-0.23	0.58	1
vehicle-routing problem	-0.14	0.11	1
design	-0.31	0.86	1
evacuation	-0.44	1.31	1
or/ms research	-0.16	-0.50	1
delivery	-0.17	0.02	1
disaster response	-0.28	0.62	1

The keyword "model" is very important in VRP research, highlighting the need for developing robust models to solve routing problems in various scenarios, including humanitarian logistics. "Optimization" indicates crucial techniques for enhancing the efficiency of VRP solutions, while "algorithm" emphasizes the fundamental implementation of VRP models to address specific challenges in vehicle routing. "Logistics" as a core component of VRP is essential, especially in humanitarian contexts where effective logistics can significantly impact the efficiency of disaster response.

The Vehicle Routing Problem ("vehicle-routing problem") is the central issue addressed by this research, with its application spanning various logistical scenarios. The design aspect ("design") of VRP models is also crucial for their effectiveness, indicating that well-thought-out design of VRP solutions is necessary to meet specific needs in disaster response. Evacuation logistics ("evacuation") is a critical application of VRP in humanitarian contexts, with high dimension values indicating a significant focus on optimizing evacuation routes during disasters.

Operational Research and Management Science (OR/MS Research) contribute both theoretically and practically to the development of VRP solutions, while efficient delivery systems ("delivery") are essential for timely aid distribution. Disaster response ("disaster response") is a primary application of VRP in humanitarian logistics, emphasizing the importance of VRP solutions in improving the efficiency and effectiveness of disaster response operations.

This clustering of keywords provides a clear picture of the main themes and focus areas in VRP research related to humanitarian logistics. Keywords such as "model," "optimization," "algorithm," and "logistics" underscore the foundational elements of VRP, while application-specific keywords like "evacuation," "delivery," and "disaster response" highlight the practical importance of VRP in improving disaster response operations. This analysis helps in understanding the multifaceted nature of VRP research and its significant applications in real-world disaster scenarios.

Fig. 7 shows a factorial analysis based on correspondence analysis, mapping the distribution of keywords and themes in the research on Vehicle Routing Problems (VRP) and their applications in humanitarian logistics. Each point represents a keyword, indicating its relationship and relevance to other keywords.

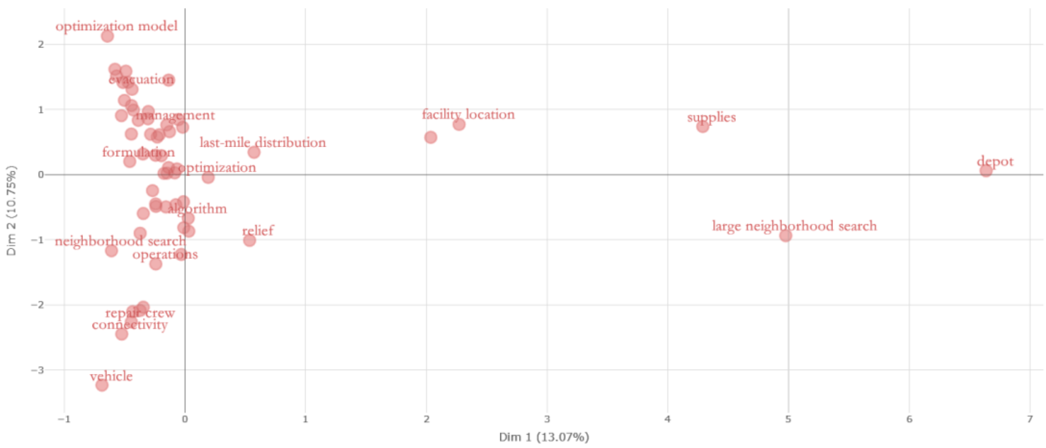


Fig. 7. Factorial Analysis by Correspondence Analysis

Keywords like "optimization model" and "formulation" are clustered together, highlighting the importance of developing robust optimization models to solve complex routing problems. "Evacuation," "management," and "operations" show a focus on managing evacuation logistics during disasters, underscoring the critical role of VRP in evacuation strategies. The proximity of "last-mile distribution" and "relief" emphasizes the efficient delivery of aid to affected areas, reflecting the practical applications of VRP in humanitarian logistics.

