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Medical Waste Vehicle Routing Problem – A Review of Objectives, Collection and Transportation Strategies, and Algorithms

Wensi LI[1], Theam Foo NG[2], Haidi IBRAHIM[3], Shir Li WANG[4]

Review
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[1] wensilee@163.com, Universiti Sains Malaysia, Centre for Global Sustainability Studies; Guilin University of Electronic Technology, Department of Economics and Management
[2] Corresponding author, tfng@usm.my, Universiti Sains Malaysia, Centre for Global Sustainability Studies
[3] haidi@usm.my, Universiti Sains Malaysia, School of Electrical & Electronic Engineering
[4] shirli_wang@meta.upsi.edu.my, Universiti Pendidikan Sultan Idris, Faculty of Computing and Meta-Technology

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ABSTRACT

There has been a dramatic increase in medical waste due to rapid urbanisation and population growth, especially the coronavirus disease 2019 outbreak. Inadequate medical waste collection and transportation will negatively impact sustainable development. Consequently, the government is confronted with a substantial challenge, and it is an urgent issue that must be resolved. This paper provides a comprehensive examination of the medical waste vehicle routing problem through a search on the Web of Science and it commences with a descriptive analysis, followed by a summary of objective functions from two perspectives: single and bi/multi-objective functions. Following that, it presents and highlights practical strategies for the medical waste vehicle routing problem, which may aid in preventing the occurrence of major disasters in the future. Subsequently, the algorithms employed are summarised. Finally, a discussion of the findings and future research directions is presented. The result revealed that sustainable multi-objective functions, the adoption of various collection and transportation strategies, and the utilisation of approximate and hybrid algorithms need to be explored further. This paper aims to provide a roadmap for decision-makers in the domain of medical waste collection and transportation.

KEYWORDS

medical waste; vehicle routing problem; collection and transportation; sustainable development.

1. INTRODUCTION

Population explosions, outbreaks of diseases such as coronavirus disease 2019 (COVID-19), and the ongoing spread of existing diseases have significantly increased the quantity of global medical waste (MW) production [1]. During the COVID-19 outbreak, MW generation in Hubei Province, China, peaked at approximately 240 tons per day, a nearly fourfold increase that exceeded the region's maximum capacity by five times [2]. With the sudden increase in MW, improper management can endanger the environment and threaten further public health [3].

MW originates from human or animal medical activities including diagnosis, treatment, and immunisation, in addition to related biological production, research, and testing [2], and approximately 85% can be considered non-hazardous, with the remainder classified as hazardous [4]. Hazardous MW comprises infectious, radioactive, toxic or genotoxic materials [5]. Due to pathogenic concerns, particularly infectious waste, MW disposal in municipal solid waste systems is inappropriate. This is because MW contains harmful pathogens, including bacteria, viruses and other microorganisms, which can survive in general waste environments and pose a serious risk of disease transmission [6]. According to reference [7], the COVID-19 virus can survive up to nine days on the surface, posing a significant challenge to MW management and public health. Furthermore, mixing MW with urban solid waste increases the potential for environmental contamination and human exposure to dangerous pathogens, potentially leading to disease outbreaks. Proper segregation, handling and disposal of MW are essential to preventing the spread of infectious diseases and protecting public health [8]. Consequently, the management of MW in a proper way is critical.

The management of MW includes collection, separation, packaging identification, transportation and disposal [9, 10]. MW collection and transportation are the components of MW management and play a critical role in the entire process, also known as the medical waste vehicle routing problem (MWVRP). Unlike other vehicle routing problems (VRP), MWVRP possesses unique characteristics. Firstly, handling MW requires strict adherence to health and safety regulations due to its infectious nature. This necessitates the use of specialised vehicles designed to manage potentially infectious and hazardous waste [11]. Secondly, the time-sensitivity of MW collection is crucial to prevent health risks from prolonged storage. According to regulations, in winter, MW should not be kept in temporary storage areas for more than 72 hours, and in the summer, for 48 hours [11–13]. Thirdly, routes often need to be dynamically adjusted for emergency MW collection and transportation, aligning with emergency response strategies to ensure disposal efficiency. Finally, there is a heightened need for coordination among multiple stakeholders, including hospitals, waste treatment facilities, enterprise suppliers and governments, to ensure compliance and safety in MWVRP [14]. Waste collection and transportation are frequently insufficient in many developing countries [15]. Moreover, MW disposal fees remain high in developed countries. In the UK, disposal fees are approximately 450 pounds per ton [16]. Furthermore, MW collection, transportation and disposal are often handled by employees of waste generation facilities, such as hospitals and clinics, or by ineligible private contractors with improper equipment [17, 18]. Such practices expose staff, children, drivers and animals to serious health risks [19]. According to reference [20], improper handling of MW often occurs in unsanitary conditions and involves illegal dumping, posing serious threats to both environmental and social dimensions. In summary, unsystematic and unscientific MW collection and transportation will harm not only the economy but also the environment, public health and the welfare of the entire population [4]. As a result, there is a pressing need for more efficient and sustainable methods for the MWVRP.

