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Soft computing for hazardous waste routing in Malaysia: a review

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ABSTRACT

Nowadays, a significant number of researchers are focusing on utilizing soft computing approaches to address the issue of scheduling in applications concerned with hazardous waste management. In Malaysia, there is thoughtless awareness of the management of hazardous waste, even though the production of wastes in hazardous domains at the industrial and domestic levels has been rising lately. According to previous research findings, the location routing problem (LRP) can be designated as one of the models closer to the actual situation, evaluating the most suitable and optimal location for establishing facilities and utilizing transportation for pick-up and distribution. Recent studies have focused on enhancing the LRP model, and its methodologies approach to solve the waste management problem in hazardous domains. In this paper, a comprehensive review of the better promising and practicable mathematical model of LRP and its methodology approach is discussed, as well as an analysis of the publishing pattern and the trend of research over the preceding five years and more, as retrieved from the web of science (WoS) database. In conclusion, this research is significant in ensuring the effectiveness of reliable mathematical model development and suitable methodologies in the future for solving hazardous waste management problems.

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1. INTRODUCTION

Hazardous wastes are industrial and domestic wastes that provide immediate or long-term threats to humans, animals, plants, and the environment. Historically, the handling of hazardous waste has been undervalued. Acquired immunodeficiency syndrome (AIDS), hepatitis B, and the coronavirus disease 2019 (COVID-19) outbreak have increased research difficulty. As previously stated, it is still challenging to manage each locality, especially in developing countries where improper management of hazardous waste endangers human health and the environment. Thus, studies management of hazardous waste must be enhanced.

Aja *et al.* [1], Malaysia produced 400 thousand tonnes of regulated waste in 1987 without a recognized waste management organization. In 2008, the country had one million tonnes of waste, and in 2010, 1.88 million tonnes. According to a study conducted by [2], Malaysia collected 2.02 million tonnes of scheduled debris in 2017, most of which was generated by the manufacturing sector. The growth in 2010 was 7 percent. Health, industry, manufacturing, agriculture, and residential construction are examples of industries that produce scheduled waste. The healthcare industry in Malaysia generates numerous medical wastes, such as contaminated disposable items, expired pharmaceuticals, chemical wastes, radioactive dyes, and needle and syringe waste. Due to the current COVID-19 pandemic, the medical waste produced by healthcare facilities in

Malaysia has more than tripled over the past two decades. Since December 2019, before the COVID-19 pandemic, medical waste such as disposable plastics, rubber gloves, and insulating robes utilized by frontline employees in healthcare facilities has increased by 111.94%. If the outbreak continued for 12 months, the monthly medical waste would increase to 173,25 tonnes. As indicated in the research [3], this circumstance has produced a large quantity that, if not appropriately controlled, might undermine the world's vegetation and environmental sustainability. The criteria evaluated in the strategic management of hazardous wastes include the hazards connected with hazardous wastes, the balanced distribution of risks, and the expenses incurred during the management process [4]. In addition, all of the following factors mentioned above can be included in the objective or constraint, which can be categorized into a routing problem, where a combination of a routing problem involving allocation and transportation constraints.

Location-routing problem (LRP) is one of the problems used to solve routing schedules containing vehicles utilized as transportation and the location selected depending on specific parameters. As in public practice, review papers are required to analyze a discipline's past, present, and future developments. Despite the efforts of numerous scholars, LRP in hazardous waste management has been explored and summarized in a few publications. This paper explores the scarce LRP literature on hazardous waste management. This study addresses a gap in the literature by doing a comprehensive systematic review of the literature on location allocation problem (LAP) and vehicle routing problem (VRP) in hazardous waste management from 1998 to August 2022 to establish if LRP in soft computing is still relevant and to recommend future research opportunities. This study also evaluates LRP research topics in hazardous waste management and covers rising concerns of vital importance. This paper emphasizes the significance of LRP in hazardous waste management with soft computing approaches by cross-referencing major study topics and proposing prospects for future research.

The remaining sections of the article follow this format. Section 2 analyses the content of the literature. Section 3 provides analysis results and study limitations. Section 4 summarizes the findings and makes recommendations for the future.