The cluster of keywords like "algorithm," "neighborhood search," and "operations" indicates ongoing efforts in developing advanced algorithms for VRP. "Facility location" and "supplies" highlight the strategic planning aspects of VRP, crucial for effective disaster response and resource allocation. "Large neighborhood search" and "depot" suggest a focus on advanced search techniques to optimize depot locations and routing.

3.5. Variants of VRP and Their Application in Humanitarian Logistics

Fig. 8 shows a factorial analysis using Multiple Correspondence Analysis (MCA), which maps the distribution of keywords and themes within the research on Vehicle Routing Problems (VRP) and their applications in humanitarian logistics. Each point represents a keyword, indicating its relationship and relevance to other keywords in the research landscape.

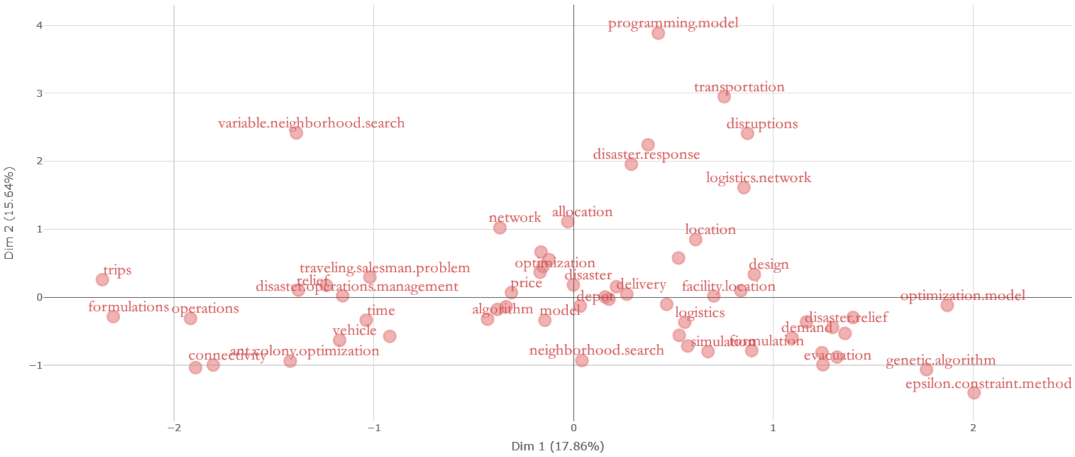


Fig. 8. Factorial Analysis by Multiple Correspondence Analysis

The clustering of keywords such as "optimization model," "genetic algorithm," and "epsilon constraint method" highlights their importance in developing robust optimization solutions for VRP. These methods are essential for addressing complex routing problems, particularly in dynamic and uncertain environments like disaster response. Similarly, terms like "disaster response," "logistics network," and "delivery" are grouped closely, indicating a strong focus on optimizing logistics operations to enhance disaster response. This cluster underscores the practical applications of VRP in managing and improving logistical efficiency during emergencies.

Keywords like "neighborhood search," "variable neighborhood search," and "algorithm" show the emphasis on developing advanced algorithms to improve the computational efficiency of VRP solutions. These methods are crucial for handling large-scale and complex routing problems. The proximity of terms like "facility location," "allocation," and "network" highlights the strategic aspects of VRP, such as determining optimal facility locations and resource allocation to improve logistics performance in humanitarian contexts.

Specific applications of VRP in humanitarian logistics are indicated by keywords such as "evacuation," "disaster relief," and "trips," emphasizing the need for tailored solutions to manage evacuation routes and ensure effective delivery of relief supplies.

This analysis reveals the various approaches and methodologies in VRP research, such as optimization models, algorithm development, and strategic planning, which are critical for addressing diverse challenges in vehicle routing and disaster response. Keywords like "disaster response," "evacuation," "logistics network," and "delivery" demonstrate the crucial role of VRP in optimizing logistics operations to improve the efficiency and effectiveness of disaster response and aid distribution. The distribution of keywords also provides insights into well-studied areas and potential research gaps, suggesting that future studies should focus on integrating advanced methods into real-world disaster response scenarios.