Several scholars have published relevant reviews in this field. Reference [15] explored the VRP in waste management networks, specifically concentrating on municipal solid waste. The paper [1] performed a thorough literature review on MW management in Zimbabwe, with a primary focus on MW classification and process management. Similarly, reviews were conducted in developing nations by some studies [4, 5, 14, 21]. Research [22] presented a thorough evaluation of the waste management system from generation to disposal. Windfeld and Brooks [6] highlighted that effective MW management requires better education for health staff and the scientific categories of MW. Ali and Parvin [23] conducted a comprehensive review of waste management during the COVID-19 outbreak to understand its impact and its relationship with the virus. Furthermore, reference [24] concentrated exclusively on benchmark databases and case studies, whereas research [25] focused on solution techniques. Two comprehensive references [26, 27] provided an extensive literature review on waste collection and management, particularly municipal solid waste, while Sar and Ghadimi [28] systematically evaluated the utilisation of VRP in reverse logistics. Drawing from the insights of these reviews, the primary contributions can be summarised as follows: First, it provides a survey of studies on MWVRP from January 2013 to 8 July 2024. Second, it highlights the analysis of objective functions, collection and transportation strategies, and algorithms. Finally, it offers future research directions for solving the MWVRP.

The remainder of this review is organised as follows: The methodology is provided in Section 2. Section 3 presents a comprehensive descriptive and content analysis. Section 4 delivers a discussion of MWVRP. In Section 5, the conclusion and directions for future research are finally described.

2. METHODOLOGY

This study provided a literature review analysis of MWVRP. According to [27, 29], we conducted a thorough search on the Web of Science to ensure a rigorous review of published work in MWVRP.

Initially, the keywords for the search strategy were carried out as follows: Topic = “hospital waste” or “infectious waste” or “medical waste” or “healthcare waste” or “clinical waste” or “hazardous waste” and Topic = “vehicle routing problem” or “collection” or “transportation” and Topic = “algorithm” or “optimisation” or “approach” or “mathematical”. The specific search string applied across the Web of Science database is detailed in *Table 1*. Articles, conference papers and book chapters were published in English as full papers between January 2013 and 8 July 2024, excluding review articles, dissertation theses and technical reports, leaving 1207 papers.

Table 1 – The search string is utilised on the Web of Science database

Database	Search string
Web of Science	((((((TS=(infectious waste)) OR TS=(medical waste)) OR TS=(hospital waste)) OR TS=(healthcare waste)) OR TS=(clinical waste)) OR TS=(hazardous waste)) AND (((TS=(collection)) OR TS=(vehicle routing problem)) OR TS=(transportation)) AND ((((TS=(algorithm)) OR TS=(mathematical)) OR TS=(optimisation)) OR TS=(approach))

In the second stage, numerous articles were identified, and the extracted articles were selected by screening titles, keywords, and abstracts. This process effectively filtered out irrelevant publications, yielding 196 papers.

Finally, the content should meet the following criteria: (1) a focus on MWVRP; and (2) all the terms "medical waste," "vehicle routing problem," "approach" or similar in the body text. Exclusion criteria include (1) duplicate papers and publications; (2) studies on MW management systems or supply chains where VRP is not the main content; (3) papers on the COVID-19 vaccine, pharmaceutical products or daily necessities and health supply delivery; and (4) papers not focused on MW, such as hazardous industrial waste, chemical waste and urban solid waste. As a result, 55 articles were selected for this review.

3. RESULTS

In this section, we examine the key findings of the MWVRP as presented in the selected publications. A descriptive analysis is conducted to provide an overview of the identified papers before engaging in a detailed content analysis.