2. LITERATURE REVIEW

This section examines soft computing approaches in mathematical models for LAP, VRP, and LRP. Moreover, the discussion relates previous findings to actual issues of hazardous waste management in Malaysia. The systematic literature review procedure is depicted in Figure 1.

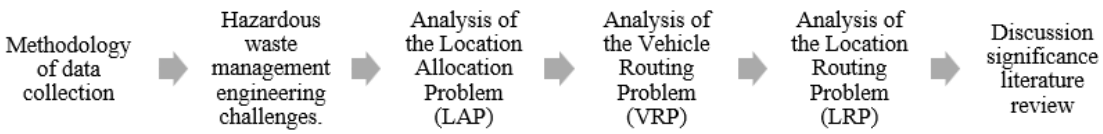


Figure 1. The systematic flow of the literature

2.1. Data collection

This section describes the process of data collection. The data from 1998 to August 2022, which could be accessed in [5], was extracted from journal articles and conference papers on the issue. All of the information was extracted from web of science (WoS) databases containing English-language articles. This section analyses the pattern of the research trend and emphasizes the importance of ongoing analysis.

2.2. Hazardous waste management in Malaysia

Management of hazardous waste is the most severe environmental problem facing Malaysia. Until recently, research on the sustainable treatment of hazardous waste in Malaysia remained scarce. Malaysia needs research on sustainable dangerous waste management due to the rapid expansion of industrial activity of hazardous waste, notably during the COVID-19 epidemic. The disposal of hazardous waste in Malaysia has increased by 27% due to the pandemic, primarily due to the removal of gloves, sharps, needles, face masks, and personal protective equipment (PPE) [6]. Incineration is the ideal practice for waste treatment, especially in hazardous domains. A research study on hazardous waste incineration [7] states that it is the most frequently applied technological solution for purifying hazardous waste for disposal in landfills.

Moreover, [8] highlight a need for more consent for the capability of hazardous waste treatment and financial and human resource resources. Since inappropriate disposal impacts the environment and public health, secure landfills are required to manage rudeness. Due to a paucity of research on soft computing scheduling, Malaysian waste management facilities, especially hazardous waste facilities, have yet to get much attention. Soft computing entails the development of a mathematical model that incorporates real-world

problem constraints and simulates computer-based problem solutions. Soft computing in routing problems, such as hazardous waste management engineering, has been analyzed in transportation and systems planning. In [9], [10] studied the threats presented by the containment, treatment, and disposal of dangerous wastes and determined whether such harmful plants were commonly scattered in lowland areas and entitled to maximize environmental protection. Several researchers subsequently investigated the management process of hazardous waste using specific analytical methods or models to identify fatal flaws in the strategic plan and devise a strategy [11]–[15]). Ahluwalia and Nema [16] proposed a multi-time step optimization supply chain-based integer linear programming model to analyze computer debris transportation risk. For waste generation uncertainty, the Monte Carlo simulation was implemented. Using immune algorithms, ant colony optimization, and tabu search techniques, the work [17] develops a model for urban hazardous waste storage site location with a selection of temporary storage stations and realistic transportation demand. In conclusion, Malaysia needs to improve its hazardous waste management. More research is required, particularly in soft computing approaches incorporating application and metaheuristic algorithms to solve problems.

2.3. Soft computing approaches for routing models

Combinatorial optimization problems, such as routing model optimization, are NP-hard. Complexity increases the number of viable solutions to NP-hard problems. The search for every possible combination is computationally and practically impossible. Since graphs are fundamental combinatorial structures, graph theory can be applied to most combinatorial optimization problems. For example, let $G = (V, E)$ be a graph (directed or undirected) where vertices, V or a set location of waste to be collected and the set edges, E or path. The weight of each edge is referred to as "distance". It can be altered with another indicator of effects, such as time and cost, in defining the weight, which will result in other routing problem variations. Figure 2 shows a network graph routing problem being used in Malaysia, rigorously the traveling salesman problem (TSP) in Figure 2(a) and the VRP in Figure 2(b).

