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Review

A Systematic Literature Review on Transit-Based Evacuation Planning in Emergency Logistics Management: Optimisation and Modelling Approaches

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Abstract: Increasing disasters in recent years have necessitated the development of emergency logistics plans. Evacuation planning plays an important role in emergency logistics management, particularly when it comes to addressing transit-dependent populations that are often neglected in previous studies. This systematic literature review explores the current state of transit-based evacuation planning and examines the current gaps. We focused on transit-based evacuation planning problems that used optimisation and modelling approaches. This review conducts an extensive analysis of relevant studies to provide a comprehensive overview, identify research gaps, and outline future directions in the evacuation planning body of knowledge. Using an integrated systematic review methodology, a thorough search of the Scopus and Web of Science databases was conducted, resulting in a total of 538 articles. These articles were screened and evaluated based on predetermined inclusion and exclusion criteria, ultimately yielding 82 studies for final analysis. The findings highlight the growing importance of optimisation and modelling approaches within transit-based evacuation planning. Studies emphasize the integration of public transportation networks into evacuation strategies to enhance operational efficiency, optimize resource allocation, and ensure evacuee safety. Transit-based evacuation planning is vital for both those without personal vehicles, making evacuation more equitable, and vehicle owners, particularly in earthquakes where vehicles might be inaccessible or trapped, demonstrating its wide usefulness in all emergency scenarios. Various optimisation and modelling approaches have been employed in transit-based evacuation planning studies to simulate and analyse the flow of evacuees and vehicles during emergencies. Transit-based evacuation planning exhibits unique characteristics within disaster management, including the consideration of spatial and temporal dynamics of transit systems, integration of social and demographic factors, and involvement of multiple stakeholders. Spatial and temporal dynamics encompass transportation schedules, capacities, and routes, while social and demographic factors involve variables such as income, age, and mobility status. Stakeholder engagement facilitates collaborative decision-making and effective plan development. However, transit-based evacuation planning faces challenges that require further research and development. Data availability and accuracy, model validation, stakeholder coordination, and the integration of uncertainty and dynamic factors pose significant hurdles. Addressing these challenges necessitates advances in data collection, robust modelling frameworks, and improved communication and coordination mechanisms among stakeholders. Addressing these gaps requires interdisciplinary collaborations and advances in data analytics and modelling techniques.

Keywords: transit-based evacuation; disaster; humanitarian operation management; modelling; optimisation

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1. Introduction

There has been an increase during recent years in the impact of natural hazards and extreme weather, such as flooding, hurricanes, tsunamis, heatwaves, fires, and earthquakes all around the world, while their intensity has also intensified resulting in significant losses for humans and societies [1]. There are many examples, including the 2008 Sichuan earthquake in China [2], the 2011 Tohoku Earthquake and Tsunami in Japan [3], the 2012 Sandy Hurricane of the USA [4], the 2019–2020 Australian bushfire season [5], and the devastating floods in eastern Australia during 2021–2022 [6]. Furthermore, newly emerging hazards have also resulted in significant property losses and human casualties, including hazardous chemical releases, massive crowds, and terror attacks [7–10].

In the face of these natural and man-made disasters, evacuation has become an increasingly important part of emergency management strategy. Reviewing past natural hazards, it becomes evident that inefficient evacuation plans have resulted in tragic outcomes in various parts of the world. For instance, during Hurricane Katrina in the US, transit-dependent individuals in New Orleans faced difficulties as the pickup locations were not announced in advance, leading to confusion and delays. In Gulfport, the absence of a comprehensive list of transit-dependent individuals impeded transportation services, endangering people during the evacuation operation [11]. Post-Katrina reviews highlighted the consequences of inadequate plans and flawed decisions, resulting in the unfortunate deaths of around 200 patients [12]. The Ballina Hospital in the northern region of New South Wales, Australia, faced an unprecedented evacuation during the 2022 floods. Hospital staff and emergency organisations encountered significant challenges in evacuating various types of patients using school buses and ambulances [13]. During the 2023 flooding in Libya, the evacuation and relief efforts in Derna City were hampered by road and bridge closures. As a result of this disaster, approximately 11,000 people died [14,15].

The necessity for research on evacuation planning and management has been emphasised in light of recent natural and man-made disasters. "Evacuation plans refer to the arrangements established in advance to enable the moving of people and assets temporarily to safer places before, during or after the occurrence of a hazardous event [16]". Evacuation planning has attracted considerable attention during the past decade [17–23]. Different aspects of transportation planning in disaster-prone areas have been studied, including identifying and managing paths and evacuation routes. Additionally, it involves examining how evacuations are carried out, how relief supplies are distributed, and how damaged transportation systems are repaired [24,25]. It is vital to evacuate people from the danger areas even if evacuation planning and disaster debris and hazardous waste transportation are included in complete disaster management [26]. Natural hazards, such as floods and hurricanes, with prior warning, can lead to substantial losses for humanity if evacuations are not carried out completely [27]. There have been numerous studies published in the field of emergency evacuation in recent years that used experimental data, mathematical modelling and optimisation algorithms, and simulation optimisation models [28,29]. The process of emergency evacuation consists of transferring people from dangerous areas using different transportation modes in a timely and safe manner [30]. Specifically, evacuation is an organised and complicated process in advance of a disaster and following one, which includes planning and optimising evacuation routes, traffic management, and logistics organisation as well as monitoring and forewarning prior to evacuation [11,31]. As a result, all aspects of evacuation planning must be investigated in order to prevent accidents and deaths [32–34]. In evacuation planning, it is crucial to consider those without access to their own vehicles, as they often include vulnerable groups such as the elderly who require extra assistance during emergencies. Additionally, individuals with cars that are inaccessible in situations like earthquakes, where vehicles may become trapped under buildings or face other accessibility challenges, also need to be included in transit-based evacuation plans. Developing an equitable emergency plan necessitates addressing the needs of both these groups.

Optimisation model approaches have been broadly utilised for developing transit-based evacuation planning problems. Sheffi et al. [35] proposed an optimisation approach to minimise the network clearance time in an emergency when a disaster strikes an urban area. Yamada [36] developed several dynamic network methods to develop urban evacuation plans. In their study, the objective of the model was the minimisation of the total distance that evacuees travel in the network. Hamacher and Tjandra [37] proposed several optimisation models based on the time-dependent flow models. Cova and Johnson [38] investigated a network flow model and proposed several algorithms for a complex road network. In a similar study, Xie and Turnquist [39] presented an integrated exact method and meta-heuristic approach to finding the optimum solution in an evacuation road network. Also, some researchers addressed capacity limitations in evacuation planning. Lu et al. [40] presented heuristic approaches to find a set of optimal solutions under the conditions that roads have limited capacities. Gan, et al. [41] presented an approach that tightly couples optimization with traffic simulation to determine optimal evacuation times for each evacuee in disaster-prone areas. Sbayti and Mahmassani [42] presented a traffic assignment model based on the system's optimal approach. The model aimed to minimize the total system evacuation time in emergency conditions. Han et al. [43] proposed an approach to assign optimal shelters and routes. Chiu and Zheng [44] presented a linear programming model for disasters with no prior notice. Bretschneider and Kimms [45] investigated the evacuation model when there are conflicts within intersections of a transportation network. In reference [46], the authors created a stochastic programming framework to develop a priori evacuation plans. Their framework incorporates side constraints, scenario-based stochastic link travel times, and capacities into the modelling process. The main objective of their study was to optimize traffic routing for effective disaster response. To tackle large-scale instance solutions efficiently, a Lagrangian relaxation-based heuristic algorithm was proposed by them.

However, it is important to note that while these studies have made significant contributions to the field of disaster evacuation planning, there are still several gaps and challenges that need to be addressed. Many of these studies focus on specific aspects of evacuation planning, such as optimising travel distances or considering limited road capacities. Yet, the complexity of real-world disaster scenarios often involves multiple objectives, uncertainties, and dynamic conditions that require a more comprehensive approach. Furthermore, the needs and vulnerabilities of specific demographic groups, such as the elderly or transit-dependent individuals, are not always adequately considered. This literature review aims to critically assess the existing body of knowledge, identify research gaps, and provide a comprehensive overview of transit-based evacuation planning within the broader context of emergency logistics management. By doing so, we intend to contribute to the development of more effective and inclusive evacuation strategies that can better address the complexities and challenges of modern disaster management.

2. Literature Taxonomy: Transit-Based Evacuation Planning

Humanitarian relief operation management during any type of disaster has a broad scope, encompassing various aspects such as relief item supply, logistical and transportation planning, healthcare provision, shelter planning, and education and mental support [47]. Different methodologies have been developed in disaster management, and most of them involve the development, implementation, and evaluation of strategies, policies, and measures to better understand disaster risks. Based on the methodology developed by Sarker et al. [48], disasters are typically managed in four stages including prevention/mitigation (reducing or eliminating the impacts of disasters through strategic mitigation), preparedness (preparation for disasters to limit or avoid their effects), response (saving lives, properties, and the environment through an operational response), and recovery (bringing affected areas back to their pre-disaster state requires long-term recovery). The United Nations International Strategy for Disaster Reduction (UNISDR) [49] advised preparing for evacuation planning in the preparedness phase and taking immediate actions for evacuation operations and evacuee sheltering in the response phase. These operations can be regarded in both the preparedness and response phases of the mentioned disaster management methodology, regardless of the type of disaster encountered [50]. Evacuation operations in humanitarian logistical and transportation planning are critical aspects of disaster management, and significant research has been conducted in this field.

It has been discussed in the literature that evacuation planning has different types based on the context in which it occurs [51]. With respect to the egress time available, there are various evacuation types, such as evacuation without prior notice of disaster (explosions [52], terrorist attacks [53], and earthquakes [54]) and evacuations with advance warning of threats (hurricanes, floods, and tsunamis) [55]. From another point of view, two parallel considerations were taken into account when categorising emergency evacuation planning studies: (a) annotated evacuation scenario taxonomy (such as building evacuations [56], mass evacuations [57], and mixed traffic evacuations [58]) and (b) annotated evacuation cause taxonomy (such as evacuation in response to natural hazards [59], evacuation in response to man-made disasters [60], and evacuation in response to hybrid disasters such as Natech events (combined technological accidents and natural hazards) [52,61,62] or cascading natural hazards [63,64]). As this study focuses on transit-based evacuation planning studies, we will articulate the "evacuation scenario taxonomy" to position our study among these classifications.

Considering emergency evacuation scenarios, there are several evacuation categories to distinguish: building evacuations, large-scale or mass evacuations, and mixed traffic evacuations. Building evacuations are critical in accidents such as fires, earthquakes, or hazardous material releases within enclosed structures like residential buildings, theatres, train stations, stadiums, or shopping malls [65]. These scenarios demand swift response and localised coordination, often dealing with complex indoor spatial layouts and high-density occupancies. Large-scale evacuations, such as those necessitated by cyclones or hurricanes, contrast starkly in scale and complexity, involving the movement of millions over long distances, typically outdoors, and spanning extended periods [66–70]. Here, the challenges lie in coordinating vast numbers of people, managing extensive transportation networks, and addressing diverse needs over a widespread area. Mixed traffic evacuations present a unique set of challenges, where individuals use a combination of public transportation and personal vehicles [71–73]. This type demands intricate planning to handle varied disaster intensities, traffic capacities, and potential disruptions to communications and transportation systems. Factors influencing travel mode choices during mixed traffic evacuations include the disaster's nature, safety distance, evacuees' locations, and available options [74]. Effective emergency evacuation planning and preparedness, considering the specific needs of residents in disaster-prone areas, can significantly reduce life loss in sudden-onset disasters [75].

Studies on transportation evacuation mode selection indicate that private cars have extensively been used and people prefer their own vehicles over the public transportation system, but they also highlight the importance of public transport not only for efficient evacuation but also for addressing careless and vulnerable groups [71,73,76,77]. In the case of hurricanes Katrina and Rita, the two largest evacuations in the history of the US, Litman [78] summarised various problems people faced and described in detail the important factors responsible for the escalated losses. According to this report, evacuation operations were the most successful and efficient for people with automobiles, but poor emergency logistical management did not allow public-transit-dependent citizens to evacuate efficiently. The situation was similar throughout the world; for instance, as a result of traffic congestion, the tsunami and earthquake in Japan in 2011 made it nearly impossible for transit-dependent people to evacuate on time [79]. In Pakistan, according to [80], a high number of losses occur consistently due to floods, and their study underscored the lack of transportation resource planning, especially for transit-dependent groups. Australia is also well-known for its flood-prone and bushfire-prone areas, especially its eastern coasts. Ref. [81] investigated transportation planning for elderly people who are part of transit-dependent groups during flood events in Western Sydney. Transportation planning for transit-dependent groups during bushfires in western parts of Australia has been conducted in multiple studies, including those by [33,82–84].

