Managing Volunteers in Disaster Situations - An Overview of Models for Decision-Makers

Florentina Hager*
University of Twente
f.hager@utwente.nl

Melanie Reuter-Oppermann
University of Twente
m.n.reuter-oppermann@utwente.nl

ABSTRACT

Volunteers are a valuable resource in disaster management. Yet to be useful, decision-makers need to manage this resource properly. However, managing volunteers differs from managing traditional work forces in multiple aspects: volunteers can spontaneously decide to offer their help, may have different skills and preferences for different tasks and can leave the system at any time. Several models for optimising volunteer management in disaster scenarios have been presented in the past. To provide an overview of existing approaches, this article provides a structured literature review, discusses the challenges of integrating these models into decision support systems and identifies future research directions. In total, 31 articles were identified, of which more than half were published in the last five years. Most authors addressed the issue of assigning volunteers to tasks, while little attention was paid to predicting the number of volunteers and optimising the composition of volunteer teams.

Keywords

Volunteers, decision support, disaster management, operational research, literature review

INTRODUCTION

When a disaster strikes, many different resources, such as medical or technical equipment and human resources, need to be available as quickly as possible. Thereby volunteers can play a significant role. For instance, according to a study conducted by the Fritz Institute in Indonesia after the 2004 tsunami, 90% of the survivors surveyed reported being rescued by volunteers (Fritz Institute 2005). If volunteers had their own sovereign nation, it would rank as the second most populous country in the world with its economy being one of the ten largest in the world (Salamon et al. 2011).

There are several definitions of volunteers. Most of them have in common that volunteers do not work for a salary but for free or only receive remuneration in the form of food and are not obliged to volunteer (Sampson 2006). Among volunteers, a second distinction is made in terms of affiliation. While some volunteers belong to an organisation such as the Red Cross, where they may receive training or similar, people may also decide to volunteer spontaneously, especially after a disaster. Therefore, these volunteers are sometimes referred to as "spontaneous" volunteers. However, this term implies that volunteers with affiliation are not spontaneous. Hence, we agree with Daddoust et al. (2021) that they should rather be called "unaffiliated emergent" volunteers. However, to be consistent with the literature, we will refer to these volunteers as spontaneous volunteers (SV). For a more detailed discussion on the definition of volunteers and SV, we refer the reader to Sampson (2006) and Paciarotti and Cesaroni (2020).

SV can be a useful resource in the aftermath of a disaster. They may be quickly available (Daddoust et al. 2021) and provide additional work force and possibly also additional skills (L. Fernandez et al. 2006) for little to no cost (Daddoust et al. 2021). Even without specialised skills, they can take on simple tasks such as making sandbags in the event of flooding or distributing food to relieve the burden on emergency management staff allowing them to focus on more specialised activities (Sauer et al. 2014).

*corresponding author

However, with a lack of an underlying organisation that exists for affiliated volunteers, the deployment of SV can also pose "serious issues and risks" (L. S. Fernandez et al. 2006). In the worst case, they can even cause additional problems after a disaster (L. Fernandez et al. 2006, S.-Q. Chen and Bai 2023) by obstructing or interfering with emergency response personnel and/or putting themselves or the victims in danger by acting according to what they think is necessary (Whittaker et al. 2015). Despite all the risks associated with the involvement of SV, it is also not an option not to involve them in disaster relief when they are available. Forgoing this additional labour force means a loss of resources, which can also distort the public perception of disaster response (L. Fernandez et al. 2006). In addition, the rejection of SV can also reduce future willingness to volunteer (Falasca, Zobel, and Fetter 2009, Daddoust et al. 2021). Hence, emergency managers should be prepared to manage volunteers in order to utilise their potential as efficiently as possible while avoiding additional risks and threads. According to research, organisations should have a centralised system to administer SV and assign tasks to them individually or in groups (L. Fernandez et al. 2006). Such systems should be able to respond to changing situations during disasters and be applied dynamically "in an on-going process", as well as anticipate needs (L. Fernandez et al. 2006).

Models developed in the field of operations research can provide decision-makers with a solution for the management of volunteers and the most efficient use of their workforce. For practical application, integrating these models into decision support systems (DSS) is important to facilitate the decision-making process. This review aims to provide an overview of existing models for the management of SV in disaster situations. The objective of this work is twofold: on the one hand, we aim to point out gaps and future directions for volunteer management in disasters. On the other hand, we want to facilitate the design of future DSS by providing an overview of the models and the data requirements that such a system should fulfil. In this work, we focus on physical volunteers who do not (only) collect data, but "offer their workforce and support at the disaster response sides within their range" (Betke 2018). In addition, we only consider volunteers in disaster situations and exclude regular emergency situations.

The remainder of this paper is structured as follows: In the next section, we provide an overview of the related literature. We then describe the methodology for the structured literature review and present the results, including an outlook on future research topics, before concluding the paper with a summary.

RELATED LITERATURE

The problem of labour scheduling has been extensively studied in the past (Van Den Bergh et al. 2013). Although volunteers can be understood as a type of labour, some assumptions made in traditional labour allocation (TLA) do not necessarily apply to voluntary labour allocation (VLA) (Sampson 2006). Following the most common definitions presented in the previous section, volunteers generally do not receive compensation, except perhaps per diems. Therefore, the overall goal shifts from minimising labour costs to maximising the tasks completed (Krstikj et al. 2021). Another key difference between TLA and VLA is the reliability of the workforce. Without significant remuneration or an employment contract, volunteers have no obligation to be available for work (Whittaker et al. 2015). Especially when dissatisfied with the assigned tasks or the amount of idle time, volunteers may decide to withdraw their help (Garcia et al. 2018). These particular characteristics inherent in the management of SV have led to extensive research into the psychological, motivational, and demographic aspects of volunteering (Einolf 2018). However, despite this general interest, the management of SV has received very little attention in the field of operational research (Sampson 2006).