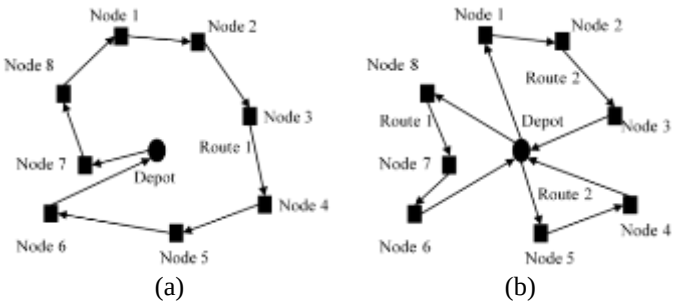


Figure 2. A variant of the graph represents the simulation of the routing (a) TSP and (b) VRP

Figure 2(a) depicts the TSP model, in which the depot stores and manages hazardous waste and the nodes 1, 2, 3, 4, 5, 6, 7, and 8 indicate where the waste is produced and collected. An algorithm determines the shortest route for the collection of waste from the depot to node 7. In Figure 2(b), the VRP, the depot and node operate similarly to TSP, with the exception that multiple vehicles transport waste to the center. To fulfill the decision threshold, the ideal cycles must be located in various places. This realistic and efficient two-type routing model is utilized to manage hazardous waste. In addition, it is selected based on real-world evaluation. Table 1 displays the optimization solutions for real-world situations from a prior research publication. Following is a description of the model and its operation in relation to the real-world problem used in the previous research.

Table 1. The details of previous research using the optimization method

Authors	Optimization method	Descriptions	Findings
[18]	Greedy whale optimization algorithm	Include greedy to the whale optimization algorithm to improve the search for solutions.	Develop a discrete version of whale optimization and use greedy for better tours.
[19]	Swap sequence-based artificial bee colony algorithm (ABC)	Introduced swap sequence and operator to improve the solution.	To improve the ABC solution for TSP, eight rules based on swap sequence and operator were introduced.
[20]	Ant colony optimization combine with genetic algorithm (GA)	The researcher combines GA and ACO to improve the input of ACO to get the optimal solution.	The combination of both algorithms shows high consistency for searching for global optimal.
[21]	Discrete particle swarm optimization (DPSO)	Improved from [22] that solved a set of nodes divided into clusters for exploring the search space.	DPSO is capable of solving TSP, but not as well as the classic method.

2.3.1. Location allocation problem model

This subsection discusses the routing problem with soft computing approaches, which involves multiple validations of the suitable allocation for intermediate facilities of waste management in hazardous domains, also known as the LAP, with consideration of a multi-objective problem including cost operation, environmental situation, and related concerns. Rakas *et al.* [23] outlined three objectives with applied soft computing approaches to improve intermediate facility locations and time management operating costs. Some researchers aim to provide working alternatives using soft computing techniques such as enumeration and CPLEX. Ulukan and Kop [24] modify Ishii's algorithm to present a new approach, choose suitable candidates, and apply it to a new proposed model to lower the cost of the preferable location of intermediate waste facilities in a hazardous area. Medaglia *et al.* [25] employs a multi-objective network model problem and an evolutionary algorithm to construct a model issue for hospital medical waste management to identify the optimal location to reduce cost and facility distance while minimizing negative impact. In the interim, List *et al.* [26] should investigate the stochastic soft computing techniques model with two-stage under uncertainty for transporting radioactive waste in the industrial sector, including weapon manufacturers, which poses a significant risk to the environment and human health if not managed properly. In [27], [28] discuss routing models and soft computing techniques to locate waste disposal sites with minimal environmental impact. In addition, [29], [30] use the analytic network process (ANP) to assess the complexity of creating non-essential and intermediate facilities for e-waste management, as well as the validity and sensitivity of the proposed solution. Numerous geographic information systems (GIS) assessment challenges necessitate considerable modifications from previous research. In the meantime, [31]–[33] utilize statistical decision processes to accomplish multiple objectives.