This literature review uniquely contributes to the field of mixed traffic evacuation planning, specifically targeting scenarios that predominantly rely on public transportation modes used by vulnerable groups. While this category has been explored from multiple angles in the existing literature, our review distinctively concentrates on studies employing optimisation and modelling approaches. By doing so, it provides a focused analysis of how these methodologies can enhance evacuation planning effectiveness for these specific scenarios. This selective emphasis sheds new light on the operational challenges and opportunities in optimising public transportation resources during emergencies, a perspective less examined in previous reviews. Consequently, our work offers novel insights and consolidates knowledge in the domain, particularly regarding the integration of sophisticated analytical techniques to improve evacuation strategies for vulnerable populations.

3. Literature Review Methodology

The purpose of this section is to provide a comprehensive and thorough summary of the literature review methodology adopted in this study to identify relevant research. Scientific contributions on a specific subject, affirming reproducible methods, are summarised in a systematic literature review (SLR) [85]. The value of systematic reviews depends largely on the purpose and quality of the studies included in them. Pittaway et al. [86] proposed ten stages in the SLR process, starting with identifying keywords and culminating with citing any selected papers. Petticrew and Roberts [87] developed a twelve-step process of reviewing all associated studies on an assigned topic by identifying, assessing, and synthesising all studies associated with it. A study by Creswell and Plano-Clark 3rd [88] outlines two processes for conducting an SLR, namely (1) defining a review protocol and assessing the relevance of research to the subject at hand and (2) identifying knowledge and research gaps in the existing literature by extending the study findings. However, research protocols for conducting SLR can be modified during implementation, as stipulated by the “PRISMA Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)” [89]. This study adopts the PRISMA methodology as the foundational framework for the review methodology and enhances it with the PICO (Population, Intervention, Comparator, Outcome) framework [90]. The PICO framework has been widely employed for crafting clinical questions because of its effectiveness in encompassing all essential elements required for specific inquiries. We now propose the incorporation of this framework into the third step of PRISMA, namely the Screening and Eligibility step, to identify the most relevant studies. Figure 1 illustrates our SLR methodology including four distinct phases (middle column), and these phases are explained in detail as follows:

1. Developing a review plan: The review plan plays an integral role during the review process as it allows researchers to identify which studies are out of scope as well as those that match the topic under investigation. Also, this step delineates the research aim and research questions.
2. Identification: In order to identify studies to be reviewed in the context, Scopus and Web of Science databases are chosen to perform the review, since they have a larger number of indexed journals [91,92]. The selected research keywords were utilised in searching through titles, abstracts, and keywords of relevant papers and books. The chosen keywords were broad enough to avoid any artificial restrictions on the retrieved literature while still ensuring that undesired results were excluded within specified limits.
3. Screening and eligibility: In this step, based on the retrieved studies to accurately delineate the scope of this SLR, the screening and eligibility evaluation is performed based on the PICO framework to guide the inclusion and exclusion criteria in SLR. In this framework, “P” stands for the population or problem that is going to be under study. “I” stands for intervention that is intended to be performed in the research. “C” stands for comparison and is related to key features that make a difference between the in-scope studies and out-of-the-scope studies. Finally, “O” stands for the desired outcome(s) that decide whether the study outcome falls within the scope of the SLR

or not. The equivalent terms of the PICO framework in this review are shown in the right column of Figure 1.

4. Analysing the content: In the content analysis stage, based on the refined studies in the previous step, a comprehensive analysis is conducted to provide an exclusive categorisation of literature and shed light on promising future research avenues.

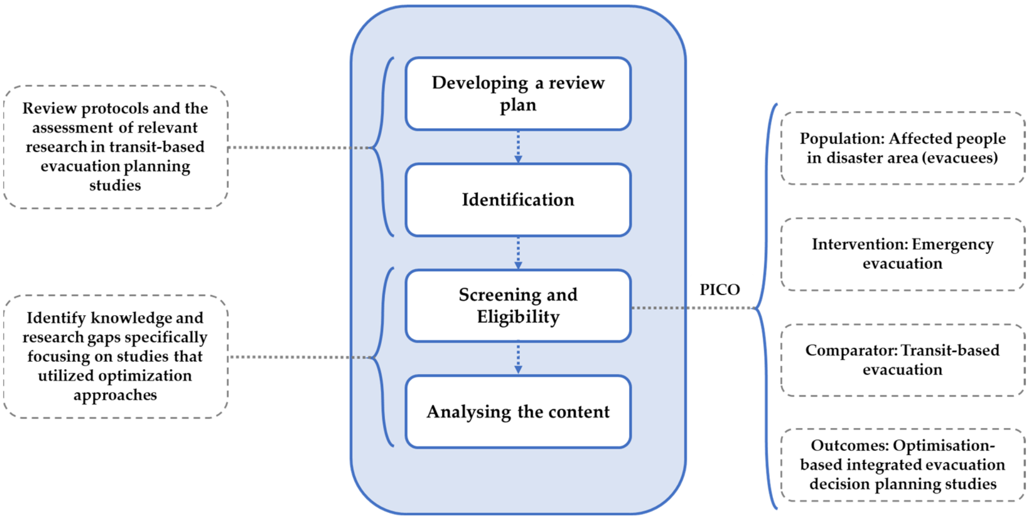

Figure 1. The proposed SLR methodology was adopted from PRISMA and PICO [89,90].

It should be noted that as the left column of Figure 1 shows, the first two steps of the proposed methodology include the definition of the review protocol and the assessment of relevant research related to transit-based evacuation planning studies. The last two steps focus on identifying knowledge and research gaps, with a particular emphasis on research that has utilised optimisation approaches.

In this study, we adopted the PRISMA methodology, complemented by the PICO framework, for our literature review methodology. The integration of PRISMA with PICO provides a robust and structured approach to systematic literature reviews, offering several unique advantages. PRISMA's clear and replicable process ensures consistency and transparency in the review, enhancing the credibility and reproducibility of our findings. The inclusion of the PICO framework further refines this approach by enabling precise and focused identification of relevant studies. This framework excels in articulating specific research queries, particularly by distinguishing between in-scope and out-of-scope studies based on well-defined criteria encompassing the population, intervention, comparison, and outcomes. Such a meticulous delineation ensures that the review is comprehensive yet targeted, covering a broad spectrum of literature while maintaining relevance to the research objectives. This combination of PRISMA and PICO not only streamlines the process of sifting through vast amounts of literature but also aids in pinpointing the most pertinent studies, which is particularly beneficial in fields like evacuation planning where diverse methodologies and outcomes are prevalent. Ultimately, this methodological fusion offers a more nuanced and thorough exploration of the subject matter than other conventional review processes.

4. Overall Findings from the Review

To conduct the literature review based on the proposed methodology presented in the previous section, two well-known electronic database searches Web of Science and Scopus are selected. These two databases are the biggest databases of abstracts and citations, and literature reviews in various fields are often conducted using them. They encompass a comprehensive collection of major and minor journals published by reputable publishers in social science, medicine, and science, so it has made them the most comprehensive and reputable databases in literature review studies [93]. The structured keywords that were used to find the relevant studies are presented in Table 1. As shown in this table, in order to cover as many studies in the context as possible, some keywords that could be used interchangeably are included in the search process by using the Boolean operators. Boolean operators including "AND", "OR", and "NOT" are the most common operators used as logical connectors to combine or exclude keywords or phrases during the search process [94]. For instance, "evacuation" has also been used in some studies with "rescue" or "egress" phrases, so the "OR" condition is used to address such clashes. Actually, Boolean operators were executed by different combinations in the research fields of Web of Science and Scopus.

Table 1. Structural research keywords and the number of studies.

Search Engine	Structural Keywords	Number of Retrieved Studies
Web of Science	"evacuation OR rescue OR egress (All Fields) AND model OR Optimisation OR logistic OR routing OR transport OR simulate OR simulation OR optimum (All Fields) NOT crowd (Abstract)"	133
	"evacuation Or rescue Or egress (All Fields) AND planning Or routing (All Fields) AND disaster Or emergency (All Fields) NOT crowd (All Fields) AND Model Or Optimisation Or logistic Or Routing Or transport (Abstract)"	51
Scopus	"(TITLE-ABS-KEY (evacuation OR rescue OR egress) AND ALL (model OR Optimisation OR logistic OR routing OR transport OR simulate OR simulation OR optimum) AND NOT ABS (crowd))"	199
	"(TITLE-ABS-KEY (evacuation OR rescue OR egress) AND ALL (planning OR routing) AND ALL (disaster OR emergency) AND NOT ABS (crowd) AND ALL (model OR Optimisation OR logistic OR routing OR transport))"	117

Also, Table 2 shows the inclusion and exclusion criteria used in the search process. It should be noted that the "SUBJAREA" area in the "Scopus" and the "Categories" in the "Web of Science" were critical indicators for refining relevant literature based on the aforementioned context of this study. In the Scopus, "Medicine", "Engineering", "Social Sciences", "Computer Science", "Environmental Science", "Earth and Planetary Sciences", and "Nursing" were the superior fields with more studies in comparison with "Mathematics" AND "Decision Sciences". Yet, in the Web of Science, the "Engineering Civil" and "Geosciences Multidisciplinary" categories were addressed more than the "Operations Research Management Science" AND "Operations Research Management Science or Management" groups. In addition, in these two search engines, "Document type" is also refined to "Article", while "Languages" only covers "English" studies.

Table 2. Search criteria for relevant studies.

Criteria	Inclusion Criteria	Exclusion Criteria
"Document Types"	"Article"	Other document types like conference papers or review papers.
"Languages"	"English"	A language other than English, such as Chinese or German.
"Web of Science Categories"	"Operations Research Management Science" AND "Management"	Other categories such as "Engineering Civil", "Geosciences Multidisciplinary", etc.
"SUBJAREA" in Scopus	"Mathematics" OR "Decision Sciences"	Other subject areas such as "Medicine", "Engineering", etc.

Through our proposed literature review methodology and search process in Scopus and Web of Science, while excluding conference papers, we found a total of 538 articles, with 184 articles in Web of Science, 316 articles in Scopus, and an additional 38 manually added articles. After combining the retrieved studies and removing duplications, we were left with 282 manuscripts. We excluded research conducted before 2000, which resulted in 257 remaining papers. From this, we reviewed the titles and abstracts, leaving 137 abstracts to evaluate for inclusion. After reading and reviewing them, we selected 82 articles to read in full, ensuring their relevance to our review. We summarise the overall findings of our literature review in Figure 2.

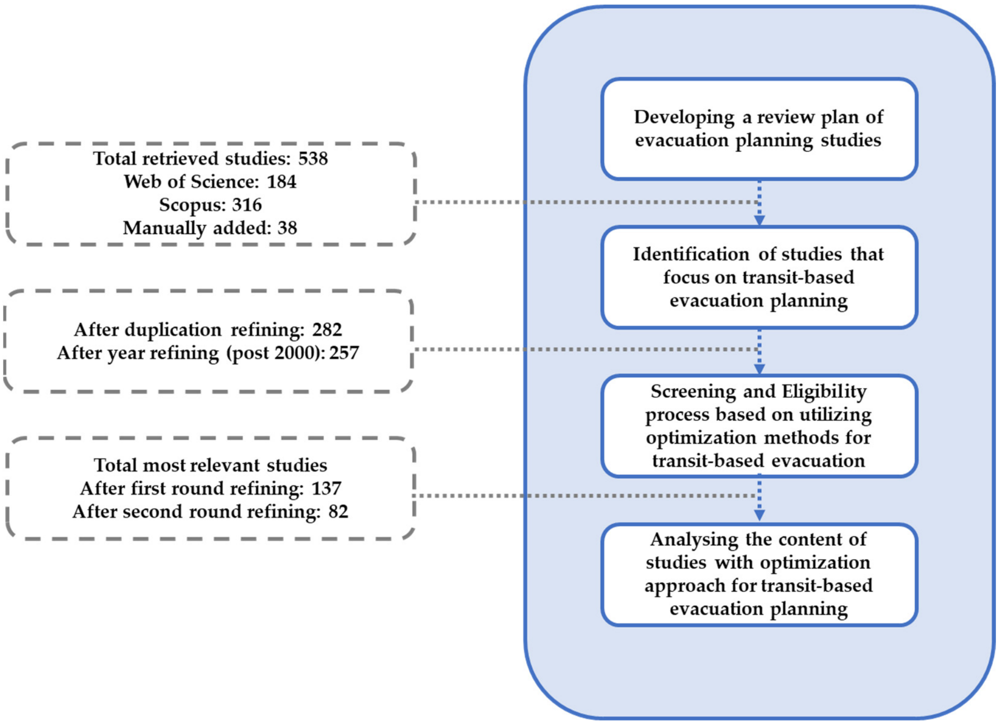

Figure 2. The proposed process of evaluating the literature review.