3.6. Variants of VRP and Their Application in Humanitarian Logistics

Table 4 and Fig. 9 provide insights into the thematic clusters and distribution of keywords in research on Vehicle Routing Problems (VRP) and their applications in humanitarian logistics. Table 4 presents a thematic map by cluster, highlighting Callon Centrality, Density values, rank, and frequency for each cluster, while Figure 7 displays a factorial analysis using Multiple Correspondence Analysis (MCA).

Table 4. Thematic Map By Cluster

Cluster	CallonCentrality	CallonDensity	RankCentrality	RankDensity	ClusterFrequency
depot	0.25	62.5	2	3.5	4
model	8.858	74.857	9	8	134
disaster	0	75	1	9	10
time	2.406	71.825	7	6	19
accessibility	0.542	62.5	4	3.5	8
logistics network	1.083	74.306	5	7	10
evacuation	2.403	69.147	6	5	23
relief	2.609	42.361	8	2	15
vehicle	0.5	33.333	3	1	3

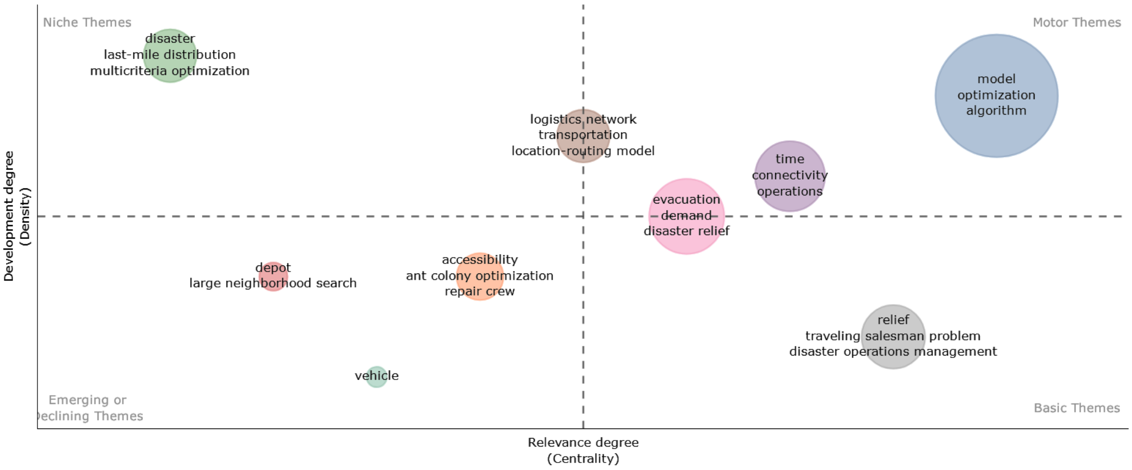


Fig. 9. Factorial Analysis by Multiple Correspondence Analysis

Major Themes (Motor Themes): The cluster of "Model Optimization and Algorithm" shows high centrality and density, emphasizing the development of robust models and algorithms as foundational elements in VRP research. This cluster is crucial for creating effective routing solutions in humanitarian logistics, reflecting its central role in the field. Basic Themes: The "Relief and Disaster Operations Management" cluster, with moderate centrality and density, focuses on applying VRP to manage relief efforts and disaster operations. This theme highlights practical strategies for efficient resource allocation and delivery in disaster scenarios, underscoring the importance of VRP in real-world applications. Emerging or Declining Themes: The "Vehicle" cluster, characterized by low centrality and density, represents an emerging or less developed theme. This area focuses on the specific role of vehicles in VRP, highlighting the need for specialized routing strategies despite its current lower prominence. Niche Themes: The "Disaster and Last-Mile Distribution" cluster has low centrality but high density, indicating it is a specialized theme. This cluster addresses specific challenges in disaster logistics, such as optimizing last-mile distribution and managing multiple criteria, which are crucial for effective disaster response. Another niche theme, "Depot and Large Neighborhood Search," focuses on optimizing depot locations and using advanced search techniques for routing, important for strategic planning in VRP.