2.3.2. Vehicle routing problem model

The VRP literature review concerns routing issues with transportation planning considerations. Zhao *et al.* [34] implements the lexicographically weighted Tchebycheff method for solving multi-objective models. This paper provides a soft computing paradigm with multiple disposal depots to minimize costs and enhance worker safety. In addition, Dotoli and Epicoco [35] provides a novel mathematical model for waste management in hazardous locations that minimizes operation costs, air pollution, and danger when collecting and transporting waste. Additionally, researchers examine hazardous waste transportation. Then, the research [36], [37] includes the additional constraints that must be accounted for when transporting trash collection in hazardous areas, namely the capacitated vehicle routing problem (CVRP) vehicle weight restrictions. CPLEX 9.0 is used to solve this simulation of a case study conducted at 12 medical centers in Tunisia. To optimize cost operations and risk in flexible hazardous waste management domains, Shih and Lin [38] proposes the programming paradigm of binary linear soft computing. In [39], mixed floating points for linear soft computing programming with uncertainty conditions find the optimal location and the number of facilities to minimize the overall cost of operation, hence optimizing the planning for healthcare waste management. RFID technology is useful for hazardous waste management using heuristic algorithms like Tabu Search that optimize route planning [40], emphasizing its utility in applying healthcare waste management in hazardous domains with the aid of heuristic algorithms such as Tabu Search to optimize route planning. In e-waste research [41] addresses the significance of employing artificial technology in unanticipated situations and testing it in real-world settings.

2.3.3. Location routing problem model

The LRP model can be solved using exact and heuristic soft computing approaches. In recent years, metaheuristic methodologies have arisen, an extension of heuristic soft computing. This section discusses the LRP model from previous research, which combines the LAP and VRP models. Figure 3 depicts the connection between LRP and solution methodology. Table 2 summarizes several research studies on hazardous waste management and the LRP.

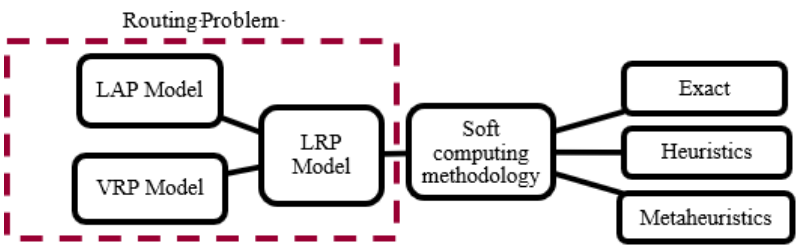


Figure 3. The methodology approaches for the various routing model

Table 2. Review of the several location routing problem research

Authors	Description	Findings
[42]	The proposed model addresses where and with which technologies treatment facilities, disposal facilities, hazardous waste treatment technologies, and waste residue disposal facilities should be located.	This study suggests testing for additional main problems utilizing an efficient heuristic technique, multiple objectives of hazardous waste management, and the placement of recycling facilities. This paper also proposed a new multiobjective location-routing model.
[43]	The model can aid decision-makers in locating treatment facilities employing various technologies, directing industrial hazardous wastes to compatible treatment facilities, recycling hazardous waste and waste residues, and disposing of waste residues.	The recommendation also evaluates wind and weather effects on population exposure during an accident, the likelihood of an accident due to weather and road conditions, traffic, and terrorism. The lexicographic weighted Tchebycheff implementation (Three-objective mathematical)

In previous LRP research, Aboutahoun [44] wrote an article on the Floyd Warshall algorithm for resolving the LRP model, which includes finding the optimum placement for intermediate facilities and a strategy for minimizing operation costs and the number of consumers passing through. The research [43], [45], [46] solve a using CPLEX software for solving the model of hazardous industrial waste. Meanwhile, Rabbani *et al.* [47] imposed restrictions on location, transportation routing, and inventory management. Using heuristic soft computing methodologies and the taboo technique in the LRP model for toxic waste research, Asgari *et al.* [48] proposes a workable solution that integrates multiple objectives. In hazardous industrial domains where waste management is crucial, Rabbani *et al.* [49] presents two innovative variants of the genetic algorithm that are more successful and faster at locating viable solutions. In [50], penalty time is addressed by capacity-based vehicle routing with load time segregation and corrosion-based algorithms. Based on demand unpredictability and risk, Berglund and Kwon [51] use a genetic algorithm to find the optimal location of intermediate facilities for treatment and route planning, with an emphasis on cost objectives. Using expensive hazardous waste transportation and treatment, Yu *et al.* [52] provided a stochastic model for the mathematical optimization of the area's permissible exposure risk rate. Homayouni and Pishvaee [53] developed a mathematical model for transferring medical waste in unknowable conditions that minimize operational costs and risk. Using simulated annealing and a genetic algorithm, Rahbari *et al.* [54] provides a multi-objective black widow optimization strategy to reduce the cost and risk of garbage collection and distribution in hazardous environments. Several academics have utilized soft computing techniques for optimal decision-making to analyze and assess hazardous waste management [55], [56]. The effectiveness of medical waste management has substantial economic and security implications. Thus, researchers have improved mathematical models and soft computing techniques [57]–[73].