Figure 3 shows the distribution of the published papers over time found in databases. It was found that the trend has markedly improved since 2011, and perhaps, this dramatic increase in this field relates to the increasing rates of natural hazards associated with emergency evacuation planning problems.

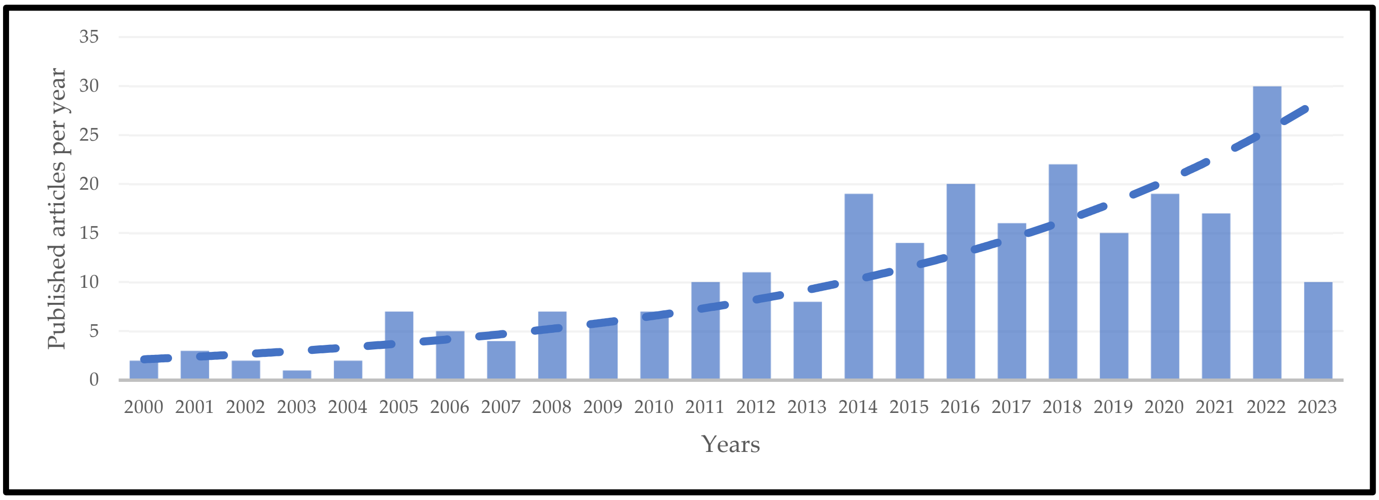

Figure 3. Publication year distribution of the retrieved articles in the Web of Science and Scopus with the trendline.

The body of knowledge on transit-based evacuation planning is vast and varied, thanks to the contributions of numerous researchers. Our analysis of the Web of Science and Scopus databases revealed that the works of several scholars such as Kimms, A., Lunday, B.J., Robbins, M.J., Smith, J.M.G., Jenkins, P.R., Karatas, Lidbetter, T., Schryen, G.M., Liu, Y., Pyakurel, U., Ozdamar, L., and Bish, D.R. have significantly impacted this field. Our review of the literature also highlights the global nature of this research, with many countries contributing to this area, including the USA, China, the United Kingdom, Germany, France, Iran, and Australia. Multiple countries have contributed to this field through universities and research centres.

Another noteworthy aspect of this literature relates to the publication titles, including the journals and publishers. Our findings reveal that a substantial number of articles were published by "Elsevier", "Springer Nature", "Taylor & Francis", "Wiley", and "Informs". Furthermore, our analysis of the most frequently cited journals in this field reveals that the *European Journal of Operational Research*, *Computers and Operations Research*, *Journal of Statistical Mechanics: Theory and Experiment*, *Journal of The Operational Research Society*, *Socio-Economic Planning Sciences*, *Information Sciences*, and *International Transactions in Operational Research* were among the most popular. Figure 4 illustrates the top journals that have focused on publishing a significant number of studies in this research area along with the journals' 2022 impact factor and their CiteScore Best Quartile. In the next section, based on the refined studies, content analysis and comprehensive research gap analysis are presented.

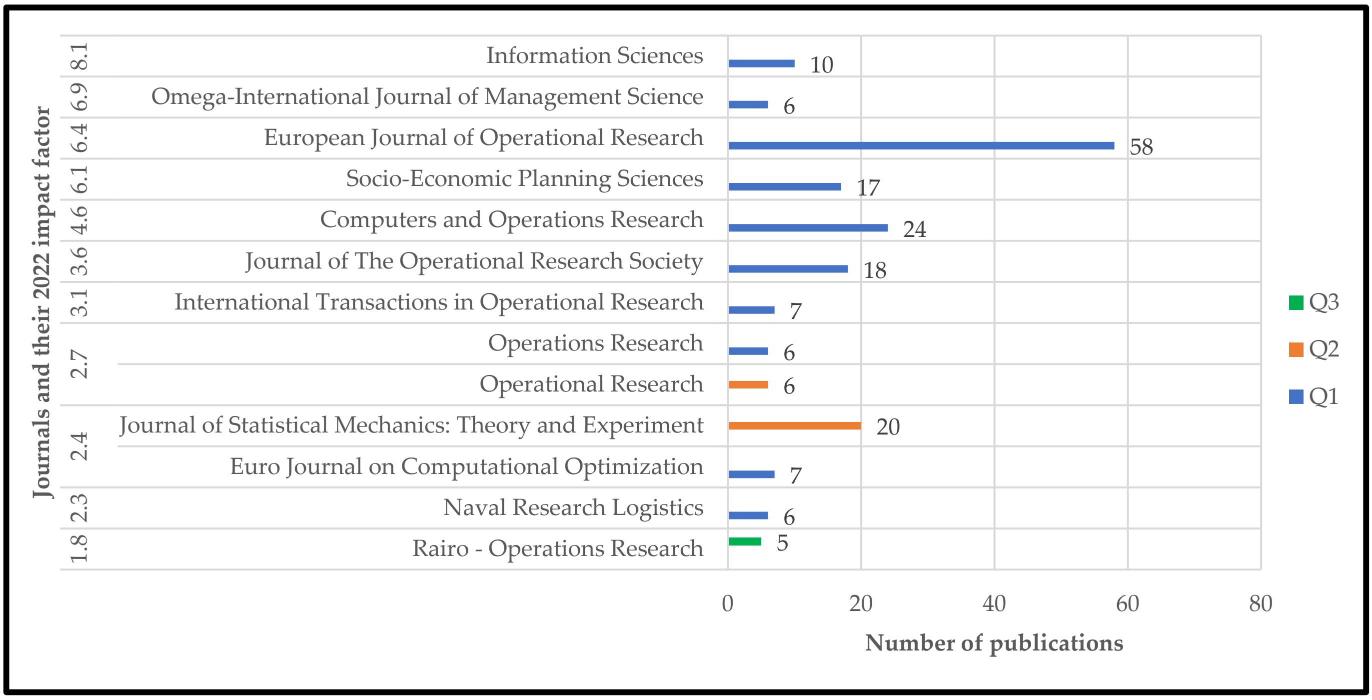

Figure 4. Publication numbers by journals of the retrieved articles in the Web of Science and Scopus.

To capture a broad view of all of the retrieved studies (i.e., 538 articles), a "keywords co-occurrence analysis" was performed here to provide a clearer view of the current body of knowledge. In this regard, by using VOSviewer (version 1.6.18) software and the structural keywords presented before, a keyword co-occurrence analysis map is conducted on the retrieved data sets from the Scopus and Web of Science results. Setting the co-occurrence minimum value of 10 and choosing a "Network Visualization" or "a map based on bibliographic data" analysis, in a "full-counting" status, 48 keywords meet the threshold out of 2806 keywords. The results are presented in Figure 5. As this map shows, four clusters are detected in the retrieved studies. The red cluster shows some key aspects of the body knowledge, including significant problems like "disaster evacuation", "evacuation planning", "disaster relief", and "humanitarian logistics". Also, the papers that fall in this cluster are associated with some keywords that show the solution method that has been used for such problems, i.e., "robust Optimisation", "uncertainty analysis", and "heuristic algorithm". The blue cluster is closely related to the red cluster with terms such as "decision making", "evacuation", "planning", and "emergency response", addressing evacuation problems that have utilised simulation and computational algorithms. The green cluster with keywords such as "behavioural research" and "crowd evacuation", is associated with the behaviour of people during evacuation operations, mainly related to evacuations from dense areas or buildings. Social science methodologies are the dominant approach to these problems. Finally, the yellow cluster with terms such as "transport planning" and "emergency traffic control" contains network flow and traffic management problems during emergency evacuation operations.

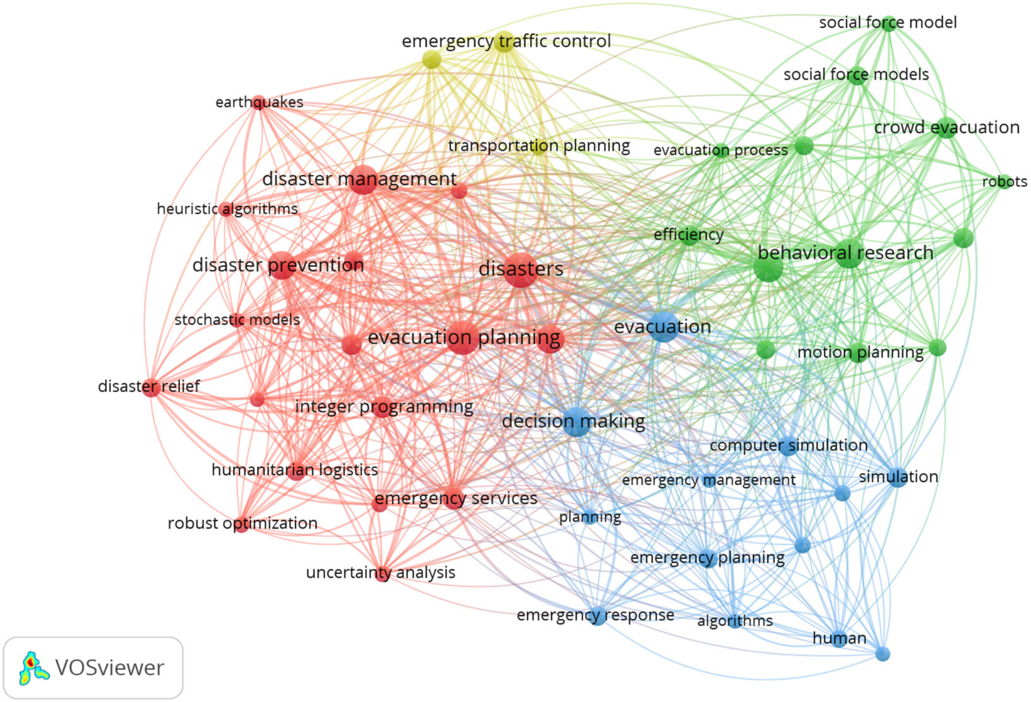

Figure 5. Keyword co-occurrence network of the retrieved studies (a "Network Visualization" of "a map based on bibliographic data" with four clusters).

A co-occurrence analysis of bibliographic data is conducted to create an "Overlay Visualization", illustrating the evolution of research terms over the past years. By setting the minimum value 2 and choosing "a map based on bibliographic data" analysis, in a "full-counting" status, 71 keywords meet the threshold out of 313 keywords. As this map shows in Figure 6, traditional concepts in the field of the study include "evacuation", "transportation", "resource allocation", and "preparedness". However, new concepts have emerged, and they encompass "Optimisation", "relief distribution", "supply chain network", "uncertainty", "evacuation routing", and "resilience".

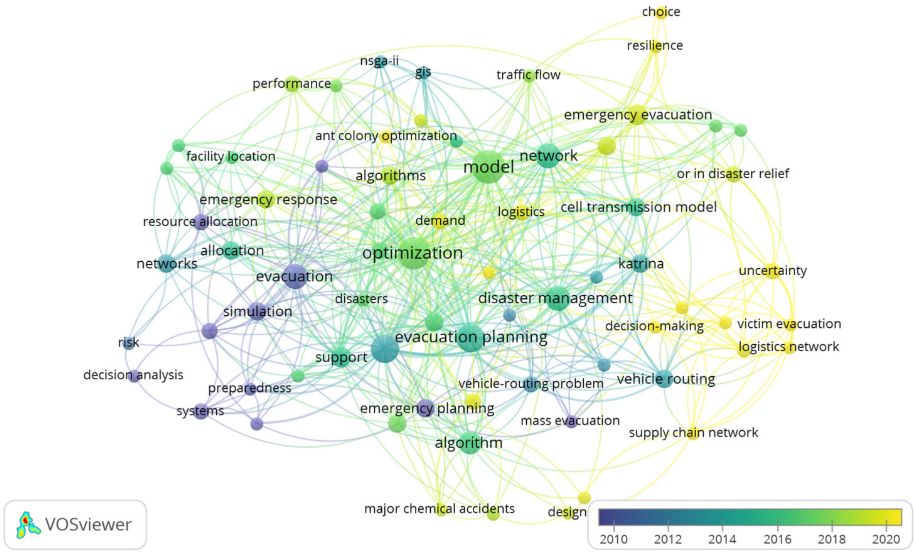

Figure 6. Keyword co-occurrence network of the retrieved studies (an "Overlay Visualization" of "a map based on bibliographic data").