3.1 Descriptive analysis

The statistical information about MWVRP contained in articles published from January 2013 to 8 July 2024, is shown in *Figure 1*. It indicates a significant increase in publications since 2020, making up about 86% of the total. In this domain, 14 publications reached their peak in 2023, twelve articles were published in 2021 and there were nine and seven papers in 2020 and 2022, respectively. Notably, until the COVID-19 epidemic, this topic was not given significant consideration. A few studies were conducted on the MWVRP between 2013 and 2019. Two papers were published each in 2017 and 2018, and four in 2014. There were no articles published in 2013, 2015, 2016 and 2019. Note that there are only five articles in 2024 because the coverage of the literature only reaches 8 July 2024, indicating that the publication count for this year is still in progress.

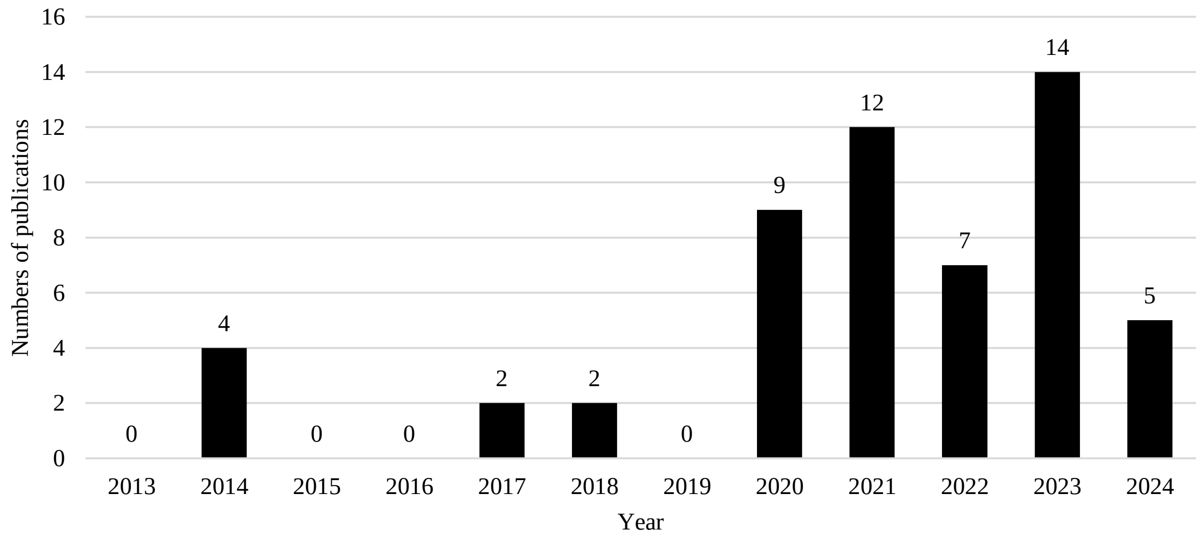

Figure 1 – Distribution of articles by year

Thirty-four different journals and conferences have published studies on MWVRP, demonstrating that a variety of publications have contributed to the research. *Table 2* shows the distribution of articles in the journals. The Journal of Cleaner Production is the most popular journal, with seven publications. Computers & Industrial Engineering and the International Journal of Environmental Research and Public Health follow, with five and four papers, respectively. Annals of Operations Research, Environmental Engineering & Management Journal, International Journal of Industrial Engineering Computations, Applied Sciences, Journal of Material Cycles and Waste Management, Sustainability, Transportation Research Part E: Logistics and Transportation Review, and Science of The Total Environment, each have two publications. Additionally, 23 other journals and conferences have each contributed one article to this field.

Table 2 – Distribution of articles in the journals and conferences

Source title	Accounts
Journal of Cleaner Production	7
Computers & Industrial Engineering	5
International Journal of Environmental Research and Public Health	4
Annals of Operations Research	2
Environmental Engineering & Management Journal	2
International Journal of Industrial Engineering Computations	2
Applied Sciences	2
Journal of Material Cycles and Waste Management	2
Sustainability	2
Transportation Research Part E: Logistics and Transportation Review	2
Science of the Total Environment	2
Networks	1
Journal of Multi-Criteria Decision Analysis	1
Scientific Programming	1
Applied Soft Computing	1
Mathematical Problems in Engineering	1
Journal of Industrial Engineering and Management	1
International Journal of Environmental Science and Technology	1
Computers & Operations Research	1
Waste Management & Research	1
International Journal of Environmental Technology and Management	1
Arabian Journal for Science and Engineering	1
Technological Forecasting and Social Change	1
International Journal of Engineering	1
Fuzzy Optimisation and Decision Making	1
Transportation Research Interdisciplinary Perspectives	1
IEEE Access	1
Journal of Environmental Management	1