These clusters represent various approaches in VRP research, such as optimization models, algorithm development, and specific applications like disaster relief and depot management. The diversity of these themes highlights the multifaceted nature of VRP research and its applications in humanitarian logistics. Keywords like "disaster response," "logistics network," "evacuation," and "relief" underscore the direct applications of VRP in improving disaster response efficiency and effectiveness.

3.7. Discussion

Research on Vehicle Routing Problems (VRP) has produced various variants applied in humanitarian logistics, including optimization models, algorithms, and design approaches aimed at enhancing the efficiency of logistical operations in disaster scenarios. The Cumulative Vehicle Routing Problem (CVRP) differs from other VRP variants by considering cumulative costs and time during routes, which is highly relevant in disaster scenarios. The Time-Dependent Cumulative Vehicle Routing Problem (TDCVRP) employs advanced methods such as genetic algorithms and neighborhood search techniques to optimize routes in dynamic temporal conditions.

Temporal factors, such as changing road conditions and demand variations, significantly influence vehicle routing in disaster response. Approaches like adaptive algorithms and optimization models that consider temporal dynamics are used to address these challenges. The application of TDCVRP in real-world disaster scenarios includes route optimization for aid delivery, evacuation management, and determining optimal facility locations. However, the main challenges include computational complexity and reliance on real-time data.

Various approaches in VRP research are evaluated based on computational efficiency, solution accuracy, and adaptability to dynamic conditions. Key findings indicate that optimization models and advanced algorithms perform best in the context of humanitarian logistics. Thematic and factorial analysis reveals several gaps in current research, including the lack of integration of advanced methods in real-world scenarios and the need for more adaptive solutions. Future research should focus on developing more comprehensive models and enhancing technology integration.

4. CONCLUSION

This systematic literature review has provided a comprehensive analysis of the Time-Dependent Cumulative Vehicle Routing Problem (TDCVRP) in humanitarian logistics. The findings emphasize the critical role of optimization models and advanced algorithms in enhancing the efficiency and effectiveness of disaster response operations. Despite significant advancements, challenges such as computational complexity and the need for real-time data remain. The study highlights several research gaps, including the necessity for more adaptive and real-world applicable solutions. Future research directions should aim to develop more robust models and improve technology integration to better address the dynamic and complex nature of disaster logistics.

Acknowledgments

The researchers would like to thank the Directorate of Research, Technology, and Community Service, Directorate General of Higher Education, Research, and Technology of the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia for funding this research under the Basic Research scheme (Fundamental Research) for the year 2024.

REFERENCES

[1] Z. A. Mani, M. A. S. Sultan, V. Plummer, And K. Goniewicz, “Navigating Interoperability In Disaster Management: Insights Of Current Trends And Challenges In Saudi Arabia,” *Int. J. Disaster Risk Sci.*, vol. 14, no. 6, pp. 873–885, 2023, https://doi.org/10.1007/S13753-023-00528-4.

[2] A. Moreno, D. Alem, M. Gendreau, P. Munari, “The Heterogeneous Multicrew Scheduling And Routing Problem In Road Restoration,” *Transp. Res. Part B-Methodological*, vol. 141, pp. 24–58, Nov. 2020, https://doi.org/10.1016/J.Trb.2020.09.002.

[3] M. Khorsi, S. K. Chaharsooghi, A. Bozorgi-Amiri, And A. H. Kashan, “A Multi-Objective Multi-Period Model For Humanitarian Relief Logistics With Split Delivery And Multiple Uses Of Vehicles,” *J. Syst. Sci. Syst. Eng.*, vol. 29, no. 3, pp. 360–378, Jun. 2020, https://doi.org/10.1007/S11518-019-5444-6.

[4] H. Adarang, A. Bozorgi-Amiri, K. Khalili-Damghani, R. Tavakkoli-Moghaddam, “A Robust Bi-Objective Location-Routing Model For Providing Emergency Medical Services,” *J. Humanit. Logist. Supply Chain Manag.*, vol. 10, no. 3, pp. 285–319, Aug. 2020, https://doi.org/10.1108/Jhlscm-11-2018-0072.