In conclusion, the pandemic has limited studies further into the sustainability of Malaysia's hazardous waste management. Despite the difficulty of developing a mathematical model for the hazardous waste problem, much empirical and analytical research in several model and methodology domains is needed to meet these limitations. Reviewing the LAP literature to determine the best location for particular constraints based on their practicability without transportation limitations. Meanwhile, the VRP concept describes collection transportation, but cost, traveling distance, and other constraints apply. LRP, a scheduling problem incorporating LAP and VRP, is studied last. LRP is a mathematical model of utilized transportation and locating disposal sites for specific locations to accomplish the objective function. The analysis of relevant literature demonstrates that LRP can enhance its hazardous waste mathematical model and methodology approaches for future research.

3. ANALYSIS OF DATA

3.1. The result of waste management data analysis for hazardous domains

Figure 4(a) depicts a scatterplot with straight lines and points for WoS articles published between 1998 and August 2022. Title, abstract, and keyword searches for "hazardous waste management in routing problem"-containing publications are conducted. Review articles, research articles, encyclopedias, book chapters, conference abstracts, book reviews, case reports, conference information, correspondence, discussion, editorials, errata, mini-reviews, news, practice guidelines, and short communications are clustered in a column graph in Figure 4(b). Figure 4(c) depicts a pie chart with the following categories: environmental science, energy, engineering, chemical engineering, social sciences, earth and planetary sciences, materials science, agricultural and biological sciences, medicine and dentistry, and chemistry. As depicted in Figures 4(a) to 4(c), the trend publication rate has increased over the past two decades, and this trend tendency will become more pronounced after 2020, indicating that the COVID-19 pandemic is the most likely cause.

Researchers are publishing more to solve the world's problems. This trend will continue, with more researchers discovering new ideas and enhancing old ones. As shown in Figure 4(b), research publications had 4,801 numbers, while book chapters had 3,527 and review articles had 2,240. According to this data, research

articles outnumber the rest. A research article is a comprehensive report on a source study field that provides highly credible data for problem-solving. For future improvement, research articles' validity, verifiability, and data analysis summaries are crucial. Figure 4(c) demonstrates that environmental science has the largest influence on hazardous waste management, followed by energy at 16%, engineering at 11%, chemical engineering at 10%, social science at 8%, and other fields at 7%. From this vantage point, engineering, decision science, and mathematics significantly impact hazardous waste management, which is the basis of soft computing applications, and have the potential for further exploration, refinement, and modification.