Source title	Accounts
Expert Systems with Applications	1
Intelligent Automation & Soft Computing	1
Journal of Computational Science	1
Materials Today: Proceedings	1
International Conference on Intelligent Transportation Systems	1
International Conference on Advanced Logistics and Transport	1

Out of all the papers, case studies were conducted in 55 papers. *Figure 2* illustrates that, with 15 studies, the most attention was focused on China. This may be explained by the fact that COVID-19 emerged in China and quickly spread throughout the country and the rest of the world [29]. Iran follows with ten case studies. Thailand and Tunisia have four papers, respectively, while Turkey and India each have three papers. Other countries, including France, Chile, Jordan and Romania, received less attention. Except for France, most of the papers discussed practices in developing nations.

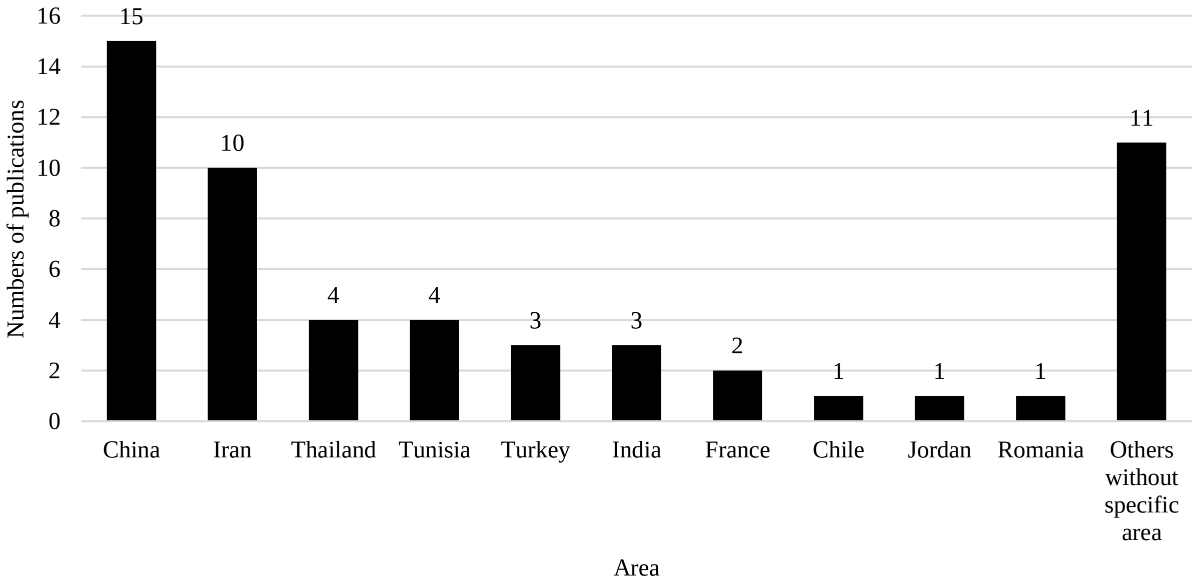

Figure 2 – Distribution of articles by area

3.2 Objective functions

This section categorises objective functions into single and bi/multi-objective functions. Of the papers that were reviewed, 14 focused on single-objective functions, while 41 explored bi/multi-objective functions and received more than 70% attention. The bi/multi-objective functions are classified into five categories: economic, social, economic-environmental, economic-social and economic-environmental-social dimensions. Various objective functions in the review papers are shown in *Table 3*.

Table 3 – Objective functions applied in review papers

Objective functions	Accounts	References(s) no.
Single objective function types	14	
Economic dimension	12	
Cost	6	[30–35]
Distance	5	[36–40]

Objective functions	Accounts	References(s) no.
Collection time	1	[41]
Social dimensions	2	
Risk of infection for public	1	[42]
Daily truckload	1	[43]
Bi/multi-objective function types	41	
Economic dimension	4	[44–47]
Social dimensions	1	[48]
Economic and environmental dimensions	3	[11, 49, 50]
Economic and social dimensions	28	[9, 10, 51–76]
Economic, environmental and social dimensions	5	[8, 20, 77–79]
Total	55	

Single objective functions: *Table 3* shows that the economic dimension is predominant in single objective functions. Cost minimisation was the most common objective covered in seven articles, and cost performance was various across different articles. For instance, research [33] focused on minimising the transportation cost of infectious waste. Other cost considerations include location and vehicle use costs [34], MW dispatching costs [30], infectious waste incineration and penalty costs [31] and multiple risk costs [35]. Moreover, a two-stage model was developed by reference [32]: the first echelon focused on total travel costs, fixed costs and inventory costs; the second echelon focused on penalty fees and unitary excess inventory costs. The other two economic objectives in single objective functions were travel distance minimisation [36–40] and collection time minimisation [41], with five and one article, respectively. Only two articles in this section paid attention to the social dimension. To avoid overwork, research [43] proposed an optimisation model to minimise the maximum daily hospital waste truckload to balance the number of customers and the workload during each day. Additionally, the risk of infection for the public was the other objective function in the social dimension, which included transportation risk, population risk, infectious risk, and storage, treatment and disposal risk. For example, an optimisation model for MW to minimise the total transportation risk was established by research [42].