[5] R. C. Bonfanti, B. Oberti, E. Ravazzoli, A. Rinaldi, S. Ruggieri, A. Schimmenti, “The Role Of Trust In Disaster Risk Reduction: A Critical Review,” *Int. J. Environ. Res. Public Health*, vol. 21, no. 1, 2024, https://doi.org/10.3390/Ijerph21010029.

[6] E. J. Raker, M. C. Arcaya, S. R. Lowe, M. Zacher, J. Rhodes, M. C. Waters, “Mitigating Health Disparities After Natural Disasters: Lessons From The Risk Project,” *Health Aff.*, vol. 39, no. 12, pp. 2128–2135, 2020, https://doi.org/10.1377/Hlthaff.2020.01161.

[7] S. Jain, M. L. Meena, V. Kumar, P. K. Detwal, “Route Optimization As An Aspect Of Humanitarian Logistics: Delineating Existing Literature From 2011 To 2022,” In *Conference of Innovative Product Design and Intelligent Manufacturing System*, pp. 647-661, 2022, https://doi.org/10.1007/978-981-99-1665-8_54.

[8] A. Sadeghi, F. Aros-Vera, H. Mosadegh, R. Younessinaki, “Social Cost-Vehicle Routing Problem And Its Application To The Delivery Of Water In Post-Disaster Humanitarian Logistics,” *Transp. Res. Part E Logist. Transp. Rev.*, vol. 176, p. 103189, 2023, Doi: https://doi.org/10.1016/j.tre.2023.103189.

[9] O. Rodríguez-Espíndola *et al.*, “Humanitarian Logistics Optimization Models: An Investigation Of Decision-Maker Involvement And Directions To Promote Implementation,” *Socioecon. Plann. Sci.*, vol. 89, 2023, https://doi.org/10.1016/J.Seps.2023.101669.