The additional capacity of human resources provided by volunteers can be particularly valuable during disasters. Emergency response in disaster situations differs in various aspects from everyday emergency response (Altay and Green 2006) and poses its own unique challenges. Several articles have already been published analysing the existing literature in the field of Operational Research (OR)/Management Science (MS) addressing these challenges. One of the first reviews was written by Altay and Green (2006), who reviewed the literature up to 2004. This review was followed by several other reviews, including Galindo and Batta (2013), Özdamar and Ertem (2015), Kovacs and Moshtari (2019) or more recently Farahani et al. (2020). Despite their broad focus on various aspects of disaster management, none of the reviews explicitly addresses volunteer management. This gap in the literature is partially addressed by Ozdemir et al. (2022), who conduct a structured literature review focusing on volunteer location, allocation, and assignment. However, as the articles reviewed are limited to one of the three tasks mentioned, they only cover a subset of the decisions faced by emergency managers.

In addition to the literature in the field of OR/MS, the issue of volunteer management has also received attention in the field of information systems, particularly in association with the design of DSS. To guide the development of a DSS, L. S. Fernandez et al. (2006) recommend a system-based approach. For an in-depth evaluation of Volunteer Management Systems (VMS), Schonbock et al. (2016) develop a reference model and conduct a detailed comparison of seven distinct VMS. In a broader context, Betke et al. (2023) introduce a taxonomy that provides a comprehensive overview of these systems, facilitating their classification and selection based on relevant characteristics.

Apart from articles generally supporting the design of DSS, several authors have also contributed to the development of such systems. Among others, Fajardo and Oppus (2010), Rauchecker and Schryen (2018), Razali et al. (2019) and Patrisina et al. (2021) outline approaches to building DSS in the context of disaster management. A comprehensive documentation of the entire design approach is provided by Lindner, Betke, et al. (2017), Lindner, Kuehnel, et al. (2018) and Betke (2018). With a focus on agent-based simulation, Lindner, Betke, et al. (2017) identify 25 relevant attributes of spontaneous unaffiliated volunteers. Building on this work, Lindner, Kuehnel, et al. (2018) present a conceptual model for simulating volunteer behaviour, demonstrated in an artefact in Betke (2018).

Despite the strong interconnection between these two fields, there is a limited body of literature addressing the integration of OR/MS models into DSS. Conversely, the information system literature tends to concentrate on the technical implementation of DSS, neglecting the exploration of models guiding specific decisions.

Our distinctive contribution lies in a systematic literature review providing a comprehensive overview of existing models designed to enhance decision-making regarding volunteers in disaster situations, with a particular focus on their integration into DSS. Furthermore, our review extends the scope of Ozdemir et al. (2022) beyond location, allocation, and task assignment to encompass all potential aspects decision-makers might encounter in volunteer management pre- and post-disaster. We also include models designed for slow-onset disasters, and consider the actions taken during these events as part of the post-disaster phase.

METHODOLOGY

To provide an accurate overview of the currently existing literature, we conducted a systematic literature review and present the results according to PRISMA 2020 (Page et al. 2021). We searched two databases, Scopus, and Web of Science, using the following query to search by title, abstract and keywords: *volunteer* AND (disaster* OR crisis*) AND (optimi* OR alloc* OR quanti*)* and restricted the language to English. This query led to 365 results in Scopus, and 249 results in Web of Science. Additionally, to obtain a complete list of articles related to volunteer management within the field of OR/MS, we performed a second search in Web of Science with a more general query: *volunteer* AND (disaster* OR crisis*)* and restricted the results to those articles linked to the category of "Operations Research and Management", again considering only publications written in English. This search yielded to 43 hits. We then removed 227 duplicates as well as notes and editorials, conference reviews, books, and book chapters. Eventually, 397 articles remained for screening. After reviewing titles and abstracts, we excluded papers that did not focus on volunteer management in disasters, leaving 80 publications for further screening. Out of these, five publications could not be retrieved and were therefore excluded. During the full-text screening, we included all articles that addressed decision-making related to volunteers in disaster situations, while excluding those related to non-disaster situations, such as regular emergency scenarios, or that lacked a model supporting volunteer-related decisions. Furthermore, we opted to exclude the paper authored by Gutjahr and Viswanath (2020) due to its lack of consideration of the characteristics of volunteers highlighted in the previous section. Although their assumption might be valid in certain scenarios, decision-makers adhering to such assumptions could alternatively use models developed for general work assignment problems. Based on the 29 papers initially selected, we conducted a forward and backward search to ensure the inclusion of all relevant papers. In this process, we identified two additional articles, for which we also performed a forward and backward search, where, however, no other relevant articles where identified. A visual representation of the workflow is outlined in Figure 1.

Similar to other fields of disaster management, such as casualty management (Farahani et al. 2020), the potential of volunteer management has only recently gained attention. Despite the limited number of publications, interest has remained constant with a few publications per year. Figure 2 depicts the timely distribution of the articles.

The diversity of fields related to volunteer management is also reflected in the number of different journals and proceedings in which the articles were published. In total, the 31 articles were published in 24 different journals and proceedings, ranging from OR-related journals such as the European Journal of Operational Research to journals and conferences more closely related to computer science such as the International Journal of Advanced Computer Science and Applications.