5. Content Analysis

In this section, the results of the literature review are presented in two main streams including transit-based evacuation modelling characteristics and the administrative function of the reviewed studies in the disaster management context. In these two sections, we analyse the literature comprehensively to investigate their commonalities and differentiations.

5.1. Transit-Based Evacuation Modelling Characteristics

Based on the main viewpoint of the reviewing method in this study, i.e., quantitative methods using mathematical modelling and simulation techniques, papers are analysed in five folds, encompassing decision variables, objective functions, mathematical modelling considerations, input parameters features, and optimisation approaches.

5.1.1. Decision Variables

The review carried out in this study is centred on evacuation decisions, with a focus on utilising a quantitative approach that involves mathematical modelling and optimisation. Although the transit-based evacuation planning problem shares similarities with the vehicle routing problem (VRP) in the context of disaster management, there are notable differences in terms of its objective and network structure [76,95]. Specifically, the transit-based evacuation planning problem focuses on rapidly evacuating the last individual from the endangered area by considering factors such as shelter capacities, distinguishing it from traditional VRPs [96]. In addition, evacuation decisions in transit-based evacuation planning relate to deciding how to allocate evacuees to shelter points while they are transferred via public vehicles provided by emergency organisations or local agencies [33]. There have been some studies where other joint decisions, such as shelter location, shelterlocation–allocation, vehicle routing, relief distribution planning, and casualty rescuing have also been made. From both a practical standpoint and an operations research perspective, it is generally sensible to make joint decisions as they tend to yield greater cost savings compared to decisions made in a hierarchical manner. The majority of studies examined evacuation decisions via vehicle routing–scheduling–allocation which is a joint decision, rather than finding them solely. In the literature, evacuation decisions have also been integrated with pick-up point location and shelter location–allocation problems. It is obvious that evacuating affected people from emergencies and transporting them to safe places are just some pieces of disaster management, and providing relief items for them would be crucial. It is seen that, in recent studies, such decisions including relief supply–distribution planning problems are also considered in emergency evacuation models. Table 3 presents decision variable exploitation in the review of related studies.

Table 3. Investigating decision variables in the retrieved studies.

Reference	Vehicle Routing	Vehicle Scheduling	Vehicle Allocation	Pick-Up Location	Shelter Allocation	Shelter Location	Relief Supplying	Relief Distribution
[97]	√	√						
[95]	√	√	√					
[104]			√		√	√	√	√ ***
[108]	√	√						
[111]			√	√	√			
[115]	√	√						
[119]	√	√						
[123]	√	√						
[125]	√	√	√					
[129]			√				√	√
[82]	√		√ *		√	√		
[136]	√	√	√		√ **			
[139]	√		√ *		√ **			
[83]	√	√	√ *					
[84]	√	√			√			
[149]			√		√ **		√	√ ***
[153]			√		√			
[157]	√		√		√	√		
[161]			√		√ **			
[165]	√	√			√ **			
[168]	√	√	√		√ **		√	√
[98]	√	√	√ *					
[101]			√ *		√ **	√	√	√ ***
[105]	√	√						
[1]	√		√		√ **	√	√	√ ***
[112]	√	√	√		√ **			
[116]					√	√	√	√ ***
[120]	√ *		√ *		√ **	√	√	
[33]	√	√	√		√			
[126]	√	√	√					
[130]	√ *	√	√					
[133]	√	√	√	√	√	√		
[137]	√	√			√ **			
[140]			√		√ **			
[143]	√				√ **			
[146]	√	√	√ *		√ **	√	√	√ ***
[150]	√		√		√ **	√		
[154]	√	√	√		√ **			
[158]	√	√	√	√	√	√		
[162]	√	√			√ **	√		
[166]					√ **			
[169]	√	√	√	√	√ **			
[99]	√	√	√ *		√ **			
[102]	√		√		√	√		
[106]	√	√	√					
[109]	√				√ **	√		
[113]	√	√	√	√	√ **			
[117]	√	√	√					
[121]	√	√	√		√ **	√		
[76]	√	√	√		√ **			
[127]	√	√			√			
[131]	√		√		√	√		
[134]	√				√	√		
[96]	√	√	√		√ **	√	√	√
[141]	√	√	√ *	√	√ **			
[144]	√	√	√	√	√ **			
[147]	√	√	√	√	√ **			
[151]	√	√						
[155]	√				√ **			
[159]	√		√ *		√ **			
[163]	√	√	√			√		
[167]	√	√			√ **			
[170]	√				√		√	√ ***
[100]					√ **	√	√	√
[103]	√	√	√		√ **			
[107]	√	√	√ *		√ **		√	√
[110]	√				√ **			
[114]		√	√		√			
[118]	√		√		√ **			
[122]	√	√						
[124]				√				
[128]	√	√			√ **	√		
[132]	√	√	√ *		√ **			
[135]	√	√	√ *		√ **			
[138]	√		√	√				
[142]	√	√	√ *		√ **	√	√	√ ***
[145]			√					
[148]	√	√						
[152]	√		√					
[156]						√	√	√
[160]		√	√					
[164]	√	√	√		√			

* The required vehicles are considered variables. ** Considering evacuee flow. *** Considering the relief centre location.

5.1.2. Objective Functions

The purpose of this section is to examine the commonalities that we observed across various transit-based evacuation planning problems, followed by highlighting the relevant observations that make them different. The first concern in evacuation planning is to meet the acceptable time window of evacuation operation due to the announced short-notice warning during disasters. In this regard, two main objective functions that have been used in the majority of studies include "Arrival time" and "Evacuation time"; it is obvious that decision-makers tend to minimize them subject to operational constraints. The other two similar objectives that relate to time are "Evacuation rate" and "Network clearance time" which have been proposed by various formulations in different studies. Considering risk factors and optimising them during disaster conditions that are inherently associated with instabilities has been the other objective function of some articles. Cost minimisation, although not the main factor, has been regarded in various research in terms of evacuation cost, transportation cost, and resource cost. Among cost-based objectives, one of the important issues was minimising fleet preparation costs, which means minimising the required number of vehicles to manage evacuation operations. Some recent studies have also included relief planning issues and minimised relief item shortages in shelters. Equity and welfare criteria are promising sections that should be investigated more in future studies, and they are crucial for disaster management, especially in the context of evacuating vulnerable groups. Developing the most appropriate evacuation strategies can reduce the rate of mortality. In different circumstances, various objective functions are used by decision-makers for optimal evacuation strategies. The most frequently used objective functions used by different authors on their evacuation model are the maximisation of the number of evacuees [171–173], minimisation of the maximum latency [174], minimisation of average evacuation time [175], minimisation of the clearance time [172,173,176–179], minimisation of the earliest arrival time [180], and minimisation of weighted sum flows on the evacuating network [45]. Table 4 presents the main objectives formulated by various authors among the retrieved studies. It should be noted that if a reference in this table has multiple ticks, it does not necessarily indicate a multi-objective model; rather, it may reflect different components in the objective function, such as transportation cost and resource cost. As this narrative analysis shows, secondary objective functions such as risk, carbon emissions, traffic congestion, and accidents can be optimised along with the common objectives mentioned earlier.

Table 4. Investigating objective functions in the retrieved studies.

Reference	Arrival Time	Evacuation Time	Evacuation Cost	Evacuation Risk	Evacuation Rate	Network Clearance Time	Transportation Cost	Resource Cost	Relief Item Shortage	Equity/Welfare	Reference	Arrival Time	Evacuation Time	Evacuation Cost	Evacuation Risk	Evacuation Rate	Network Clearance Time	Transportation cost	Resource Cost	Relief item Shortage	Equity/Welfare	Reference	Arrival Time	Evacuation Time	Evacuation Cost	Evacuation Risk	Evacuation Rate	Network Clearance Time	Transportation Cost	Resource Cost	Relief Item Shortage	Equity/Welfare
[97]	√										[33]					√						[147]		√				√				
[95]		√									[126]				√	√					√	[151]	√									
[104]							√				[130]		√	√								[155]		√					√			
[108]	√										[133]			√				√				[159]		√								
[111]			√		√						[137]	√	√									[163]		√					√			
[115]		√				√					[140]		√	√		√						[167]		√			√					
[119]		√		√							[143]		√								√	[170]			√				√	√	√	
[123]		√		√							[146]					√				√		[100]		√	√				√	√	√	√
[125]		√									[150]			√		√						[103]	√									
[129]			√						√		[154]						√					[107]		√	√		√				√	
[82]				√	√			√			[158]		√									[110]		√								
[136]		√				√					[162]		√								√	[114]					√			√		
[139]			√	√	√						[166]		√								√	[118]	√	√				√				
[83]				√	√						[169]		√					√				[122]		√								
[84]				√	√						[99]			√	√							[124]										√
[149]							√			√	[102]		√									[128]			√	√		√				
[153]					√	√				√	[106]		√						√			[132]			√				√	√		
[157]		√									[109]		√									[135]			√				√	√		
[161]		√			√						[113]	√										[138]		√								
[165]		√									[117]		√									[142]			√				√		√	√
[168]	√								√		[121]		√									[145]		√								
[98]		√						√			[76]	√	√					√				[148]	√									
[101]					√		√		√		[127]	√		√							√	[152]	√							√		√
[105]		√									[131]		√									[156]							√	√	√	√
[1]							√		√		[134]		√									[160]					√					
[112]		√			√						[96]			√				√	√			[164]		√								√
[116]			√					√	√		[141]	√	√						√													
[120]			√	√			√	√	√		[144]						√	√														

5.1.3. Mathematical Modelling Considerations

As stated previously, the transit-based evacuation planning problem stems from the VRP, so the main sets of constraints in the literature have considered VRP constraints that control the logical flow and vehicle constraints along with the touring eliminations of vehicle travels during the planning horizon. Shelter planning is the most concurrent problem that has been considered in evacuation problems. In this regard, shelter capacity and the maximum number of available shelters due to budget limitations are the other constraints in the modelling of transit-based evacuation planning problems, e.g., [82,115,119,123]. It was mentioned that the transit-based evacuation planning problem is highly dependent on public transport fleets, and such facilities have limited capacities; the maximum number of available ones is also another common constraint, e.g., [95,97,123,153,156]. Network capacity reflects road capability to transfer vehicles in emergency conditions and could be a vital concern in evacuation planning, e.g., [83,84,149,168]. Standard maximum tolerable evacuation time window and maximum radius covering critical facilities are some critical issues for emergency organisations that have been reflected in the constraints of some studies recently, e.g., [101,105,112,129]. Most transit-based evacuation operations require rescue team support, especially for vulnerable groups; however, mostly, a limited number of them are available during disasters, so this is another category of constraint, e.g., [111,145,152,160,164].

Relief item supplying and distribution planning have been incorporated into the evacuation planning problems recently, and they can improve to cover a broader range of disaster management concerns, e.g., [104,129,149]. Other studies include Hamacher et al. [181], Lu, George, and Shekhar [178], Bretschneider and Kimms [182], Bretschneider and Kimms [45], Kim and Shekhar [176], Pillac, Van Hentenryck, and Even [173], and Pillac, Cebrian, and Van Hentenryck [172]. Hamacher et al. [181] explored evacuation models that take into account dynamic network flows. Lu, George, and Shekhar [178], for instance, employed a heuristic methodology and considered capacity constraints in analysing time-dependent networks. Furthermore, they formulated the network capacity as a series over time and applied the algorithm to identify sub-optimal solutions for evacuation planning. The algorithm's effectiveness was demonstrated in the case of medium-sized networks. Later, Kim et al. [183] improved the scalability of the algorithm by adding heuristic structures to accelerate the routing computation. These algorithms are not applicable when travel time exhibits variability. Kim and Shekhar [176] studied changing the direction of lanes for evacuation. They presented a greedy algorithm, i.e., an algorithm that makes locally optimal decisions at each step based on some metrics towards an optimal solution. This algorithm utilised the time-expanded network and a simulated annealing-based heuristic. Lim, Zangeneh, Baharnemati, and Assavapokee [171] introduced a heuristic algorithm and mathematical models to calculate the appropriate starting times, schedules, and recommended routes for evacuations based on estimated hurricane path and landfall timing. Hamacher, Heller, and Rupp [181] combined evacuation problems with location analysis to effectively forecast and assess evacuation plans. Bretschneider and Kimms [182] introduced a two-stage heuristic solution approach for a mixed-integer dynamic network flow model based on patterns.