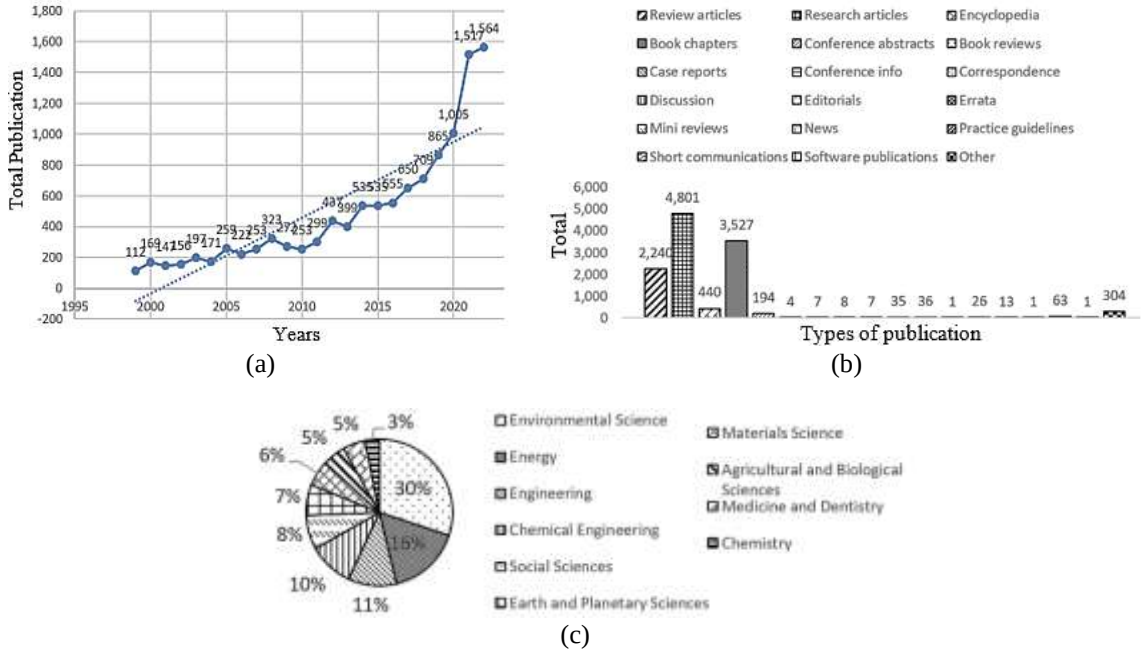


Figure 4. Result of analysis of data waste management for hazardous domains between 1998 and August 2022 (a) the trend publication, (b) types of publication, and (c) percentage of subject areas publication

3.2. Analysis of information for soft computing approaches model

The data used in this section are documents retrieved from Science Direct's WoS database from 1998 to August 2022. The phrases "Soft computing location routing problem for hazardous waste management," "location-allocation problem," and "vehicle routing problem" appeared in the titles, abstracts, and keyword searches for articles containing this phrase. The graph depicts a statistically substantial increase in the field of study, particularly in three configurations of soft computing approaches. As shown in Figure 5, LAP is lower than VRP, while most published research focuses on LRP, which has the most citations. Therefore, LRP is more suitable than LAP and VRP for managing hazardous waste since it contributes significantly to the problem.

Meanwhile, Figure 6 depicts the publication type frequencies for LRP, VRP, and LAP. VRP includes 48 types of review articles, while LAP has 37 and LRP has 72. The LRP model receives the highest number of research articles (108), followed by the LAP model (89) and the VRP model (77). In addition, there is more study on the LRP model for book chapters (237), the VRP model (153), and the LAP model (81). Most researchers publish book chapters, followed by research articles and review articles, as book chapters are more accessible to write than research publications, which need more significant effort to establish rationale and experiments.

In Figure 7, engineering disciplines represent the majority of research, compensating for 17% of the LRP model, 16% of the VRP model, and 18% of the LAP model. LAP, LRP, and VRP are 8% popular in computer science. The decision science percentage of LAP, LRP, and VRP models is 5%. Thus, most subject areas will utilize the LAP model instead of LRP or VRP. The LAP model is simple and lays the groundwork for the LRP and VRP models, which are more complex.

Figure 8 depicts hazardous waste management publications. This investigation focuses on engineering and decision science, which utilizes soft computing to address problems. The figure shows 71 papers published in 2017, 76 in 2018, 93 in 2019, and 93 in 2020. One hundred thirty articles were published in 2021 by August 2022. In 2021 and 2022, most academics intend to study hazardous waste management, mostly due to the COVID-19 epidemic. Figure 9 depicts trends in engineering, computer science, decision science, and

mathematics publications during the past five years. According to the graph, no hazardous waste management research articles were published in 2017. In 2018, two publications evaluated the significance of research on these topics. In 2019, two relevant papers were published, whereas in 2020, only one was. Between 2021 and 2022, four articles concerning this issue were published, indicating a trend. The number of publications grew between 2021 and 2022 due to the COVID-19 epidemic. Most academics were willing to investigate soft computing for LRP, LAP, and VRP models in hazardous waste management when uncertainty resembled a pandemic five years ago.