[10] H. Li, J. Zhou, K. Xu, "Evolution Of Green Vehicle Routing Problem: A Bibliometric And Visualized Review," *Sustainability*, vol. 15, no. 23, p. 16149, 2023, https://doi.org/10.3390/Su152316149.
[11] K. Sar P. Ghadimi, "A Systematic Literature Review Of The Vehicle Routing Problem In Reverse Logistics Operations," *Comput. Ind. Eng.*, vol. 177, p. 109011, 2023, https://doi.org/10.1016/J.Cie.2023.109011.
[12] K. Corona-Gutiérrez, S. Nucamendi-Guillén, E. Lalla-Ruiz, "Vehicle Routing With Cumulative Objectives: A State Of The Art And Analysis," *Comput. Ind. Eng.*, vol. 169, 2022, https://doi.org/10.1016/J.Cie.2022.108054.
[13] B. Balcik, I. Yanikoglu, "A Robust Optimization Approach For Humanitarian Needs Assessment Planning Under Travel Time Uncertainty," *Eur. J. Oper. Res.*, vol. 282, no. 1, pp. 40–57, Apr. 2020, https://doi.org/10.1016/J.Ejor.2019.09.008.
[14] S. Mohammadi, S. A. Darestani, B. Vahdani, A. Alinezhad, "A Robust Neutrosophic Fuzzy-Based Approach To Integrate Reliable Facility Location And Routing Decisions For Disaster Relief Under Fairness And Aftershocks Concerns," *Comput. Ind. Eng.*, vol. 148, Oct. 2020, https://doi.org/10.1016/J.Cie.2020.106734.
[15] R. Sakiani, A. Seifi, R. R. Khorshiddoust, "Inventory Routing And Dynamic Redistribution Of Relief Goods In Post-Disaster Operations," *Comput. Ind. Eng.*, vol. 140, Feb. 2020, https://doi.org/10.1016/J.Cie.2019.106219.
[16] B. Ma, D. Hu, Y. Wang, Q. Sun, L. He, X. Chen, "Time-Dependent Vehicle Routing Problem With Departure Time And Speed Optimization For Shared Autonomous Electric Vehicle Service," *Appl. Math. Model.*, vol. 113, pp. 333–357, 2023, https://Doi.Org/10.1016/J.Apm.2022.09.020.
[17] A. Khare, R. Batta, J. E. Kang, "On The Analysis Of Last-Mile Relief Delivery On A Tree Network: Application To The 2015 Nepal Earthquake," *J. Oper. Res. Soc.*, vol. 72, no. 4, pp. 727–743, Mar. 2021, https://doi.org/10.1080/01605682.2019.1708824.
[18] H. M. Saatchi, A. A. Khamseh, R. Tavakkoli-Moghaddam, "Solving A New Bi-Objective Model For Relief Logistics In A Humanitarian Supply Chain Using Bi-Objective Meta-Heuristic Algorithms," *Sci. Iran.*, vol. 28, no. 5, pp. 2948–2971, 2021, https://doi.org/10.24200/Sci.2020.53823.3438.
[19] J. Garcia-Alviz, G. Galindo, J. Arellana, R. Yie-Pinedo, "Planning Road Network Restoration And Relief Distribution Under Heterogeneous Road Disruptions," *Or Spectr.*, vol. 43, no. 4, pp. 941–981, Dec. 2021, https://doi.org/10.1007/S00291-021-00644-X.
[20] M. N. Kritikos, T. Metzidakis, G. Ioannou, "The Cumulative Vehicle Routing Problem With Arc Time Windows," *Expert Syst. Appl.*, vol. 240, p. 122447, 2024, https://doi.org/10.1016/J.Eswa.2023.122447.
[21] C. Liu, G. Kou, X. Zhou, Y. Peng, H. Sheng, F. E. Alsaadi, "Time-Dependent Vehicle Routing Problem With Time Windows Of City Logistics With A Congestion Avoidance Approach," *Knowledge-Based Syst.*, vol. 188, p. 104813, 2020, https://doi.org/10.1016/j.knosys.2019.06.021.
[22] D. Wu, J. Li, J. Cui, D. Hu, "Research On The Time-Dependent Vehicle Routing Problem For Fresh Agricultural Products Based On Customer Value," *Agric.*, vol. 13, no. 3, 2023, https://doi.org/10.3390/Agriculture13030681.
[23] K. Guo, S. Hu, H. Zhu, W. Tan, "Industrial Information Integration Method To Vehicle Routing Optimization Using Grey Target Decision," *J. Ind. Inf. Integr.*, vol. 27, p. 100336, 2022, Doi: https://doi.org/10.1016/j.jii.2022.100336.
[24] L. Do C. Martins, P. Hirsch, A. A. Juan, "Agile Optimization Of A Two-Echelon Vehicle Routing Problem With Pickup And Delivery," *Int. Trans. Oper. Res.*, vol. 28, no. 1, pp. 201–221, Jan. 2021, https://doi.org/10.1111/Itor.12796.
[25] G. Zhang, N. Zhu, S. Ma, J. Xia, "Humanitarian Relief Network Assessment Using Collaborative Truck-And-Drone System," *Transp. Res. Part E-Logistics Transp. Rev.*, vol. 152, Aug. 2021, https://doi.org//10.1016/J.Tre.2021.102417.
[26] J. Zhang, Y. Liu, G. Yu, Z.-J. (Max) Shen, "Robustifying Humanitarian Relief Systems Against Travel Time Uncertainty," *Nav. Res. Logist.*, vol. 68, no. 7, pp. 871–885, Oct. 2021, https://doi.org/10.1002/Nav.21981.
[27] Á. Tóth, A. Suta, J. Pimentel, A. Argoti, "A Comprehensive, Semi-Automated Systematic Literature Review (Slr) Design: Application To P-Graph Research With A Focus On Sustainability," *J. Clean. Prod.*, vol. 415, 2023, https://doi.org/10.1016/J.Jclepro.2023.137741.
[28] N. Jahan, S. Naveed, M. Zeshan, M. A. Tahir, "How To Conduct A Systematic Review: A Narrative Literature Review," *Cureus*, vol. 8, no. 11, 2016, https://doi.org/10.7759/Cureus.864.
[29] M. Masoumi, A. Aghsami, M. Alipour-Vaezi, F. Jolai, B. Esmailifar, "An M/M/C/K Queueing System In An Inventory Routing Problem Considering Congestion And Response Time For Post-Disaster Humanitarian Relief: A Case Study," *J. Humanit. Logist. Supply Chain Manag.*, vol. 12, no. 2, pp. 182–219, Mar. 2022, https://doi.org/10.1108/Jhlscm-12-2020-0119.
[30] B. Vahdani, D. Veysmoradi, S. M. Mousavi, M. Amiri, "Planning For Relief Distribution, Victim Evacuation, Redistricting And Service Sharing Under Uncertainty," *Socioecon. Plann. Sci.*, vol. 80, Mar. 2022, https://doi.org/10.1016/J.Seps.2021.101158.
[31] M. Ajam, V. Akbari, S. Salman, "Routing Multiple Work Teams To Minimize Latency In Post-Disaster Road Network Restoration," *Eur. J. Oper. Res.*, vol. 300, no. 1, pp. 237–254, Jul. 2022, https://doi.org/10.1016/J.Ejor.2021.07.048.
[32] A. Aliakbari, A. R. Komijan, R. Tavakkoli-Moghaddam, E. Najafi, "A New Robust Optimization Model For Relief Logistics Planning Under Uncertainty: A Real-Case Study," *Soft Comput.*, vol. 26, no. 8, pp. 3883–3901, Apr. 2022, https://doi.org/10.1007/S00500-022-06823-4.
[33] L. S. Almeida, F. Goerlandt, R. Pelot, K. Sorensen, "A Greedy Randomized Adaptive Search Procedure (Grasp) For The Multi-Vehicle Prize Collecting Arc Routing For Connectivity Problem," *Comput. Oper. Res.*, vol. 143, Jul. 2022,