Based on the questions addressed in the articles, we have identified seven different decision areas for emergency management. These fields include predicting the number of SV needed, hiring/admitting volunteers, training volunteers to acquire new skills, pairing volunteers, locating them in different geographical areas, and allocating them to tasks and queues. Figure 3 shows the distribution[1]. The most studied area is the assignment of volunteers to tasks, with more than half of the selected articles addressing this aspect. Some papers propose an approach to the hiring/admission of volunteers, their location and allocation to queues. The aspects of prediction, training, and pairing, however, are hardly addressed in the literature. Table 1 provides a brief overview of the selected articles.

[1]Note that some articles refer to two areas and are therefore counted twice.

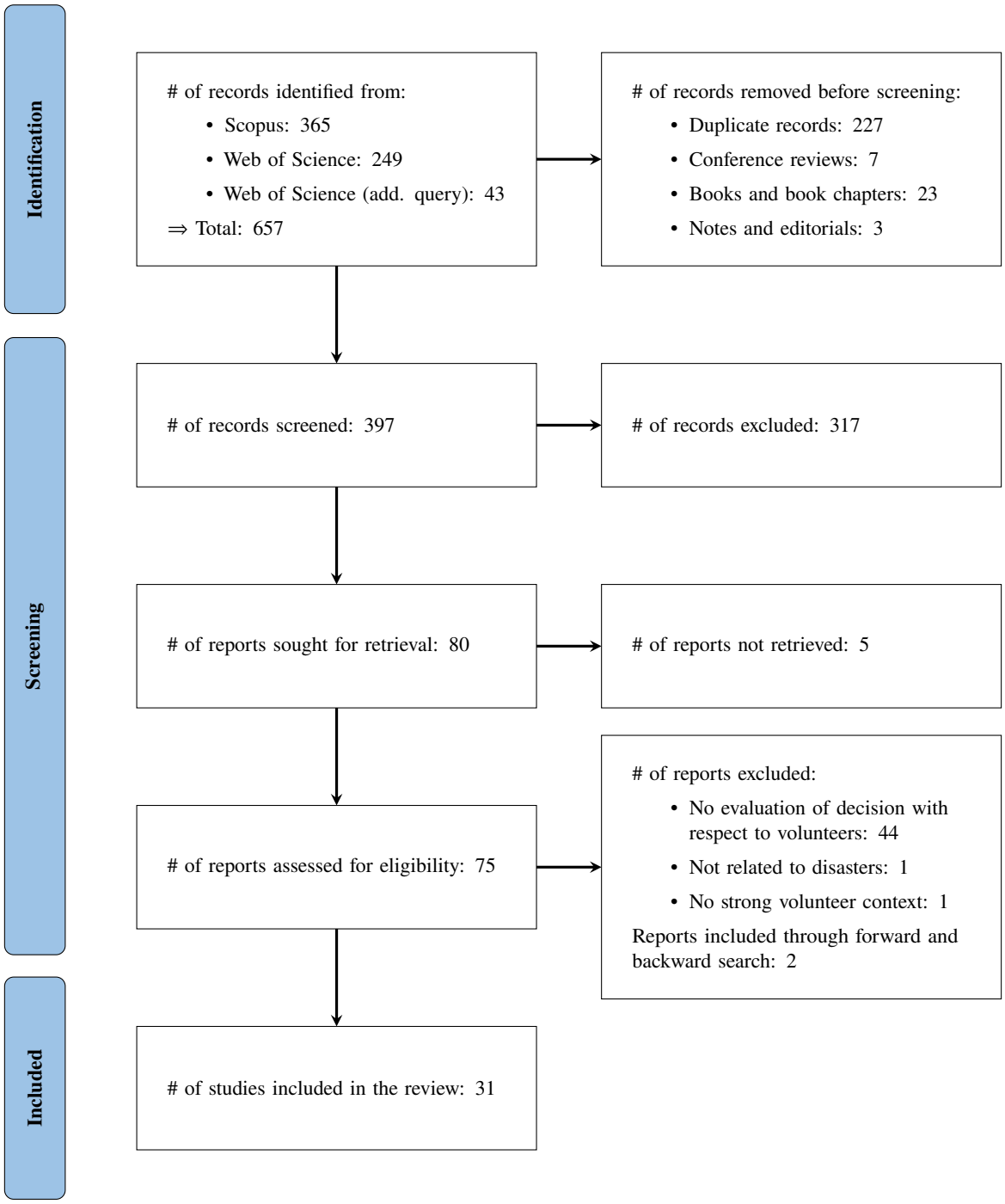

Figure 1. Review process mapped to PRISMA 2020 (following Page et al. 2021)