Bi/multi-objective functions: Four articles focused on the economic dimension. Research [45] took the transportation cost and total distance into account as their objective functions, with Polat [47] adding the installation and operation costs of treatment centres as objectives. The other two papers considered not only the cost and distance minimisation but also the maximisation of the total priority weight of candidate municipalities [46] and the total location weight [44]. One study focused on the social dimension. Research [48] aimed to minimise the maximum transport and temporary storage risk. The most prevalent objective functions in the reviewed literature were those focusing on economic and social dimensions simultaneously, as observed in 28 publications. The total cost and the public exposure risk minimisation simultaneously were frequently considered [9, 51–53, 55, 57, 60, 63, 65]. In addition to cost minimisation, studies also focused on transportation risk minimisation [54, 59, 71–73], treatment site risk minimisation [60], and maximum infectious risk minimisation [67]. Furthermore, references [10, 58, 68–70, 74, 75] considered the cost, transportation risk, storage, treatment or disposal risks concurrently. Additional considerations included total traveling time [56, 66], total distance [64], number of vehicles [66], satisfaction of customers [51], job creation opportunities [62, 76] and safety scores [64]. Less attention was paid to economic-environmental dimensions. Nikzamir and Baradaran [11] designed a bi-objective model to simultaneously minimise both the total costs and the emission of contamination to the environment associated with infectious and non-infectious waste. Five articles focused on all dimensions of sustainable development. Ghannadpour et al. [8] aimed to minimise transportation costs, vehicle fuel consumption, and transportation and storage site risk. In contrast to [8], Niranjani and Umamaheswari [77] presented a mathematical model for managing MW. This model aims to minimise sustainable costs in three areas: travel costs (representing the economic component), emission costs (indicating the environmental component) and total driver allowance costs (representing the social component). In addition, two studies [20, 78] maximised profits to achieve economic performance, minimised total risks to the environment posed by carbon emissions and accidents during MW transportation and minimised public health risks to measure social sustainability. To achieve sustainable development, reference [79] aimed to minimise the total cost, greenhouse gas emissions, and risk of MW treatment and transportation while simultaneously maximising the sustainability of using the technology.

3.3 Efficient collection and transportation strategies

This section outlines the strategies employed in the MWVRP. The diversity of circumstances in this domain presents a challenge in providing all the strategies. However, *Table 4* shows the most prominent strategies extracted from the reviewed papers. Among the strategies discussed, 20 articles focused on establishing a collection and transportation system, the most common strategy in the reviewed papers. 19 articles focused on separating MW into different categories, while 17 papers employed different types of vehicles. In addition, each establishing temporary or new facilities came in at roughly 27% and developing a differentiated collection strategy at about 18%. It is essential to acknowledge the existence of “other” strategies that have not been explicitly mentioned but may play a role in addressing the MWVRP. Furthermore, it is noteworthy that 23 papers adopted a combination of at least two different strategies, highlighting the complexity and diversity of approaches within this domain.

Table 4 – Strategies applied in review papers

References(s) No.	Strategies					
	A1	A2	A3	A4	A5	A6
[8, 41, 75]	✓	✓				
[20]			✓		✓	
[56]		✓	✓			
[49, 53, 72]	✓		✓			
[38, 39, 57, 59]	✓				✓	
[11, 52, 62, 65]	✓		✓		✓	
[50]	✓			✓	✓	
[63, 76]	✓	✓			✓	
[73]		✓		✓	✓	
[79]		✓	✓		✓	
[58]	✓	✓	✓		✓	
[74]		✓	✓	✓		✓
[68, 77]					✓	
[78]	✓					
[30, 32, 36, 37, 43, 51, 54]				✓		
[10, 31, 45, 55, 61]		✓				
[33, 34, 40, 42, 47, 66, 69, 70]			✓			
[9, 35, 44, 46, 48, 60, 64, 67, 71]						✓
Total	19	15	20	10	17	10

A1: separate the MW into different categories; A2: establish temporary or new facilities; A3: establish collection and transportation systems; A4: differentiated collection strategy; A5: employ different types of vehicles; A6: others.