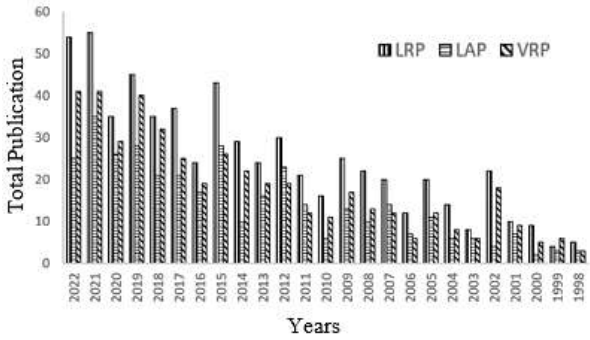
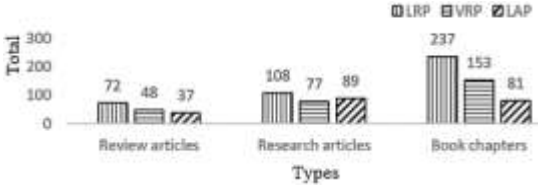


Figure 5. Trends of publishing for LRP, LAP, and VRP



Figures 6. Types of publishing for LRP, LAP, and VRP

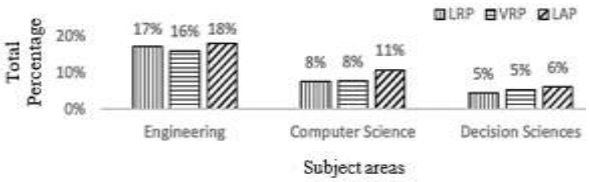


Figure 7. Subject areas of publishing for LRP, LAP, and VRP from 1998 to 2022

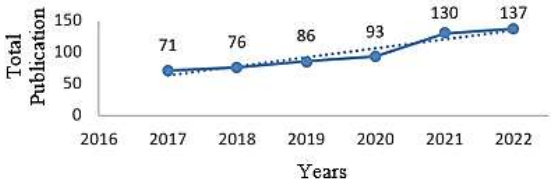


Figure 8. The five-year trend in hazardous waste management publication (2017 to August 2022)

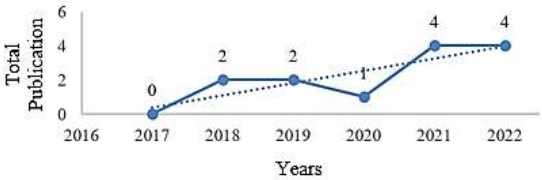


Figure 9. The publishing trend for LRP, LAP, and VRP from 2017 to 2022

4. CONCLUSION

This article explores soft computing scheduling issues in hazardous waste management from 1998 to August 2022, focusing on Malaysia. This study began with an introduction and literature analysis on worldwide hazardous waste management, particularly in Malaysia, with a priority on research publications on industrial and residence hazardous waste production using soft computing approaches. As highlighted, many researchers utilized metaheuristics methods since real-world problems have numerous complex parameters and constraints, making accurate and heuristic methods ineffective. In the section on analysis results, the analysis and discussion focus primarily on previous research articles to examine rising or decreasing trends for the tendency, publishing types, and specific subject areas involved in hazardous waste management domains, as well as the direction of the used soft computing approaches model based on the previous study. This study also analyses the five-year publication trend for waste management in hazardous locations and evaluates soft computing approaches for various model designs. According to the current study, soft computing research for hazardous waste management has increased over the past two decades. Malaysia must bolster soft computing waste management research in hazardous industries, especially for the location routing problem. Due to the confidential

nature of the data, the lack of past research, the mathematical complexity of the model, and the lack of a supercomputer, simulations still need to be made possible. Local researchers, industries, and other nations can collaborate to reduce vulnerabilities. This research is beneficial for government policies to tackle the hazardous waste management problem for environmental sustainability and the progress of humanity and society.

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