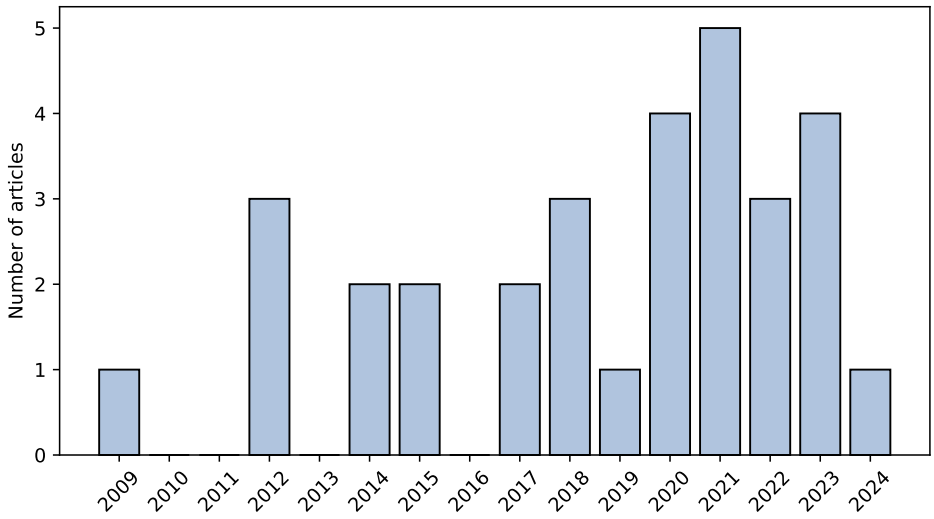

Figure 2. Timely distribution of papers

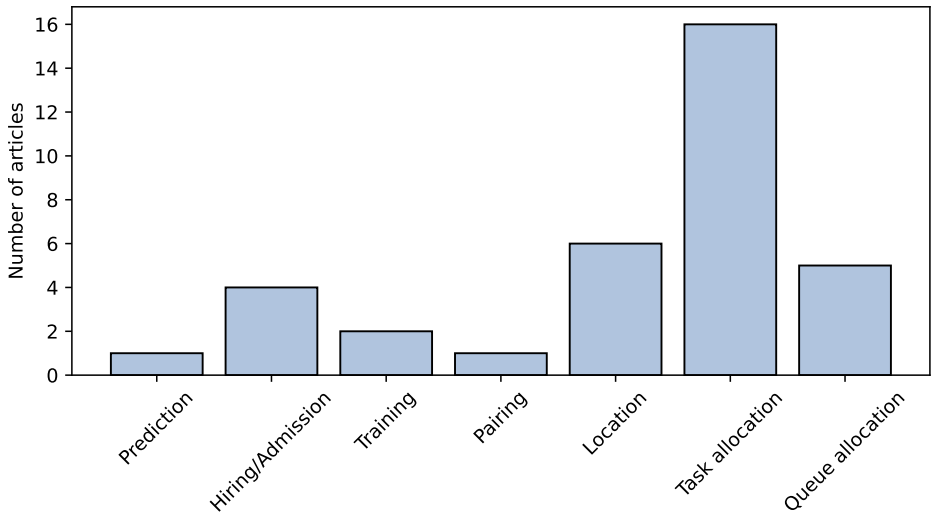

Figure 3. Emergency management decisions

The columns in "Major Decision" identify the key emergency management decisions as introduced above. The columns in section "Objective" specify the modelling objectives, which correspond to the objective functions for mathematical models and the primary evaluation metrics for other methods such as simulations. The column "Preprocessing" indicates whether the authors suggest data transformation actions. These actions can either facilitate data collection (e.g. to derive the demand at a particular location) or be necessary for the model (e.g. to calculate certain metrics). The applied methodologies are detailed in the "Methodology" section. A more extensive review of the papers follows in the next section.

Table 1. Overview - Min: Minimise, Max: Maximise, Opt demand / tasks: Min unfulfilled demand / Max (weighted) fulfilled tasks, Opt satisfaction: Min dissatisfaction (preference, skill, idle time) / Max satisfaction, CTMDP: Continuous time Markov Decision Process

Article	Major decision							Objective									Preprocessing	Methodology							
	Prediction	Hiring/Admission	Training	Pairing	Location	Task allocation	Queue allocation	Opt demand / tasks	Min deviations from demand	Min waiting time	Min reallocation	Max equity	Min required volunteers	Min attrition / rejection costs of volunteers	Opt satisfaction	Min travel cost / distance	Min infeasibility		Linear programming	CTMDP	Agent-based simulation	System Dynamics	Goal Programming	Machine Learning	Heuristics	Other
Falasca, Zobel, and Fetter 2009						x		x							x				x							
Aman et al. 2012 [2]						x			x														x			
Arai et al. 2012					x											x			x							
Falasca and Zobel 2012						x		x							x				x							
Alwahishie and Taaffe 2014						x									x						x					
Lassiter, Alwahishie, et al. 2014			x			x		x					x	x	x				x							
Lassiter, Khademi, et al. 2015			x			x		x									x		x							
Pielorz and Lampert 2016					x								x					x	x							
Mayorga et al. 2017							x	x												x						
Pielorz, Prandtstetter, et al. 2017					x								x					x	x							
Garcia et al. 2018						x		x			x								x							
Rauchecker and Schryen 2018						x		x										x	x							
Sopha and Asih 2018						x		x														x				
Urrea et al. 2019		x		x				x													x					
Abualkhair et al. 2020							x			x											x					
Ozen and Krishnamurthy 2020							x	x												x						
Yang et al. 2020					x											x		x	x							

[2] Only referring to the humanitarian aid workforce's assignment problem

Table 1 Continued. Overview - Min: Minimise, Max: Maximise, Opt demand / tasks: Min unfulfilled demand / Max (weighted) fulfilled tasks, Opt satisfaction: Min dissatisfaction (preference, skill, idle time) / Max satisfaction, CTMDP: Continuous time Markov Decision Process

Article	Major decision							Objective									Preprocessing	Methodology							
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Zayas-Cabán et al. 2020		x					x			x			x	x						x						
Kebriyaii et al. 2021		x											x						x							
Krstikj et al. 2021					x							x						x							x	
Paret et al. 2021							x			x										x						
S.-Q. Chen, Wang, et al. 2021						x									x			x	x							
S.-Q. Chen, Zhang, et al. 2021						x									x			x	x							
L.-T. Chen and S.-Q. Chen 2022						x									x			x	x							
Moug et al. 2023		x														x			x							
Schmidt and Albert 2022						x		x							x				x							
Sperling and Schryen 2022						x		x				x							x							
S.-Q. Chen and Bai 2023	x																	x					x			
Rabiei et al. 2023						x		x							x			x								x
Zhong et al. 2023					x											x		x	x							
Xue et al. 2024						x									x			x								x

RESULTS

Prediction

To manage volunteers efficiently and avoid a scenario where too many volunteers are deployed and hinder emergency response, emergency managers may first be interested in estimating the number of volunteers required. Prediction models can be useful to support this estimation. S.-Q. Chen and Bai (2023) address this problem and present an approach using machine learning models to predict the damage and derive the number of required volunteers. However, a significant limitation of this model for decision-makers is the focus on typhoons. Additionally, the model was only trained on data from the Philippines, so it is questionable to what extent this kind of model can be applied to a wider range of disasters around the world. Moreover, the authors are not very transparent about their final model parameters, limiting their article's relevance for practitioners. Despite these limitations, the approach described in the article can serve as a guideline for the development of similar prediction models for other types of disasters.