Separate MW into different categories: Although most MW is non-infectious waste [4], many studies focus on infectious waste or do not classify the MW in a proper way for collection and transportation. Windfeld and Brooks [6] demonstrated that poor sorting practices often lead to non-infectious waste being contaminated by mixing with infectious waste, necessitating its treatment as infectious waste and incurring a substantial cost. For instance, to collect the MW safety and efficiency, references [8, 20, 38, 39] separated the MW into infectious and non-infectious waste. Reference [72] separated the MW into the waste recycled, burned and buried. Reference [49] classified the MW based on their properties, toxicity levels and disposal methods. References [53, 59, 62, 65] also separated, collected and transported multiple types of MW but did not specify these categories in their studies.

Establish temporary or new facilities: Research [61] indicated that collecting and transporting the increased infectious waste volume while maintaining public health and safety standards is a challenge. Saeidi-Mobarakeh [63] demonstrated that installing a new facility with cutting-edge treatment and disposal technology can enhance MW management with a lower negative impact. For instance, reference [45] established temporary storage stations for proper MW management. Other facilities, including disposal centres [41, 56, 74, 75], recycling centers [58], treatment and waste generation centers [76], regional temporary gathering points [73], temporary hospitals [79], temporary transfer stations [20], temporary treatment centres [55, 61] and infectious waste incinerators [31], were also established for efficient collection and transportation. Furthermore, Luo and Liao [10] found that mobile processing centres can offer better disposal strategies than fixed processing centres, which can greatly support the government in making MW management decisions.

Establish a collection and transportation system: As part of healthcare waste management, MW transportation is a global issue. For instance, research [52] established a multi-echelon network consisting of hospitals and centres of recycling, treatment and disposal to minimise total costs and public exposure risk. Nikzamir and Baradaran [11] proposed a logistic network comprised of healthcare, treatment, and disposal centres for MWVRP. Similar studies were conducted by references [34, 53, 56, 69, 70, 72, 78]. Moreover, research [65] proposed a reverse logistic network for MW, focusing on centre location and VRP. Aydemir-Karadag [58] designed a system for managing healthcare waste that combined location selection with the periodic inventory VRP. Research [74] established a three-level supply chain network with MW generation points, transfer points and disposal centres to manage the transportation and disposal of MW. Reference [49] implemented a real-time tracking and monitoring system to provide visibility into MW’s location, condition and disposal. This system optimises MW collection and disposal processes, enhancing tracking and regulatory compliance.

Employ different types of vehicles: More than 30 articles utilised internal combustion and homogeneous vehicles simultaneously. Internal combustion vehicles are widely acknowledged to consume gasoline and emit hazardous gases. While homogeneous and single-compartment vehicles could make the problem easier to address, employing other types of vehicles may be more realistic [26]. For instance, to address these limitations and enhance efficiency, studies have used heterogeneous vehicles [11, 50, 52], electric vehicles [59], multi-compartment vehicles [38, 39] and rental vehicles [65].

Differentiated collection strategy: Due to the higher risks in the transportation and storage processes compared to general waste, more frequent service is required in MWVRP [36]. Furthermore, the volume of MW generated varies by location, necessitating different collection frequencies. For example, research [36] explored a periodic VRP model with time windows for the MW collecting network, taking into account the differential collecting measures based on different grades of medical facilities. To promptly dispose of MW and mitigate the risk of transmission, reference [50] proposed prioritising collection points with substantial quantities of MW. Similarly, reference [54] designed a weekly inventory MWVRP, allowing temporary non-service to some centres while ensuring all receive service within the time horizon. Additionally, reference [74] proposed a cross-regional transport strategy to reduce total risks and enhance the performance of COVID-19 MW clean-up activities.

Others: Other strategies discussed in this section are not easy to categorise into strategies. For instance, reference [9] considered the possibility of outsourcing to improve vehicle operations in MWVRP, aiming for timely service in all or some city districts. Research [60] utilised various forecast techniques to predict infectious disease volumes and daily waste quantities and finally optimised the routes. Research [74] utilised digital twin technology to estimate the amount of MW and optimise the locations and routes, benefiting COVID-19 pandemic control efforts.