https://doi.org/10.1016/J.Cor.2022.105804.

[34] D. Hachiya, E. Mas, S. Koshimura, "A Reinforcement Learning Model Of Multiple Uavs For Transporting Emergency Relief Supplies," *Appl. Sci.*, vol. 12, no. 20, Oct. 2022, https://doi.org/10.3390/App122010427.

[35] G. Zhang, N. Jia, N. Zhu, Y. Adulyasak, S. Ma, "Robust Drone Selective Routing In Humanitarian Transportation Network Assessment," *Eur. J. Oper. Res.*, vol. 305, no. 1, pp. 400–428, Feb. 2023, https://doi.org/10.1016/J.Ejor.2022.05.046.

[36] T. Zhu, S. D. Boyles, A. Unnikrishnan, "Two-Stage Robust Facility Location Problem With Drones," *Transp. Res. Part C-Emerging Technol.*, vol. 137, Apr. 2022, https://doi.org/10.1016/J.Trc.2022.103563.

[37] M. Gentili, p. B. Mirchandani, A. Agnetis, Z. Ghelichi, "Locating Platforms And Scheduling A Fleet Of Drones For Emergency Delivery Of Perishable Items," *Comput. Ind. Eng.*, vol. 168, Jun. 2022, https://doi.org/10.1016/J.Cie.2022.108057.

[38] D. Wang, K. Yang, L. Yang, S. Li, "Distributional Robustness And Lateral Transshipment For Disaster Relief Logistics Planning Under Demand Ambiguity," *Int. Trans. Oper. Res.*, vol. 31, no. 3, pp. 1736–1761, May 2024, https://doi.org/10.1111/Itor.13227.

[39] M. Yang, S. Kumar, X. Wang, M. J. Fry, "Scenario-Robust Pre-Disaster Planning For Multiple Relief Items," *Ann. Oper. Res.*, vol. 335, no. 3, Si, pp. 1241–1266, Apr. 2024, https://doi.org/10.1007/S10479-021-04237-3.

[40] Y. Yin, Y. Yang, Y. Yu, D. Wang, T. C. E. Cheng, "Robust Vehicle Routing With Drones Under Uncertain Demands And Truck Travel Times In Humanitarian Logistics," *Transp. Res. Part B-Methodological*, vol. 174, Aug. 2023, https://doi.org/10.1016/J.Trb.2023.102781.