Hiring and Admission

Once the emergency managers can estimate the number of volunteers required, decisions must be made on how many and which volunteers to "hire" or to admit/reject. This problem has been addressed in several papers. At a higher level, Kebriyaii et al. (2021) present a linear optimisation model with the objective of minimising the total costs of the supply chain and casualty management. In addition to the costs of facility location, transportation and inventory, these costs also include the costs of volunteer deployment, e.g. per diem. Although this model does not exclusively focus on volunteers, but rather incorporates them in the general model, it can support emergency managers at a higher decision level.

On a more individual level, Moug et al. (2023) provide a linear mathematical model to decide which volunteers to hire for evacuating people. They propose a two-stage model in which the decision of which volunteer to hire is made before the disaster hits, while the demand for evacuation rides is only known after the disaster has hit. Thereby, the objective is to minimise the costs associated with hiring volunteers and the expected travel costs. The authors present several approaches to solve this rather general model, allowing a practical implementation in a DSS.

Rather than focusing on the cost, but instead on the time required to fulfil "orders", Urrea et al. (2019) present a model to support emergency managers in deciding whether they should allow for congestion in different ranges of supply and demand. Although the authors consider a charity warehouse belonging to a faith-based organisation in their article, we believe that the assumptions regarding volunteers can be translated to SV. Their contribution is twofold, addressing both the question of allowing for congestion and team composition. The presented approach can be useful for emergency managers to determine the optimal number of volunteers per task, especially in spatially restricted areas.

The question of whether SV willing to work should be admitted or rejected upon arrival is addressed by Zayas-Cabán et al. (2020). The authors analyse a queuing model with the goal of minimising the holding costs for customers, which are assumed to be linearly related to the queue length, the holding costs for volunteers (e.g. costs for equipment and food), and the rejection costs for volunteers. In their model, volunteer managers first have to decide whether a volunteer is admitted. If this is the case, the volunteer is then assigned to one of the queues and can be reassigned at any time. The model is formulated as a continuous-time Markov decision process to solve these questions optimally. While this approach could be implemented in a DSS to provide the optimal answer depending on a given state, i.e. the number of volunteers and "customers" in the system, the authors are aware that in a disaster situation simple policies might be more practical. Therefore, they propose heuristic admission policies to decide whether volunteers should be admitted. While one of the policies only requires the current number of volunteers in the system, the authors also propose more advanced policies that additionally consider the expected workload.

Addressing the problem of hiring and admitting volunteers from very different angles, the presented models can support emergency managers at various levels of decision-making both before and after the disaster has hit. From a cost perspective, the model presented by Kebriyaii et al. (2021) could be integrated into financial decision support tools, as they require several financial metrics as input. In addition to financial metrics, the model presented by Moug et al. (2023) also requires information about the geographic location of potential drivers and evacuees needing a ride. To collect this information, databases of potential volunteers, people requiring help, and geographical information systems can support emergency managers in the decision process. To decide on a level of congestion based on the model presented by Urrea et al. (2019), decision-makers require up-to-date estimates of demand, availability of volunteers and current volunteers in the system, as well as average service times depending on the volunteers' skill level and pairing. Linking this model to sensor data can support the model's accuracy with respect to the real-life representation and thus improve decisions. The same applies to the model presented by Zayas-Cabán

et al. (2020). Moreover, the heuristic policies proposed by the authors require not only data to tune the model, but also the constant monitoring of certain metrics. In addition to the number of volunteers currently in the system, the more advanced policies further require an estimate of the current workload. To keep track of these numbers, especially with multiple queues and sites, monitoring and tracking systems could assist emergency managers to continuously evaluate these metrics and adjust their policies.

Training

Acknowledging the different skills of volunteers and the possibility of training volunteers, especially when considering longer-lasting tasks such as reconstruction work, represents another potential decision point. In our review, we identified two articles addressing this aspect. In the earlier article, Lassiter, Alwahishie, et al. (2014) propose a linear optimisation model in which volunteers with different skill levels have to be assigned to different tasks requiring different skill levels. While some volunteers already have some skills, emergency managers may also decide to train volunteers to acquire new skills. This, however, limits the efficiency of volunteers during their training, affecting the tasks completed for a particular skill level and therefore the future number of tasks for a particular skill. It also influences the future availability of skilled volunteers and hence their dissatisfaction if these skills are not used. A similar approach is presented in Lassiter, Khademi, et al. (2015). While their model differs slightly in the way of how they deal with skill mismatch, the assumptions regarding training are similar.

Both papers propose a solution for emergency managers to consider the medium-term decision on volunteer training. Since both models need an estimate of the skills required for tasks over a longer horizon as well as an overview of the current skills of volunteers, applications collecting this data could support the usage of these models by providing an up-to-date database.