3.4 Algorithms

This section provides the algorithms employed in the reviewed papers and is outlined in *Table 5*. According to the categorisation offered by references [28, 29, 80], algorithms in this review are categorised into exact methods, approximate algorithms and hybrid algorithms; exact methods include commercial solvers and exact algorithms; approximate algorithms comprise heuristics and metaheuristics; and hybrid algorithms combine two or more techniques.

Table 5 – Algorithms applied in review papers.

Algorithms	Accounts	References(s) no.
Exact methods	22	
Commercial solvers	6	[20, 33, 44, 64, 69, 78]
Exact algorithms	16	[9, 10, 43, 49, 52, 55–57, 61, 62, 65, 67, 68, 72, 74, 75]
Approximate algorithms	16	
Heuristics	1	[76]
Metaheuristics	15	[8, 11, 32, 35, 36–39, 41, 42, 50, 51, 58, 63, 66]
Hybrid algorithms	17	
☙ Heuristics + metaheuristics	5	[30, 34, 48, 59, 77]
☙ Metaheuristics + metaheuristics	4	[31, 45, 70, 73]
☙ Exact + metaheuristics	2	[46, 47]
☙ Exact + heuristics	3	[44, 54, 79]
☙ Exact + simulation	1	[53]
☙ Uncertainly	2	[60, 71]
Total	55	

Exact methods: Twenty-two papers used exact methods, of which six utilised commercial solvers and 16 used exact algorithms. CPLEX was the most popular commercial solver [20, 33, 40, 64, 78], while research [69] used LINGO. Exact algorithms included the goal programming-based expansion algorithm [9, 57, 62, 68, 75], branch-and-bound [43, 74], ε-constraint method [10, 49, 65, 67, 72], benders decomposition [52], and fuzzy chance-constrained programming [56]. Additionally, reference [56] compared different exact methods within the same papers. Reference [61] solved the small and medium-scale instances by CPLEX and the large-scale by branch-and-price. However, most papers only employed exact methods for small or medium-scale instances due to the complexity of the problems [81, 82].

Approximate algorithms: Approximate algorithms constituted about 29% of the reviewed papers. *Table 5* shows that only one paper used heuristic algorithm. Reference [76] suggested a novel parallel heuristic approach to solve the proposed problem. Considerable efforts were devoted to developing metaheuristics, as employed by 15 papers. For example, research [58] developed a mixed-integer linear model to generate visiting schedules for source nodes. They applied a bi-objective adaptive large neighbourhood search to solve the MW periodic location inventory routing problem. Widely used metaheuristics included particle swarm optimisation [36, 41, 42], genetic algorithm [35, 37, 39, 63], adaptive evolutionary-based algorithm [8, 38], modified differential algorithm [50] and ant colony algorithm [66]. Moreover, references [11, 51] contrasted multiple metaheuristics in a single data set, and adaptive large neighbourhood search and CPLEX were also compared in [32].

Hybrid algorithms: *Table 5* indicates that 17 papers used hybrid algorithms. Five studies employed a combination of metaheuristics and heuristics. For instance, Niranjani and Umamaheswari [77] proposed a grouping algorithm that combined the nearest neighbour and the simulated annealing algorithm for general waste to minimise the total costs. Other hybrid algorithm types, including exact methods and metaheuristics [46, 47], exact methods and simulation [53], an exact method and heuristics [44, 54, 79], and different metaheuristics [31, 45, 70, 73], received less attention. Two studies were not easy to categorise due to their complexity. For example, Xin et al. [60] employed the susceptible-exposed-infected-recovered model for predicting infectious disease volumes, a time evolution prediction model for daily waste generation and an exact method for optimal routing.

4. DISCUSSION

Governments worldwide face a challenge due to the exponential rise in the volume of MW. This review paper highlights the objective functions, key collection and transportation strategies, and algorithms for solving the complexities of MWVRP. In this section, we discuss the significance of the findings and identify the gaps based on the comprehensive analysis of review papers.

According to the descriptive analysis, about 85% of the publications have been published since 2020, indicating a growing interest in MWVRP. Journals across diverse fields have contributed to MWVRP; a wide range of journals and conferences reflect the interdisciplinary nature of this research. Moreover, China received the most attention in case studies, and developing nations were the focus of many publications. Future studies in waste collection and transportation practices may shed additional light on developed countries in addition to developing countries.