The approach aims to restructure traffic routing in urban areas affected by disasters to facilitate efficient evacuation. Pillac, Cebrian, and Van Hentenryck [172] proposed a column-generation approach that combines mobilisation and evacuation planning. This approach determines the optimal evacuation time, route, and resource allocation for each evacuated area, with the objective of minimising the total evacuation duration and maximising the number of evacuees reaching safe areas. Pillac, Van Hentenryck, and Even [173] proposed a conflict-based path-generation approach for evacuation planning [184]. This approach is a typical transportation planning technique where constraints are outlined for each entity to discover optimal routes that align with the designed constraints. They decomposed evacuation planning problems into a master and a subproblem. The subproblem generated new evacuation paths for each evacuated area, while the master problem optimised the flow of evacuees and produced an evacuation plan. Goerigk, Deghdak, and T'Kindt [119] proposed a two-stage bicriteria model to evacuate endangered zones using buses. Bus evacuation problem with uncertain numbers of evacuees was studied by Goerigk and Grün [115]. Table 5 summarizes the studies and the main constraints of the reviewed studies.

In addition to constraints, mathematical models are always developed based on the assumptions designed by the decision makers, since they are a model of the real-world problem that should reflect as many features of the real problem as possible. Transit-based evacuation planning problems are developed by assuming that there are some predefined shelters in specified locations outside the disaster area, which could be true for most cases, while some recent studies have considered shelter location finding as a decision variable for specific disasters. Considering different types of shelter, making some echelons for designing evacuation networks is the other assumption made by some authors. Assembly locations as stages to board evacuees are one of the most important aspects of the evacuation problems that have been considered either predefined or as location decision variables. Using different modes of transportation, including land or air, while considering them identical or unique, gives different insights for decision makers for emergency evacuation planning problems. Risk issue modelling has been reflected in the facility, network, and vehicle disruptions in various studies of evacuation planning problems. Graph theory frameworks and theoretical concepts have great potential to be used in evacuation planning problems [185]; however, they have not been used widely by researchers. Allowing split delivery in VRP problems has been used widely as a strategy to improve the efficiency of vehicle planning [186], and the same story can happen in transit-based evacuation problems, while, until now, researchers have not used it in a wide range of situations. Splitting delivery refers to using the whole capacity of vehicles during multiple trips, which can improve efficiency but also require more computational efforts to plan. The last but not the least assumption in evacuation planning problems relates to categorising evacuees, to provide service for vulnerable groups with higher priority, for instance, in hospitals and aged care centres. In Table 6, the studies are summarised with their main assumptions.

Table 5. Investigating the main constraints in the retrieved studies.

Reference	VRP Constraints	Shelter Capacity	Number of Shelters	Vehicle Capacity	Number of Vehicles	Network Capacity	Evacuation Time Window	Radius Covering	Rescue Team Capacity	Relief Item Capacity
[97]	√			√		√				
[95]	√			√						
[104]						√				√
[108]	√					√				
[111]	√			√					√	
[115]	√	√								
[119]	√	√								
[123]	√	√		√	√					
[125]	√			√						
[129]		√				√	√	√		√
[82]		√	√	√	√	√	√			
[136]	√	√		√						
[139]	√	√		√						
[83]	√	√		√		√	√			
[84]	√	√		√		√				
[149]		√		√		√	√			√
[153]		√		√	√					
[157]	√	√	√	√						
[161]		√		√	√	√				
[165]	√	√		√		√				
[168]	√	√	√	√	√	√				
[98]	√	√		√			√			
[101]	√	√		√		√				√
[105]	√	√		√		√	√	√		
[1]	√	√		√		√				√
[112]	√			√		√				
[116]		√						√	√	√
[120]		√		√		√				√
[33]	√	√	√	√	√		√			
[126]	√			√	√					
[130]	√	√		√			√			
[133]	√	√	√					√		
[137]	√			√	√		√			
[140]		√		√		√				
[143]	√	√	√			√				
[146]		√		√	√	√		√		√
[150]		√						√		
[154]	√	√	√	√	√				√	
[158]	√		√		√			√		
[162]	√	√		√						
[166]		√							√	
[169]	√	√		√		√			√	
[99]	√	√	√	√						
[102]	√		√	√	√		√			
[106]	√			√						
[109]	√	√				√				√
[113]	√	√		√			√			
[117]	√	√	√	√	√					
[121]		√	√			√				
[76]	√		√	√	√	√	√			
[127]	√			√	√			√		
[131]	√			√						
[134]	√	√	√	√			√			
[96]	√	√		√			√	√		√
[141]	√	√	√	√	√	√	√			
[144]	√	√		√						
[147]	√	√		√						
[151]	√			√	√				√	
[155]	√	√				√				
[159]	√	√	√	√	√		√			
[163]	√		√	√			√	√		
[167]	√	√	√	√	√	√				
[170]	√	√			√				√	√
[100]		√	√		√			√		√
[103]	√	√			√		√			
[107]	√	√		√	√					√
[110]	√			√	√		√			
[114]		√	√	√	√					√
[118]	√	√		√	√					
[122]	√	√		√						
[124]								√		
[128]	√	√	√	√	√	√				
[132]	√		√	√	√				√	
[135]		√		√			√		√	
[138]	√	√			√		√	√		
[142]	√	√		√				√		√
[145]					√		√		√	
[148]	√				√		√	√		
[152]					√				√	
[156]							√		√	√
[160]					√			√		
[164]	√				√		√	√	√	

Table 6. Investigating the main assumptions in the retrieved studies.

Reference	Predefined Location of Shelters	Shelter Types	Predefined Assembly Locations	Multi-Mode Transportation	Non-Homogeneous Vehicles	Facility Disruption	Network Disruption	Vehicle Disruption	Graph Theory Concepts	Split Delivery	Evacuee Priorities
[97]	√		√						√		
[95]	√		√						√	√	
[104]		√									
[108]	√		√								
[111]	√	√				√					
[115]	√		√		√						
[119]	√		√		√	√	√	√			
[123]	√		√			√	√				
[125]	√		√				√				
[129]	√		√	√							
[82]	√		√	√		√	√				
[136]	√		√		√				√	√	
[139]	√		√				√				
[83]	√		√			√	√		√		
[84]	√		√	√		√	√				
[149]	√		√								
[153]	√		√	√							
[157]	√		√			√	√	√			√
[161]	√		√	√						√	√
[165]	√		√								
[168]	√		√							√	
[98]	√		√						√		
[101]	√		√								√
[105]	√		√						√		
[1]			√	√					√		
[112]	√		√				√				
[116]			√			√					
[120]	√		√		√	√					√
[33]	√		√		√	√	√	√			
[126]	√		√						√	√	
[130]	√		√		√			√			√
[133]	√										
[137]	√		√		√					√	
[140]	√		√	√					√		√
[143]	√	√	√				√				√
[146]	√		√		√		√				
[150]			√					√			
[154]	√	√	√	√	√						√
[158]					√						
[162]			√	√	√				√	√	
[166]			√							√	√
[169]	√		√	√	√		√		√		
[99]	√	√	√	√	√		√			√	√
[102]			√		√		√		√		
[106]	√		√		√						
[109]			√				√		√		
[113]	√						√			√	
[117]	√		√		√		√				
[121]			√			√	√		√		
[76]	√		√		√		√				
[127]	√		√	√	√				√		
[131]	√		√						√		
[134]	√		√		√				√		
[96]		√	√		√		√				
[141]	√								√	√	
[144]	√				√				√		
[147]	√				√				√		
[151]	√		√	√	√						√
[155]	√		√				√				
[159]	√		√		√		√				√
[163]			√	√	√						√
[167]	√		√				√				
[170]		√			√						√
[100]			√			√	√				
[103]	√		√		√						
[107]	√	√	√	√	√		√		√		√
[110]	√		√				√				
[114]	√	√	√		√						√
[118]	√		√		√				√		
[122]	√		√		√				√		
[124]	√									√	√
[128]			√	√	√		√		√	√	
[132]	√		√	√	√					√	√
[135]	√	√	√	√	√		√			√	√
[138]	√				√		√		√		
[142]			√	√	√	√					
[145]			√	√	√			√			√
[148]			√						√		
[152]							√				√
[156]	√						√			√	
[160]							√		√		
[164]			√				√				√

5.1.4. Input Parameter Features

Common input data of transit-based evacuation models are listed in Table 7, essentially shelter capacity, vehicle capacity, and road/network capacity. The main parameters include evacuation demand, shelter capacity, vehicle capacity, and road/network capacity. Due to the inclusion of relief planning issues in evacuation planning problems, relief item demand and capacity are two sets of input parameters in the reviewed studies. Maximum egress time that is related to the evacuation time window constraints has also been addressed in a couple of previous studies in the literature. Travel time and travel cost are also some of the other input components not only in VRP studies but also in transit-based evacuation planning problems. Uncertainty associated with input parameters could be modelled via stochastic or possibilistic programming approaches or a combination of them. The majority of research in evacuation planning addresses uncertainty in demand [177,187–193] and/or capacity [177,187,190,191,193–195]. Goerigk, Deghdak, and T'Kindt [119] and Goerigk and Grün [115] worked on multi-modal evacuation approaches considering the uncertainty in demand. Without considering uncertainty, evacuation models become unrealistic and are not able to cope properly with disaster situations; furthermore, in a disaster situation, some information is not accurate, and planners have to predict some inputs in their models. Yao, Mandala, and Do Chung [189] presented a robust linear programming model that addresses evacuation management in large-scale networks, specifically considering uncertain demands. Huibregtse et al. [196] proposed a model to optimize evacuation measures, taking into account uncertainties related to the number of evacuees, their behaviour, and hazard characteristics such as location, time, and intensity. The model transformed these uncertainties into various scenarios, allowing for a comprehensive analysis of possible outcomes.

Ng and Waller [193] considered uncertainties in both the number of evacuees (demands) and road capacities (capacity) in their evacuation planning model based on different scenarios. They developed a framework that calculates the required adjustments in demand inflation and supply deflation to achieve a reliability level specified by the user. In a comparable investigation, researchers Ng and Lin [191] introduced a technique for identifying optimal evacuation routes in situations where complete information is lacking regarding evacuation demand and road capacities. Lim, Rungta, and Baharnemati [177] proposed a model for evacuation that considered uncertainties in road capacities, aiming to analyse the correlation between the number of evacuation paths, clearance time, and the probability of congestion during evacuations. Li and Ozbay [190] proposed a cell-based evacuation model that integrates uncertainties in flow-related capacities. These capacities were treated as variables that dynamically adapt over time based on assigned flows.

Table 7. Investigating input parameter features in the retrieved studies.