Teaming

Some tasks in disaster response should be carried out in teams. Surprisingly, little research has been performed on this topic. As introduced above, Urrea et al. (2019) address the question of the optimal team composition in their model for a charity warehouse. The authors differentiate between two levels of experience, “experienced” and “inexperienced”, and consider various options of pairing. They show that depending on the level of congestion, demand and available volunteers, different pairing options are preferable to fulfil as many orders as possible.

This model can serve as an initial guideline for emergency managers to decide on how to form teams for specific tasks. However, it is limited to teams of two, which may be applicable for certain tasks such as order-picking but may not be a suitable team size for other tasks.

Location

When volunteers are needed at different sites, emergency managers first face the decision to locate the volunteers. A classic model for this task is presented by Pielorz and Lampert (2016). They adapt a facility location model to minimise the number of volunteers needed, with the restriction that each demand point is covered by a minimum number of volunteers reaching that location within a certain threshold. Although the model is relatively general, it allows emergency managers to analyse the influence of different parameters, such as the required number of volunteers per demand point, on the spatial distribution of volunteers. The authors then extended the case study (Pielorz, Prandtstetter, et al. 2017) and replaced the previously used “flying distance” with a more realistic “driving distance”. Although this study does not provide any additions to the mathematical model itself, it gives insights into the differences in locating volunteers when different distance metrics are used.

Krstikj et al. (2021) propose a method to distribute volunteers equitably across neighbourhoods depending on an index reflecting marginalisation. They first suggest an approach to calculate a marginalisation index before presenting a heuristic approach to support the allocation of volunteers to neighbourhoods. Although their case study is based on a pandemic situation and therefore focuses particularly on elderly citizens requiring help, the model can also be adapted to other disaster situations.

A solution approach to match individual volunteers with victims is proposed in the article by Yang et al. (2020). The authors present a heuristic multi-agent reinforcement learning scheduling algorithm to minimise the total time (distance) while ensuring that at least one volunteer rescues each victim. Zhong et al. (2023) propose to use civilian vehicles for evacuation. The authors present a prototype for a constraint-based recommender system that matches volunteers with a suitable vehicle and people who need to be evacuated to a shelter based on constraints on vehicle type and experience, with the objective of minimising the total evacuation time. A similar problem is addressed by Arai et al. (2012). In the suggested approach, volunteers can propose “bids” on disabled persons to help, with the

costs of the bids depending on distance and health status. Using a linear optimisation model, the bids resulting in the minimum overall costs are then selected so that each disabled person is rescued.

The above-mentioned papers propose very different approaches for the spatial allocation of volunteers, ranging from heuristics to linear programming and reinforcement learning. To address the need of up-to-date input data, Yang et al. (2020) suggest analysing data from social media to identify the geographical locations of victims and potential volunteers. However, as regulations regarding access to data from social media platforms potentially change over time, this strategy is not entirely risk-free for emergency managers.

Task Allocation

The vast majority on studies addresses the question of how to allocate volunteers to tasks. One of the objectives in most of these models is either to maximise completed tasks (minimise the uncompleted tasks) or maximise volunteer satisfaction (minimise the dissatisfaction) (Table 1), sometimes in combination with additional objectives. To match the volunteers and the tasks, authors considered different criteria, such as the priorities set by the decision-makers, the volunteers' skills, or their preferences. In the remainder of this subsection, each criterion will be described in more detail.

Collective Level

On a collective level, Sopha and Asih (2018) present a system dynamics model that visualises the impact of allocation policies. In their model, decision-makers must decide on the ratio of volunteers to be assigned to each of the two available tasks, taking into account the dependency between the two tasks. While the model does not support individual decisions, it visualises the overall impact of different assignment policies.

For decision-makers, such a model can be particularly useful when preparing for potential disasters and evaluating different policies. For practical application, future research could therefore focus on linking such a model to databases to retrieve relevant parameters and integrate it into DSS. From an academic perspective, the model could be extended to multiple tasks and their interaction to consider more complex relationships between the tasks.

General Models

Most models aim to support assignments at an individual level. A relatively broad model that addresses this issue is presented by Garcia et al. (2018). The model's objective is to maximise the benefit of allocating resources to tasks (primarily, but not only, volunteers), while also accounting for conflicts and dependencies between different resources. To adapt the model to more specific cases, the authors propose additional constraints, including maximum time limits for volunteers, the allocation of consumable resources, the combination of volunteers with other resources and the inclusion of transport costs.

Rather than maximising the benefit, Falasca, Zobel, and Fetter (2009) present an approach to optimise the allocation of volunteers to tasks by balancing shortage costs due to unfulfilled tasks and deviations from volunteers' preferences and skills with respect to different availability of volunteers and the costs associated with volunteers, e.g. per diem allowances. The model is then extended by Falasca and Zobel (2012) to also account for different group sizes.

Another model that aims to minimise penalty costs caused by a shortage of volunteers as well as deviations from preferences and skills is presented by Aman et al. (2012). Yet, the authors acknowledge that volunteers can be a scarce resource, resulting in an infeasible model. To prevent such a scenario, the authors therefore suggest first solving a model that minimises the volunteers' scarcity before solving the actual model.

These models provide decision-makers with relatively general models for allocating volunteers to tasks, covering the most important aspects. However, even for these models, several parameters need to be known in advance, such as the estimated tasks, the volunteers' preferences, and their skills. In a chaotic disaster situation, it is questionable to what extent these parameters can be estimated or how they could be collected, especially if volunteers arrive continuously. Future research could therefore focus on developing robust practical applications for data collection and optimisation that can be used in disaster situations. To account for the dynamic changes in both tasks and volunteers, another stream of research could focus on developing heuristics and policies that can be applied when tasks and volunteers arrive randomly over time.