About a quarter of the reviewed paper concentrated on single-objective functions, showing that modelling simplification might not fully capture the complexity of real-world scenarios in MWVRP. Additionally, economic dimensions, including cost and distance minimisation have received considerable attention, emphasising their importance in the field. In contrast, bi/multi-objective functions accounted for 74% of the total articles, and economic-social dimensions were most highlighted, with other categories in bi/multi-objective functions receiving less attention. Remarkably, only five articles simultaneously considered economic, environmental and social dimensions, indicating a significant gap in the objective functions of the integrated economic, environmental, and social dimensions that require further investigation to achieve sustainable MWVRP.

The categorisation of MW significantly impacts its collection and transportation efficiency, with different types of MW requiring varied handling methods. Hazardous MW, such as infectious materials, which not only increase the potential cost but also pose a high risk to public health and necessitate specialised handling procedures, should be separated from general waste. The establishment of temporary or new facilities for MW management has been crucial in containing the spread of the virus and improving the efficiency of MW collection and transportation. Besides, other strategies, including established MW collection and transportation systems, differential collection strategies, and the adoption of diverse vehicle types, including electric, multi-compartment, rental, hybrid electric and fuel vehicles, have emerged as key approaches to tackle the complexities of MWVRP, reflecting a paradigm shift towards more eco-friendly, adaptable and sustainable MWVRP solutions.

The study reveals a wide utilisation of various algorithms in MWVRP, ranging from exact methods to approximate and hybrid algorithms. Given the limitations of exact methods being inadequate for large-scale instances within feasible computation times, there is an increasing trend among researchers and practitioners towards exploring and utilising approximate and hybrid algorithms, finding them superior in efficiency and scalability compared to exact techniques.

5. CONCLUSION

In summary, this paper presents a comprehensive assessment of the status of MWVRP, offering a profound opportunity for the development of more efficient, adaptable and sustainable MW collection and transportation systems. It revealed a notable increase in MWVRP in recent years, particularly since 2020, which highlights the growing importance of MW collection and transportation. Collaboration across disciplines and geographical regions will be crucial in addressing the complex challenges associated with MWVRP in both developed and developing countries. Moreover, there is a significant gap in the consideration of all dimensions of sustainable development within bi/multi-objective functions. Our analysis also highlighted the various MWVRP strategies, providing insights into the multifaceted nature of addressing this complex problem. Notably, the study has identified a priority preference for approximate and hybrid algorithms over exact algorithms, revealing potential trends in the practicality and efficiency of such algorithms and critical gaps within the domain. In conclusion, as the challenges of MWVRP continue to evolve globally, particularly in response to global health crises like COVID-19, Ebola and the Monkeypox virus, consequently, ongoing research should remain adaptive and responsive to emerging challenges and requirements in MWVRP. Several potential directions for future research are summarised as follows:

Firstly, interdisciplinary collaborations between researchers from different subject areas and comparative studies between developed and developing nations deserve further attention and research. Secondly, more studies are needed for multi-objective functions, with a particular emphasis on multi-dimensional objective functions that closely mirror real-world scenarios. This entails the integration of economic, environmental and social dimensions into MWVRP models, fostering more comprehensive decision-making. Furthermore, in addition to the five strategies mentioned, a more in-depth exploration of MW collection and transportation strategies is needed. A nuanced understanding of these strategies can lead to more effective waste management practices. Finally, due to the challenge of solving large-scale instances in a reasonable computation time, further exploration of efficient algorithms, especially hybrid algorithms, is essential. State-of-the-art technologies such as artificial intelligence and the Internet of Things can be incorporated into the algorithms for optimising MWVRP.

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李文斯, Theam Foo Ng, Haidi Ibrahim, Shir Li Wang

医疗废物车辆路径问题：目标函数、收集和运输策略及算法的综述

摘要

由于城市化进程加快和人口增长，特别是 2019 年冠状病毒疫情爆发，医疗废物数量急剧增加。不充分的医疗废物收集和运输将对可持续发展产生负面影响。因此，政府面临着严峻的挑战，这是一个亟需解决的紧迫问题。本文通过在 Web of science 上的检索，全面审视了医疗废物车辆路径问题，首先进行了描述性分析，接着从单目标和双目标函数两个方面对目标函数进行了总结。随后，文章提炼并强调了针对医疗废物车辆路径问题的实用策略，这些策略有助于防止未来重大灾害的发生。接着，本文对所使用的算法进行了总结。最后，对研究结果和未来的研究方向进行了探讨。结果表明，可持续的多目标函数、各种收集和运输策略的应用，以及近似和混合算法的运用仍需进一步探索。本文旨在为医疗废物收集和运输领域的决策者提供一个决策路线图。

关键词

医疗废物；车辆路径问题；收集和运输；可持续发展