										Uncertainty													Uncertainty		
Reference	**Shelter Capacity**	**Vehicle Capacity**	**Road Capacity**	**Evacuation Demand**	**Relief Demand**	**Relief Capacity**	**Maximum Egress Time**	**Travel Time**	**Travel Cost**	**Deterministic**	**Stochastic/Possibilistic**	**Mixed**	**Reference**	**Shelter Capacity**	**Vehicle Capacity**	**Road Capacity**	**Evacuation Demand**	**Relief Demand**	**Relief Capacity**	**Maximum Egress Time**	**Travel Time**	**Travel Cost**	**Deterministic**	**Stochastic/Possibilistic**	**Mixed**
[97]	√					√			√		√		[169]	√	√		√				√	√			√
[95]	√			√						√			[99]	√	√		√	√				√			√
[104]				√					√		√		[102]		√		√			√	√			√	
[108]	√			√							√		[106]	√	√		√				√				√
[111]	√			√				√			√		[109]	√		√	√				√				√
[115]				√				√		√			[113]	√	√		√			√	√		√		
[119]		√								√			[117]	√	√		√				√				√
[123]				√	√			√			√		[121]	√		√	√				√			√	
[125]	√		√	√			√	√		√			[76]		√		√			√	√		√		
[129]	√	√		√				√		√			[127]		√		√			√	√		√		
[82]			√	√					√			√	[131]	√	√	√					√	√		√	
[136]				√			√	√			√		[134]	√	√		√			√	√		√		
[139]	√	√		√			√					√	[96]	√	√		√	√	√	√		√			√
[83]		√					√	√	√		√		[141]	√	√	√	√			√	√		√		
[84]	√	√						√		√			[144]	√	√		√				√	√	√		
[149]			√	√				√			√		[147]	√	√		√				√	√	√		
[153]	√	√		√				√				√	[151]		√		√				√		√		
[157]	√	√	√	√				√		√			[155]	√			√				√		√		
[161]	√	√		√	√			√		√			[159]	√	√	√	√				√		√		
[165]	√	√		√			√				√		[163]		√		√				√		√		
[168]	√	√			√	√					√		[167]	√	√	√	√				√			√	
[98]		√	√					√		√			[170]	√	√		√	√	√			√			√
[101]	√	√		√	√	√			√			√	[100]	√			√	√	√			√			√
[105]		√		√					√			√	[103]	√	√		√				√		√		
[1]	√	√		√						√			[107]	√	√		√	√	√		√	√			√
[112]	√					√			√		√		[110]		√		√				√		√		
[116]	√			√	√	√			√		√		[114]							√	√		√		
[120]	√	√		√	√	√		√			√		[118]	√	√		√				√		√		

Table 7. *Cont.*

										Uncertainty													**Uncertainty**		
Reference	**Shelter Capacity**	**Vehicle Capacity**	**Road Capacity**	**Evacuation Demand**	**Relief Demand**	**Relief Capacity**	**Maximum Egress Time**	**Travel Time**	**Travel Cost**	**Deterministic**	**Stochastic/Possibilistic**	**Mixed**	**Reference**	**Shelter Capacity**	**Vehicle Capacity**	**Road Capacity**	**Evacuation Demand**	**Relief Demand**	**Relief Capacity**	**Maximum Egress Time**	**Travel Time**	**Travel Cost**	**Deterministic**	**Stochastic/Possibilistic**	**Mixed**
[33]	√	√		√				√				√	[122]	√	√						√		√		
[126]		√		√				√				√	[124]				√					√	√		
[130]		√		√				√		√		√	[128]	√	√	√	√				√		√		
[133]	√								√			√	[132]		√		√					√	√		
[137]		√		√			√		√	√			[135]	√	√		√			√	√	√		√	
[140]	√	√		√				√	√	√			[138]	√			√			√	√				√
[143]	√		√	√				√		√			[142]	√	√		√	√	√		√				√
[146]	√	√		√	√	√	√	√				√	[145]				√	√		√	√			√	
[150]	√	√		√			√	√				√	[148]								√		√		
[154]	√	√		√			√					√	[152]		√						√		√		
[158]	√	√		√				√		√			[156]	√				√	√			√			√
[162]	√	√		√				√				√	[160]		√		√					√		√	
[166]	√			√				√				√	[164]		√		√				√				√

5.1.5. Optimisation Approaches

Transit-based evacuation planning mathematical models as a variety of VRP problems are essentially associated with integer or specifically binary variables for route selection, so “Integer programming” is the most common approach in modelling such problems. In addition, in some cases, routing is not the only decision that should be made, and other continuous variables like evacuee flows are also considered, so “Mixed integer programming” could be another approach in mathematical modelling. “Linear programming” and “Non-linear programming” approaches are also used in this problem; however, they have not been used vastly. In recent years, two/multi-stage-scenario-based stochastic programming has been used in disaster management applications and can be viewed as an appropriate approach for planning evacuations as well. In addition, multi-objective evacuation planning allows decision-makers to optimize multiple goals simultaneously while finding compromise solutions that make trade-offs between different objectives, such as arrival time and resource cost, that have logically reverse correlations. Dynamic and static are the two most frequently used terms in evacuation planning and management to define time-dependent characteristics of the traffic flows in a road network. In the dynamic flow, time-dependent systems are accounted for, and the state of the flows can change during the evacuation time horizon, whereas in the static flow, rates are not time-dependent and are fixed during an evacuation [197].

Although the large body of existing studies has addressed static formulation in their models [111,157,194,198–203], which are also broadly used by the planner to evaluate a transportation network in normal conditions [204], these models have a major drawback in realistically representing the real characteristics and user behaviours in different conditions of a disaster. Thus, many dynamic models have been developed in past years to overcome these difficulties of static models, and most of them were designed based on simulation and were macroscopic, mesoscopic, or microscopic [35,205–210]. Dynamic models represent evacuation conditions more realistically, but they suffer from the drawback of coping with the large scale of the network in a reasonable time. Most of the existing models in the literature such as [175,193,195,211,212] solved relatively small-scale models and could not address the real world. Evacuation models considering dynamic network flows have been studied by some researchers such as Hamacher, Heller, and Rupp [181], Lu, George, and Shekhar [178], Bretschneider and Kimms [182], Bretschneider and Kimms [45], Kim and Shekhar [176], Pillac, Van Hentenryck, and Even [173], and Pillac, Cebrian, and Van Hentenryck [172]. Lu, George, and Shekhar [178] utilised a heuristic method along with capacity limitations to analyse time-dependent networks. Moreover, they incorporated network capacity as a series of time-based data and applied the algorithm to identify suboptimal evacuation strategies. The efficacy of the algorithm was demonstrated for networks of moderate size. Kim and Shekhar [176] studied changing the direction of lanes for evacuation. They presented a greedy algorithm that utilised the time-expanded network and simulated an annealing-based heuristic. Lim, Zangeneh, Baharnemati, and Assavapokee [171] proposed an algorithmic approach and mathematical models to effectively determine the initiation times, schedules, and optimal routes for evacuations. This was done by considering the estimated path of a hurricane and the expected time of landfall as key information. Hamacher, Heller, and Rupp [181] addressed the evacuation problems along with location analysis by simultaneously predicting and evaluating evacuation plans. They proposed a two-stage heuristic solution approach for a dynamic network flow model to restructure traffic routing in urban areas affected by disasters.

This approach focused on optimising the evacuation process by considering patterns and integer constraints. Pillac, Cebrian, and Van Hentenryck [172] developed an approach using column generation to optimize mobilisation and evacuation planning. The objective was to minimize the total evacuation duration and maximize the number of evacuees reaching safe areas by determining evacuation times, routes, and resource allocations for each evacuated area. Pillac, Van Hentenryck, and Even [173] introduced a conflict-based path-generation approach for effective evacuation planning. The problem was divided into a master problem and a subproblem. The subproblem focused on generating evacuation paths for each evacuated area, while the master problem aimed to optimize the flow of evacuees and create an efficient evacuation plan. Table 8 presents some mathematical modelling approaches that have been used in the retrieved papers.

Table 9 compares and contrasts various methods of solving transit-based evacuation planning problems. Some approaches can be used to find the evacuation planning solutions, including exact approaches (e.g., simplex and dynamic programming), heuristic and meta-heuristics algorithms (e.g., swarm intelligence algorithms, genetic algorithms, tabu search algorithms, variable neighbourhood search and simulated annealing, etc.). Since heuristic methods are very unstructured, we cannot establish a set of specific heuristic methods (a few heuristic approaches are referred to as “2-opt”, “3-opt”, and “Greedy algorithms”, but these terms lack comprehensive classification). The authors of some papers also model a problem using LPs, MIPs, and IPs without developing any solution techniques. Moreover, since they use commercial solvers such as “LINGO”, “CPLEX”, “LINDO”, “GAMS”, and “XPRESS” to solve the mathematical problem, we consider them as exact methods. In most cases, these software products contain an exact solver, and this is why we categorize them as exact approaches. Branch and bound algorithms and decomposition algorithms are solution methods that are used in mathematical models that contain integer variables. Robust optimisation methods and fuzzy mathematical modelling approaches have also been used in this context when different kinds of uncertainty are considered in the input data. Multi-objective algorithms to convert a multi-objective to the equivalent single objective to be solved by conventional single-objective approaches have been used in evacuation planning, too. Bi-level programming and game theory approaches have been used in cases where more than one decision-maker is involved in the decision-making process. Simulation approaches have commonly been employed as complementary methods to enhance the quality of solutions. They provide more precise input data for the critical parameters of mathematical models and assess the applicability of solutions in real-world situations. For instance, in reference [101], demands are predicted through a simulation approach and then imported into the mathematical model. In references [139,149], simulations were utilised to assess disaster risk characteristics, including likelihood and impact. Additionally, in reference [159], the risk of traffic collisions and their impact on transit-based evacuation operations was investigated. Overall, we found that due to the complex nature of VRP problems, similarly transit-based evacuation models and heuristic and meta-heuristic algorithms were the most popular approaches.

Table 8. Investigating mathematical modelling approaches in the retrieved studies.

Reference	Linear Programming	Integer Programming	Mixed-Integer Programming	Non-Linear Programming	Two/Multi-Stage-Scenario-Based Stochastic Programming	Multi-Objective	Reference	Linear Programming	Integer Programming	Mixed-Integer Programming	Non-Linear Programming	Two/Multi-Stage-Scenario-Based Stochastic Programming	Multi-Objective	Reference	Linear Programming	Integer Programming	Mixed-Integer Programming	Non-Linear Programming	Two/Multi-Stage-Scenario-Based Stochastic Programming	Multi-Objective	Reference	Linear Programming	Integer Programming	Mixed-Integer Programming	Non-Linear Programming	Two/Multi-Stage-Scenario-Based Stochastic Programming	Multi-Objective
[97]			√				[98]			√				[99]		√			√		[100]			√		√	√
[95]			√				[101]			√		√	√	[102]		√					[103]			√			
[104]					√		[105]			√	√			[106]				√			[107]			√			√
[108]			√				[1]			√			√	[109]				√	√		[110]	√		√			
[111]		√					[112]	√				√		[113]			√	√			[114]			√			
[115]			√				[116]			√				[117]		√					[118]	√		√			
[119]					√		[120]			√			√	[121]			√		√		[122]		√				
[123]		√					[33]			√				[76]			√			√	[124]		√		√		
[125]			√				[126]		√					[127]			√				[128]			√			
[129]			√				[130]			√				[131]		√					[132]			√			
[82]		√					[133]		√					[134]		√					[135]				√		
[136]	√		√				[137]			√				[96]	√		√				[138]	√		√			
[139]				√	√		[140]			√			√	[141]		√	√	√	√	√	[142]			√		√	√
[83]		√					[143]			√			√	[144]		√	√				[145]			√			
[84]		√					[146]			√			√	[147]		√	√				[148]			√			
[149]			√			√	[150]		√				√	[151]	√		√				[152]		√		√		√
[153]	√	√		√			[154]			√	√			[155]		√		√			[156]	√		√			
[157]				√	√		[158]		√					[159]	√	√					[160]			√			
[161]			√			√	[162]			√		√		[163]			√				[164]			√		√	
[165]			√				[166]			√		√		[167]				√									
[168]			√		√		[169]			√			√	[170]		√	√		√								

Table 9. Investigating mathematical solution approaches used in the retrieved studies.

Reference	**Exact Method**	**Meta/Heuristic Algorithm**	**Hybrid Algorithm**	**Branch and Bound Algorithm**	**Decomposition Algorithm**	**Robust/Fuzzy Optimisation**	**Multi-objective Algorithms**	**Bi-Level Programming**	**Game Theory**	**Simulation**	**Reference**	**Exact Method**	**Meta/Heuristic Algorithm**	**Hybrid Algorithm**	**Branch and Bound Algorithm**	**Decomposition Algorithm**	**Robust/Fuzzy Optimisation**	**Multi-Objective Algorithms**	**Bi-Level Programming**	**Game Theory**	**Simulation**	**Reference**	**Exact Method**	**Meta/Heuristic Algorithm**	**Hybrid Algorithm**	**Branch and Bound Algorithm**	**Decomposition Algorithm**	**Robust/Fuzzy Optimisation**	**Multi-Objective Algorithms**	**Bi-Level Programming**	**Game Theory**	**Simulation**
[97]		√									[33]	√	√									[147]	√	√		√						
[95]	√				√						[126]	√	√				√					[151]		√								
[104]				√							[130]	√										[155]		√								
[108]		√									[133]	√	√								√	[159]	√									√
[111]	√	√									[137]	√	√	√								[163]		√					√			
[115]	√	√				√					[140]	√						√				[167]										√
[119]	√	√				√					[143]		√					√				[170]	√					√				
[123]	√	√		√			√				[146]	√										[100]			√		√	√	√			
[125]	√	√									[150]		√				√	√				[103]	√	√								
[129]	√					√		√	√		[154]	√	√			√	√				√	[107]	√									
[82]	√						√				[158]	√	√		√							[110]	√									
[136]		√		√							[162]	√	√				√					[114]	√	√	√							
[139]	√					√				√	[166]	√					√					[118]	√	√	√							
[83]	√	√				√					[169]	√	√				√	√			√	[122]		√	√							
[84]	√	√									[99]	√	√				√				√	[124]	√									√
[149]	√									√	[102]		√				√					[128]		√	√							
[153]	√	√									[106]										√	[132]	√	√	√							
[157]	√										[109]		√						√			[135]		√								√
[161]	√	√				√	√				[113]	√	√									[138]	√		√			√				
[165]		√									[117]		√				√				√	[142]		√				√	√			
[168]	√	√									[121]	√				√						[145]		√	√			√				
[98]		√				√					[76]	√	√	√				√			√	[148]		√	√							
[101]		√				√	√			√	[127]		√	√							√	[152]		√					√			√
[105]	√										[131]	√	√				√					[156]	√		√	√	√	√				
[1]	√					√					[134]		√	√								[160]		√	√							
[112]	√	√									[96]	√					√				√	[164]	√					√				
[116]	√					√					[141]		√	√				√														
[120]		√					√				[144]	√	√		√																	