Priorities by Decision-Makers

In the aftermath of a disaster, tasks may vary not only in their subjective attractiveness to volunteers, but also in their priority for emergency managers. A model that incorporates these priorities is presented by Rauchecker and Schryen (2018). To ensure that each task is fulfilled at least to a certain extent, the model balances the workload across the tasks by maximising the weighted minimum workload. Moreover, the authors also include constraints to enforce volunteers to work on a single task for a minimum amount of time with respect to their skills and timely availability to avoid chaotic situations and inefficiencies resulting from set-up times.

A strong focus on the different priorities of various tasks is also evident in the model of Sperling and Schryen (2022). Distinguishing between strong and weak priorities, their model aims to assign as many volunteers as necessary to strongly prioritised tasks, while balancing volunteers for weakly prioritised tasks based on quotas. In addition to the time availability and skills, the authors also limit the allocation to non-preemptive schedules.

A model with a special focus on emergency departments is presented by Rabiei et al. (2023). The authors estimate the importance of volunteers' unmet needs and the degree of unsatisfied preferences by proposing a fuzzy interference system. These two metrics are then minimised in a linear mathematical model constrained by the maximum assignment of each volunteer to a single task. To account for the multi-objectivity, the authors present two evolutionary algorithms.

Balancing volunteer allocation between tasks of varying importance can pose a challenge for decision-makers. The models presented above provide different approaches to address this problem. For the practical implementation of these models, several research directions are possible. One potential direction could be the generalisation of these models, as all the authors acknowledge that their model is only tuned for a specific disaster type. Moreover, future research could also put emphasis on the relationship between tasks (e.g. predecessor relationships), or the change in importance over time.

Skills

While most models assume that skills are a fixed parameter, some authors also consider the possibility of training volunteers "on the job". Two models incorporating this option are by Lassiter, Alwahishie, et al. (2014) and Lassiter, Khademi, et al. (2015). As introduced above, both articles present an approach in which volunteers are assigned to tasks according to their skills, but also have the opportunity to acquire new skills through training. While those two models do not really differ in the approach with respect to the training aspect (as discussed above), a significant difference is the mismatch of volunteers' skills and tasks. Lassiter, Alwahishie, et al. (2014) allow for a certain percentage of mismatches, i.e. volunteers are assigned to tasks below their skill level as determined by the emergency manager. On the other hand, Lassiter, Khademi, et al. (2015) do not restrict mismatching by a threshold but assume that the probability of a volunteer leaving depends on the mismatch of skills and thus influences the availability of future volunteers. Moreover, they also associate costs with the mismatch, and include these in the objective function.

To account for the dissatisfaction arising from the mismatch of qualification, Alwahishie and Taaffe (2014) model the problem using agent-based simulation. Their main assumption is that volunteers abandon earlier when dissatisfied, with dissatisfaction arising from both idle time and mismatch of qualification. While the presented agent-based simulation does not suggest an optimal policy, it supports the comparison of different policies with respect to the volunteers' satisfaction and task completion.

By considering the volunteers' skills, decision-makers can increase not only the efficiency, but also the volunteers' satisfaction. While this approach may seem promising in theory, as discussed above, keeping track of the different qualifications and preferences of all volunteers could pose a problem in the aftermath of a disaster. In addition to the research directions already mentioned in the corresponding subsection, future research could also focus on extending the existing models by including bilateral preferences (as introduced in the next paragraphs), e.g. to also consider the preferences of decision-makers for both volunteers performing a task and volunteers being trained.

Bilateral Preferences

Not only volunteers can have preferences regarding tasks, but also decision-makers regarding the volunteers carrying out these tasks. S.-Q. Chen, Wang, et al. (2021) and S.-Q. Chen, Zhang, et al. (2021) address this problem and present a two-sided matching model, in which not only volunteers can place their preferences for different tasks, but also task leaders can indicate their preferences for different volunteer teams. The problem is further extended by considering that volunteers/task leaders may have strong preferences for or aversions to certain tasks/volunteer groups but may not have a preference (positive or negative) for most of the tasks/volunteer groups. To account for the uncertainty that this problem entails, the authors propose an evidential reasoning approach.

The concept of bilateral preferences is also addressed by L.-T. Chen and S.-Q. Chen (2022). In contrast to S.-Q. Chen, Wang, et al. (2021), however, the authors consider individual volunteers (instead of teams) and allow several volunteers to perform several tasks. The optimal allocation is then determined based on a linear optimisation model with the bilateral satisfaction as input.

To collect the preferences of volunteers and their suitability for tasks, emergency managers may use linguistic questionnaires. Xue et al. (2024) therefore propose a method to derive a matrix representing perceived satisfaction. Using this matrix as input, the authors present an algorithm based on foreground theory, differential evolutionary algorithms, and Dempster-Shafer theory to match volunteers to tasks.

The concept of two-sided matching is also included in Schmidt and Albert (2022). However, the suggested approach is unique in that volunteers are offered a list from which they can select a task, rather than assigning them to a task. The authors further extend the model to be also applicable in a multi-epoch setting, and to include individual acceptance probabilities, resulting in customised task recommendations.

For the practical application of the proposed approaches, time might be a relevant factor. Volunteers and decision-makers might be willing to define a few preferences but might be discouraged from filling in long questionnaires. Therefore, future research could focus on predicting preferences based on minimal input from users. Moreover, in addition to preferences for certain tasks, volunteers may also have preferences for collaboration with other volunteers or for certain spatial areas. Including these aspects could increase the volunteers' satisfaction, and thereby, decrease the chance of volunteers abandoning.