[41] D. Moher, A. Liberati, J. Tetzlaff, D. G. Altman, "Preferred Reporting Items For Systematic Reviews And Meta-Analyses: The Prisma Statement," *Int. J. Surg.*, vol. 8, no. 5, pp. 336–341, 2010, https://doi.org/10.1016/J.Ijsu.2010.02.007.

[42] M. J. Page *et al.*, "The Prisma 2020 Statement: An Updated Guideline For Reporting Systematic Reviews.," *Bmj*, vol. 372, p. N71, Mar. 2021, https://doi.org/10.1136/Bmj.N71.

BIOGRAPHY OF AUTHORS

Dedy Hartama is a Lecturer at STIKOOM Tunas Bangsa Information Systems Programme, Pematangsiantar, Indonesia. He holds a Doctorate degree in Computer Science from Universitas Sumatera Utara (USU) with specialisation in Operations Research Modelling. His research areas are Computational Science Modelling, Data Mining, data science analysis, and machine learning. He is the Chairman of STIKOM Tunas Bangsa Pematangsiantar until now. He is also active in the APTIKOM Organisation, IPKIN and international conferences, Visiting Lecturer International and international keynote speaker. He is one of the founders of the Prof Herman Mawengkang Foundation which is a research institution in the field of Operations Research and Data Science based on Mathematical Computing. Dr Dedy Hartama has filed a number of Intellectual Property Rights in the form of a Mathematical Model entitled Disaster Evacuation Handle Routing Time. His research interests include Modelling, Data Mining, Data Visualisation Analysis and Machine learning. He can be contacted via email: dedyhartama@amiktunasbangsa.ac.id.

Wanayumini obtained a Bachelor of Computers (S. Kom) from STMIK YPTK Padang in 1995, majoring in Information Management with expertise in Systems Analysis. In 2008, he earned a Master of Computers (M. Kom) from UPI YPTK Padang, specializing in Artificial Intelligence. In 2021, he received a Doctorate (Dr.) in Computer Science from the University of North Sumatra, focusing on Data Mining, Image Processing, Machine Learning, and AI. Since completing his studies, he has taught at various institutions: STMIK BUDIDARA Medan (1996-2002), STIE Muhammadiyah Kisaran (2002-2005), and Asahan Kisaran University (2005-Present). He is the Head of the Pacsa Bachelor (S2) Program at Medan Potential University, teaching Algorithm Analysis and Deep Learning. He is an active participant in national and international seminars and a permanent reviewer for the Sinta 2 RESTI National Journal and IJIRSE National Journal. Wanayumini is a member of APTIKOM, ADI, and INDOCEISS North Sumatra. He has published numerous scientific works in reputable journals and proceedings. He has been a keynote speaker at various events and participated in community service activities. In 2022, he served as a Field Supervisor (DPL) at Teaching Campus 5 of the Ministry of Research, Technology, and Higher Education. He is an assessor for LAM INFOKOM and Lecturer Performance Loads (BKD) and is active as Secretary of the Srikandi NGO in Asahan Regency. He can be contacted at wanayumini@yahoo.co.id.

Irfan Sudahri Damanik Born in Simalungun, August 18, 1986, currently studying for a Doctorate in Computer Science at the University of North Sumatra. At the same university, the author completed his master's degree (M.Kom) in Informatics Engineering in 2016. Obtained a Bachelor's degree in Information Systems at STMIK Time. Research interests include data mining, data science and system development. Currently, the author is an active lecturer and also serves as the head of the Information System Facilities study program at STIKOM Tunas Bangsa. From 2010 until now, he has been a Lecturer in the Database and Programming, system design and artificial intelligence courses. In addition, the author is also active as a member and administrator of the APTIKOM organization, becoming a national journal reviewer. In addition to being a lecturer, the author is also active as a practicing programmer with BNSP competency certification in the field of system analysts and the founder of Base Project IT in the field of software development. The author can be contacted via email: irfansudahri@gmail.com.