5.2. Administrative Functions

In this section, we examine three main aspects of the reviewed studies, including "Experiments/Disaster type", "Case study", and "Integrated emergency management". Through the first criterion, we examine whether the study is presented via a special kind of disaster or contains numerical experiments that can be used as a general approach for various kinds of situations. Among the natural hazards, hurricanes, floods, bushfires, and earthquakes were considered the most, while some man-made disasters have also been addressed, including bombing and nuclear leakage accidents. According to the second criterion, various case studies or aimed groups of the study are investigated. USA, Australia, Germany, and Iran hold most of the case studies, and low-mobility people and isolated communities, which fall within vulnerable groups, have been investigated in some papers. The third criterion reflects the integration of transit-based evacuation planning problems with other phases of the disaster management process. Some studies encompassed shelter planning, resource planning (e.g., evacuation staff planning), relief item planning, and traffic management, while some other studies consider mitigation and recovery efforts in the face of disasters. Table 10 summarises the real-case administrative functions of the retrieved studies. This table highlights critical research gaps, such as securing comprehensive real-world data, addressing inclusivity and equity, adapting to dynamic situations, conducting comparative analyses, and expanding the domain of the disaster management problem to encompass pre- and post-disaster concerns simultaneously. These areas represent opportunities for further research to enhance the effectiveness of transit-based evacuation strategies across various disaster scenarios.

Table 10. Investigating real-case administrative functions of the retrieved studies.

Reference	Experiments/Disaster Type	Case Study	Integrated Emergency Management
[97]	Numerical experiments	Regional evacuation after a hazard	
[95]	Hurricanes/Numerical experiments	Regional evacuation after a hazard	
[104]	Hurricanes	Gulf Coast region, USA	Shelter planning; resource planning
[108]	Bombing/Numerical experiments	Regional evacuation after a hazard	
[111]	Hurricanes	Three coastal cities in the State of Mississippi, USA	Integrated pre- and post-disaster planning
[115]	Bombing/Numerical experiments	Kaiserslautern, Germany	
[119]	Bombing/Numerical experiments	Kaiserslautern, Germany	
[123]	Numerical experiments	Regional evacuation/Sample data of Nice, France	
[125]	Numerical experiments	Regional evacuation after a natural hazard	
[129]	Earthquakes	Tehran, Iran	Relief item planning
[82]	Murrindindi Mill fire Black Saturday/Bushfire	Victoria, Australia	Shelter planning; resource planning
[136]	Numerical experiments	Transporting casualties after a natural hazard or terrorist incident	
[139]	Storms/Wildfire debris flow hazard management	Santa Barbara 2009 Jesusita, USA	Integrated pre- and post-disaster planning
[83]	Bushfires	2009 Black Saturday in Victoria, Australia	
[84]	Bushfires	2009 Black Saturday in Victoria, Australia	
[149]	Floods	Chiang Mai Province in Northern Thailand	Integrated pre- and post-disaster planning
[153]	Numerical experiments	Regional evacuation after a hazard	

Table 10. *Cont.*

Reference	Experiments/Disaster Type	Case Study	Integrated Emergency Management
[157]	Earthquakes	Istanbul, Turkey	Shelter planning; traffic management
[161]	Numerical experiments	Hospital evacuation after a hazard	
[165]	Numerical experiments	Low-mobility people evacuation after a natural hazard	
[168]	Earthquakes	Tehran, Iran	Relief item planning
[98]	Nuclear leakage accident	India	
[101]	Earthquakes	Tehran, Iran	Integrated pre- and post-disaster planning
[105]	Nuclear leakage accident	Regional evacuation after nuclear leakage accident	
[1]	Earthquakes	Sarpol-e Zahub and Gilan-e Gharb, Iran	
[112]	Numerical experiments	Isolated communities	Shelter planning; relief item planning
[116]	Numerical experiments/Earthquakes	Tehran, Iran	Relief logistics network design; facility location
[120]	Earthquakes	Tehran, Iran	Integrated pre- and post-disaster planning; location and storage decisions for relief centres; temporary care centre locations and efficient supply distribution
[33]	Bushfires	Black Saturday bushfires in Victoria, Australia	
[126]	Numerical experiments	Regional evacuation after a hazard	Resource planning
[130]	Radiological accidents in nuclear power plants	Kakrapar Atomic Power Station, Gujarat, India	
[133]	Floods	Regional evacuation after a hazard	Shelter planning; resource planning; facility location
[137]	Numerical experiments	Regional evacuation after a hazard/Ningbo, China	
[140]	Earthquake/Tsunami	Palu, Indonesia	Relief item planning
[143]	Numerical experiments/Catastrophic natural hazards	Broward County, Florida, USA	Shelter planning; minimising mental, physical, and temporal effort and frustration faced by evacuees
[146]	Earthquakes	Tehran, Iran	Relief item planning
[150]	Tsunami	The catastrophic tsunami of 2011 in Ishinomaki, Japan	
[154]	Flood	Hospital evacuation, New South Wales, Australia	
[158]	Bomb disposal	Kaiserslautern, Germany	Facility location
[162]	Numerical experiments/Catastrophic natural hazards	Sioux Falls, South Dakota, USA	Shelter planning
[166]	Numerical experiments/Catastrophic natural hazards	Beaufort County, South Carolina, USA	
[169]	Earthquake	Kermanshah, Iran	Integrated victim evacuation and debris removal planning
[99]	Numerical experiments/A hypothetical hospital evacuation during hurricanes	North Carolina, USA	Predicting flood, wind, and roadway traffic conditions.
[102]	Hurricane	Gulfport, Mississippi, USA	
[106]	Floods	Simulating hospital evacuation	Resource planning
[109]	Numerical experiments	Lombardy, Italy	Shelter planning
[113]	Terrorist attack	Baltimore, Maryland, USA	Facility location; evacuee demand planning

Table 10. *Cont.*

Reference	Experiments/Disaster Type	Case Study	Integrated Emergency Management
[117]	Numerical experiments/Catastrophic natural hazards	Regional evacuation after a hazard	
[121]	Numerical experiments	Regional evacuation after a hazard	Shelter planning; traffic management
[76]	Numerical experiments/Catastrophic natural hazards	Toronto, Canada	Traffic management
[127]	Numerical experiments/Floods	Regional evacuation after a hazard/Hongshan District, China	Facility location (charging stations for electric buses used in evacuation operation); equity consideration in emergency management
[131]	Numerical experiments	Regional evacuation after a hazard	Evacuee demand planning
[134]	Earthquake	Bucaramanga, Colombia	Facility location
[96]	Earthquakes	Tehran, Iran	Shelter planning; relief item planning; integrated pre- and post-disaster planning
[141]	Numerical experiments	Regional evacuation after a hazard/man-made disaster	Facility location
[144]	Numerical experiments	Regional evacuation after a hazard	Evacuees' lateness patterns
[147]	Numerical experiments	Regional evacuation after a hazard	Evacuees' demand planning
[151]	Earthquake	Kermanshah, Iran	
[155]	Numerical experiments/Catastrophic natural hazards	Sioux Falls, South Dakota, USA	Traffic management; evacuees' behaviour modelling
[159]	Numerical experiments/Floods	Nova Scotia Emergency Health Services, Halifax, Canada	Traffic simulation and traffic management
[163]	Numerical experiments	Regional evacuation of people with disabilities after a hazard	Shelter planning; facility location
[167]	Hurricane Katrina	New Orleans, USA	Traffic simulation and traffic management
[170]	Floods	Taipei City, Northern Taiwan	Shelter planning; resource planning; facility location
[100]	Numerical Experiments/Hurricane	Texas, USA	Shelter planning; relief item planning; facility location
[103]	Numerical experiments	Regional evacuation after a hazard	
[107]	Bushfires	Saddleridge Fire, San Fernando Valley, Los Angeles County, California, USA	Shelter planning; relief item planning
[110]	Floods	Kawajima, Japan	Evacuee demand planning
[114]	Numerical experiments/Large-scale disasters	Hospital evacuation, Tasmania, Australia	Resource (staff and equipment)
[118]	Numerical experiments/Large-scale disasters	Regional evacuation after a hazard	Pedestrian evacuation network design
[122]	Numerical experiments	Regional evacuation after a hazard	
[124]	Hurricane	Regional evacuation of vulnerable people in New Orleans, USA	Facility location; evacuee demand planning
[128]	Bombing/Earthquake followed by floods	Kaiserslautern Germany/Nice, France	Shelter planning; facility location; traffic management
[132]	Numerical experiments	Hospital evacuation, USA	Resource (staff) planning
[135]	Numerical experiments	Hospital evacuation, USA	Resource (staff and vehicle) planning; considering traffic effects
[138]	Numerical experiments/Catastrophic natural hazards	Sioux Falls, South Dakota, USA	Shelter planning; facility location
[142]	Earthquakes	Tehran, Iran	Shelter planning; relief item planning; integrated pre- and post-disaster planning

Table 10. *Cont.*

Reference	Experiments/Disaster Type	Case Study	Integrated Emergency Management
[145]	Floods	Agh-Qala, Golestan, Iran	Rescue team assignment; rescue precedence constraints; rescue time windows
[148]	Numerical experiments	Comparing results with well-known benchmarks	Optimising humanitarian coverage path planning via cumulative UAV routing approach
[152]	Forest fires	Heilongjiang Province, China	Assessing rescue priority based on the fire's condition of each affected area
[156]	Earthquake	Jiuzhaigou, China	Resource planning
[160]	Numerical experiments	Regional evacuation after a natural hazard	Search and rescue operation planning
[164]	Earthquake	Tehran, Iran	Search and rescue operation planning; risk assessment for secondary destruction; resource planning

6. Research Gap Analysis and Discussion

This study highlights the absence of a comprehensive and systematic review of literature in the field of transit-based evacuation planning. By conducting a traditional systematic literature review, the research gaps are identified in existing research, and those areas that require further exploration and investigation are highlighted in what follows. In addition, at the end of this section, a mapping of the evolving landscape of transit-based evacuation planning problems is presented and discussed.

6.1. Modelling Characteristics

The exploration of transit-based evacuation planning in existing literature, while evolving, still shows a relative scarcity despite the development of various models by researchers. These models, often recognised as an extension and modification of VRPs, have mainly focused on optimising transportation between pick-up points and safe shelter destinations. In VRPs, the goal is to minimize travel costs and distances using vehicles to meet demand. However, transit-based evacuation planning extends beyond this by encompassing a more complex set of decision variables, such as routing, scheduling, and, to a lesser extent, shelter location and relief planning. A critical aspect often overlooked in these models is the comprehensive resource planning required during evacuation operations. Resources in this context include not just machinery and equipment necessary for evacuation but also detailed planning for the use of vehicles, helicopters, and other forms of transportation. Traffic management becomes a pivotal factor, especially when evacuation operations need to be coordinated with existing public transportation systems. Furthermore, human resource planning is a significant challenge, as disasters often lead to staff shortages and a reliance on volunteer assistance. This brings an element of uncertainty that must be factored into evacuation planning. To enhance the effectiveness and relevance of these models, there is a need to analyse actual past experiences and gather expert input through questionnaires and interviews. Such an approach can lead to the modification of existing decision variables and the inclusion of new ones to better reflect the dynamic and multifaceted nature of evacuation scenarios. Specifically, incorporating variables related to resource allocation, transportation logistics, traffic management, and human resource considerations will provide a more holistic and practical framework for transit-based evacuation planning. This expanded focus will better equip planners to handle the complexities and uncertainties inherent in real-world disaster situations, ensuring more efficient, effective, and adaptable evacuation strategies.

The objective functions identified in previous studies predominantly focused on time-dependent objectives, such as minimising arrival and evacuation times, alongside goals like reducing evacuation costs and addressing equity and welfare concerns. Notably, the resilience of transit-based evacuation plans, an aspect yet to be explored in existing research, emerges as a promising research area. In contrast to single-objective models, the field of transit-based evacuation planning mathematical models requires more exploration in multi-objective decision-making. Key constraints like evacuation time windows and the radius coverage of evacuation centres have been underemphasised. Moreover, introducing concepts like split delivery and evacuation segmentation could significantly improve evacuation efficiency. In real-world evacuation operations, problems are rarely single-objective, underscoring the need for a shift towards multi-objective models. Such models must balance various objectives, like minimising evacuation time for transit-dependent individuals in various centres, which is crucial for equity in evacuation planning. An interesting approach is the simultaneous minimisation of traffic congestion and maximisation of equity. Multi-stage optimisation frameworks, such as a two-stage approach focusing on cost minimisation for establishing assembly points initially, followed by minimising evacuation time, offer intriguing possibilities. Furthermore, bi-level programming frameworks that optimise individual travel time and reduce overall traffic congestion or total evacuation time from a transportation organisation's standpoint present valuable future research avenues. The development of methods and techniques that effectively address these multi-objective problems and yield optimal and robust solutions is imperative. Such advancements would enable more comprehensive and effective transit-based evacuation planning, accommodating a wider range of objectives and constraints reflective of real-world scenarios. This approach could lead to more equitable, efficient, and effective evacuation strategies, offering a nuanced understanding of the complexities involved in disaster management and evacuation logistics.

Considering the modelling approach, most previous studies used integer and mixed-integer programming, while quadratic programming, convex optimisation, and network optimisation modelling methods have not been commonly used. Integrated pre- and post-disaster management decisions can be addressed through two-stage stochastic programming. When decision makers seek multiple opposite objectives such as costs and time, a multi-objective modelling approach can be utilised. Bi-level programming is not a widely used approach, although it is an efficient modelling method when decisions are made at two different levels, often referred to as follower and leader. In transit-based evacuation problems, such as traffic assignment to roads and vehicle routing, transit vehicles follow the decisions made at the traffic assignment level. The vast majority of research in the field of evacuation planning assumes that complete and accurate information is available for all aspects of transit-based evacuations. However, given the highly unpredictable nature of evacuation scenarios, deterministic studies are not practical or realistic. In order to enhance the practicality of the plan for scenarios involving disasters, robust optimisation methods or fuzzy mathematical modelling can be used to incorporate uncertainties in input data. Moreover, during the past years, dynamic modelling has received insufficient attention in the context of transit-based evacuation planning problems. Emergency planning during evacuation operations presents significant challenges due to the unavailability of reliable information. Acquiring the necessary data for planning is a time-consuming process in nearly all emergency situations, and some data may only become available during the course of evacuation. For instance, the number of available shelters for different evacuee groups and the number of limited resources, such as vehicles, are continuously updated with more precise information. Furthermore, the number and condition of evacuees and new disaster-related events or infrastructure collapses can create travel time dynamics. These issues highlight the importance of exploring dynamic models in future research.

In transit-dependent evacuation planning mathematical models, the development of efficient solution methods is essential, providing timely and critical decision support to managers. This need has propelled mathematical optimisation to the forefront, with a central aim of curtailing computational times while augmenting decision-making efficacy in high-pressure emergency scenarios. Within the specific context of transit-based evacuation planning, mathematical models are challenged by the high computational burden, particularly those based on VRPs. This challenge necessitates the development of heuristic solution approaches, which offer a practical and expedient means of addressing these complex problems. To this end, heuristic and meta-heuristic optimisation approaches have been gaining significant attention among researchers. These methods, known for their ability to find good solutions in a reasonable timeframe, are particularly suited to the dynamic and time-sensitive nature of emergency evacuation planning. Additionally, hybrid methods that blend exact and heuristic techniques are emerging as innovative solutions in this space, providing a balanced approach to accuracy and computational efficiency. Moreover, advanced methods like column generation, branch and price, and Benders decomposition are showing great promise in tackling the complexities inherent in VRP-based mathematical models for evacuation planning. These techniques, renowned for their effectiveness in large-scale and complex optimisation problems, could significantly improve the computational performance of transit-based evacuation models. By exploring and refining these heuristic and advanced mathematical methods, future research can make substantial contributions towards more effective, efficient, and responsive evacuation strategies in emergency logistics management. The potential for these methods to revolutionise the field by offering more sophisticated and tailored solutions to the unique challenges of transit-based evacuation planning is immense and warrants further exploration and development.

6.2. Administrative Function

The significance of a particular type of disaster can have a substantial impact on transit-based evacuation plans. Future studies should explore the specific implications of different types of disasters; for instance, some disasters like earthquakes occur with little or no warning, whereas others, such as storms or hurricanes, offer some advance notice and allow planners time to prepare for evacuation. Previous studies have overlooked the importance of cascading or multi-hazards, such as when a severe earthquake can cause landslides. These landslides, in turn, can block rivers and create dams. The build-up of water behind these dams can lead to the flooding of downstream areas, further exacerbating the damage caused by the initial earthquake. Cascading disasters pose significant challenges for emergency management, including transit-based evacuation plans, as they often require a comprehensive and coordinated response to mitigate their effects. Another issue in transportation planning relates to network conditions. The majority of existing studies on evacuation planning assume that the road network infrastructure is reliable and operational during emergency evacuations. However, the occurrence of a disaster can result in significant damage to the transportation network, thereby impeding efficient evacuation operations. Therefore, it is important to address the issue of road network performance comprehensively in future research on evacuation planning. This would involve developing models that account for the impact of disrupted road networks on evacuation operations, as well as identifying strategies to mitigate the effects of such disruptions. Moreover, most existing evacuation studies have primarily focused on land-based transportation modes like buses and vans, overlooking the potential need for alternative modes of transportation based on the specific characteristics of the disaster. For instance, a widespread disaster like a hurricane might necessitate the utilisation of helicopters for evacuation to cover a large affected area. Similarly, in situations where evacuation centres are surrounded by floodwaters, boats can be used to transport individuals in need of evacuation.

It is crucial to recognize the emergence of advanced transportation systems like autonomous vehicles (AVs) and connected autonomous vehicles (CAVs) and investigate their impact on evacuation plans. These innovative technologies are being integrated into urban transportation networks these days and they are able to exchange information, collaborate, and make informed decisions. Accordingly, they have the potential to revolutionize transit-based evacuation strategies. By harnessing the capabilities of these intelligent transport systems, routing operations can be significantly improved, leading to more efficient and effective evacuation processes. Similarly, the utilisation of unmanned aerial vehicles (UAVs) and drones can play a significant role in evacuation scenarios by providing valuable real-time data and surveillance capabilities. This information can greatly assist decision-makers in selecting optimal routes and determining the safest and most efficient modes of evacuation. The integration of such innovative technologies in evacuation planning presents a promising avenue for enhancing the efficacy and safety of evacuation operations.

In the aftermath of natural disasters, the impact on transportation infrastructure, such as road damage, poses significant challenges to evacuation efforts. Transit-based evacuation planning must therefore robustly address these challenges, including the aspect of vehicle accessibility when roads are impacted by disasters. This involves not only devising alternative ground routes but also considering the use of aerial transportation modes, such as helicopters, when terrestrial paths are closed or obstructed. The integration of such aerial strategies into post-disaster transportation planning is vital. It ensures that evacuation options remain viable and efficient, even when traditional road networks are unusable. This approach is crucial for both individuals with personal vehicles and those reliant on public transit, underlining the need for an equitable and adaptable evacuation strategy. Incorporating aerial solutions, alongside other flexible transportation methods, enhances the overall effectiveness of transit-based evacuation plans. It demonstrates a comprehensive understanding of the varied and complex transportation challenges that arise in post-disaster scenarios, thereby improving the robustness and applicability of these plans in real-world emergency situations.

To date, existing research on transit-based evacuation has assumed that evacuees maintain stable health conditions throughout the entire evacuation planning process. Nevertheless, this assumption does not reflect reality, as evacuees may experience deteriorating health conditions that can depend on various factors, such as the duration of the evacuation or the quality of the operations. Therefore, it is essential to establish practical probability functions that can account for these uncertainties in evacuation problems. In addition, the assumption that all evacuees are ready for evacuation at the start of the process is prevalent in most transit-based evacuation studies. Consequently, it is plausible that some evacuees may arrive at pick-up points before others. Therefore, it is essential to investigate transit-based evacuation problems while considering varying evacuees' readiness times at the assembly point to obtain a comprehensive understanding of the problem and guarantee the safety of all evacuees during evacuation operations.

In summarising the administrative function of studies in transit-based evacuation planning, it is essential to acknowledge how academic research translates into effective real-world applications, particularly for disasters requiring pre-event evacuation such as floods, cyclones, and typhoons. These situations necessitate timely and well-coordinated evacuation plans. The study found that transit-based evacuation planning is critical for various transit-dependent groups, including elderly individuals in aged care centres, patients in hospitals, prisoners in prisons, pupils in schools, and culturally and linguistically diverse people who may not have proficient local language comprehension and are less likely to follow local media effectively. Moreover, efficient resource utilisation and prompt action are paramount in these scenarios. Integrating pre-disaster and post-disaster operations, such as risk mitigation, shelter planning, and relief planning, can significantly enhance the effectiveness of evacuation operations. The development of integrated models that consider multiple aspects of disaster management simultaneously is a promising avenue for future research. For example, decisions about temporary shelter locations involve complex considerations, including the positions of assembly points, which directly influence the travel times of evacuation vehicles. Furthermore, a key challenge in disaster response is the efficient utilisation of resources, especially human resources. There is a notable research gap in developing transit-based evacuation problem models that incorporate human resource management during emergencies, such as addressing staff shortages for operating vehicles and preparing vulnerable groups who require assistance during transit. Addressing these aspects in academic research can directly inform policymaking and lead to more robust, efficient evacuation plans, bridging the gap between theoretical frameworks and their practical implementation in diverse, real-world disaster contexts.

7. Conclusions

This literature review paper investigated transit-based evacuation modelling, focusing on model characteristics and real-world applications. Its primary contribution lies in exploring the use of operations research and mathematical modelling in evacuation planning. Conducted through a systematic review methodology, the study involved developing a review plan, identifying relevant literature from the Scopus and Web of Science databases, and critically appraising studies using the PICO framework for research quality and topic relevance. Content analysis was then used to categorize literature and identify future research directions. Of the initial 538 studies, 82 met the predefined inclusion and exclusion criteria and were included in the final review. Evaluation of the studies focused on research design, data sources, modelling approaches, and outcomes. The findings indicate a growing focus on transit-based evacuation modelling in transportation and disaster management. Prior research has underscored the significance of incorporating public transport networks into emergency evacuation plans, demonstrating how such modelling aids in identifying optimal evacuation strategies for both natural and human-induced disasters. These studies also suggest that transit-based modelling enhances evacuation efficiency, reduces time, and increases evacuee safety. Transit-based evacuation modelling studies, distinct from traditional ones, focus on using public transit systems like buses, trains, boats, and ambulances for evacuating people without personal vehicles. These studies account for the spatial and temporal aspects of transit systems, including schedules, capacities, and routes, and integrate social and demographic factors for inclusive and equitable evacuation plans. However, challenges such as data availability, model accuracy, and stakeholder coordination remain areas for future research improvement.

To create effective emergency evacuation plans, transit-based modelling studies use various data sources and approaches, acknowledging the complexity of the process in densely populated urban areas with intricate transport systems. Techniques like integer programming, mixed-integer programming, scenario-based stochastic programming, and network flow modelling are utilised for optimising evacuee and vehicle flow. Network flow modelling visualizes the network as a graph of transportation facilities and links. The effectiveness of these models hinges on realistic assumptions, parameter calibration, and data quality on population, infrastructure, and evacuation demand. Incorporating realistic emergency scenarios, including fluctuating travel demand and dynamic traffic conditions, is vital to enhance the models' utility in transit-based evacuation planning. The administrative aspect of transit-based evacuation modelling studies was examined to gauge their impact on emergency management policies and practices. Some studies offered suggestions for enhancing transit system capabilities in crises, while others assessed real-world evacuation plan effectiveness. These studies underscored the importance of stakeholder and decision-maker roles in modelling, considering various disaster types like hurricanes, bombings, nuclear incidents, earthquakes, and notably bushfires and floods. Key stakeholders include transportation and emergency management agencies, as well as local governments, necessitating their collaboration for effective evacuation planning. The literature review also indicated a trend towards integrating transit-based evacuation with other emergency strategies like shelter, resource, and relief item planning, suggesting a promising area for future research.

The literature review conducted in this study identified several research gaps related to transit-based evacuation modelling. These include the need for more comprehensive data sources, the development of more accurate and realistic models, and the integration of stakeholder perspectives into the modelling process. Additionally, the review underscored the necessity for further research on the effectiveness of transit-based evacuation plans in real-world scenarios, particularly in urban contexts. The research gaps identified offer directions for future research in transit-based evacuation modelling, which can inform policy and practice in emergency management. Addressing these gaps will necessitate interdisciplinary collaborations and innovative research approaches to develop more effective and inclusive transit-based evacuation plans.

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