Allocation to Queues

Closely related to the allocation of volunteers to tasks is the allocation of volunteers to queues. In these models, queues can either represent counters serving people (disaster-affected people or donors), or assembly lines representing different tasks. The focus of these models is mainly on uncertainty on both sides, on demand, i.e. the arrival of tasks, and on the arrival and abandonment of volunteers. With the exception of the model proposed by Abualkhair et al. (2020), all authors formulate the problem as a continuous time Markov decision process. However, the authors acknowledge the limitations in a chaotic disaster environment, and thus propose practical heuristic policies.

Mayorga et al. (2017) present a problem in which the number of different tasks is fixed and deterministic, while the arrival and abandonment of volunteers and the service rates are stochastic. Each of the different queues is thereby characterised by the number of tasks, the service rate and the maximum number of volunteers that can be allocated to this queue. This problem is then generalised by Paret et al. (2021) to a stochastic arrival of tasks following a Poisson process with rate α_i.

As already introduced above, Zayas-Cabán et al. (2020) analyse policies for admitting volunteers to a system, and once admitted, assigning, and reassigning them to different queues. These queues differ both in their service time and in their urgency, approximated with holding costs. While several policies are proposed for the decision to admit volunteers, the authors can prove that even for different settings, such as volunteers arriving in batches or working collaboratively on a task, a simply $c\mu$ policy leads to an optimal solution.

The question of how to allocate volunteers to sort donated goods is addressed by Ozen and Krishnamurthy (2020). The authors consider solicited and unsolicited donations, assuming that solicited donations contain only high-priority goods, while unsolicited donation contain a some high-priority goods but also non-priority goods. They aim to support emergency managers in deciding how to allocate a limited number of volunteers to those two queues in order to maximise the throughput of high-priority goods while preventing congestion from unsorted, unsolicited goods.

Another problem related to donations is presented in Abualkhair et al. (2020). The authors model two different queues, one for accepting donations and one for distributing them to beneficiaries. In the scenario where inventories are scarce, the queue of beneficiaries not only depends on the number of volunteers allocated, but also the goods received from donors (and therefore the other queue). The authors then propose a practical solution by suggesting four different heuristic allocation policies.

The models presented can help practitioners to decide on how the allocation of volunteers to queues. In disaster planning, simulating the queues and analysing the consequences of different policies can improve the disaster response. However, this requires a good estimation of parameters such as the arrival or service rates. In the aftermath of a disaster, the practical (heuristic) policies provide a fast decision support. Yet, depending on these policies, different data is required to describe the current state is required. In a chaotic environment, monitoring and tracking systems could support this collection.

FUTURE RESEARCH

As research on the management of volunteers in disaster situations has only been published in recent years, future research can advance all decision problems by extending existing approaches as well as developing new ones.

To the best of our knowledge, there is only one article by S.-Q. Chen and Bai (2023) that addresses the prediction of available volunteers. This leaves room for further research. In addition to extending this model to other disaster types and areas, future research could therefore focus on a more general prediction model that is applicable to multiple disaster types. Another stream of research could shift the focus from the damage to the specific volunteer tasks. S.-Q. Chen and Bai (2023) acknowledged the relationship between the number of volunteers required and the damage caused by the disaster but had to simplify this ratio due to a lack of theoretical background. Future research could therefore focus on the expected number of different tasks depending on the damage and derivation of the number of volunteers required.

There are multiple research directions to further investigate the hiring and admission of volunteers. One potential future direction would be the short-term costs and medium- and long-term effects of rejecting volunteers. While Zayas-Cabán et al. (2020) consider "rejection costs" in their model to account for the negative consequences of not admitting a volunteer, future research could place more emphasis on the impact of future volunteer availability. In Kebriyaii et al. (2021) and Moug et al. (2023), this effect could be included by also considering the costs if volunteers are not used, while in Urrea et al. (2019) and Zayas-Cabán et al. (2020), the future arrival rates may depend on the rejection rates. Moreover, future studies could also extend the presented models by including heterogeneous characteristics of volunteers such as experience, skill, or other personal attributes in the decision on how many and which volunteers should be admitted.

A potential future research direction for volunteer training would be the consideration of different, non-hierarchical skills. Volunteers may be highly skilled in one area but lack skills in another. This could result in a volunteer assigned to a task having various levels of satisfaction and efficiency depending on the nature of the task and the skills required. Another future area of research could be the preferences of volunteers in terms of acquiring different skills. In the medium term in particular, the provision of training in the skills favoured by volunteers could have an impact on volunteer satisfaction and therefore on the future availability of these trained volunteers.

Future research on teaming could extend the model by Urrea et al. (2019) to larger team-sizes and more pronounced experience levels. Another potential research direction could also focus on the medium and long-term consequences of pairing. Inexperienced volunteers could benefit from being paired with an experienced volunteer and become an experienced volunteer more quickly than if they were paired with an inexperienced member or vice versa. In the early days, emergency managers may therefore opt for non-optimal pairing strategies in the short-term, allowing them to increase the proportion of experienced volunteers in the medium and long term. For SV, this can be the case a few days or weeks after the disaster.

Several options are available for further research on location planning. First, the model presented by Krstikj et al. (2021) could be extended to more general disaster situations to provide emergency managers with a toolbox for different benchmarks to measure a neighbourhood's marginalisation. Moreover, another research stream could also focus on spatial allocation when tasks differ. Future models could also consider scenarios in which volunteers can easily transfer between locations, but at the costs of time lost for travelling, and scenarios in which this is not possible if the distances between different locations exceeds a certain threshold, thus extending the models presented by Pielorz and Lampert (2016) and Pielorz, Prandtstetter, et al. (2017). To account for the dynamic nature of disasters, future research could apply the approaches by Yang et al. (2020), Zhong et al. (2023) and Arai et al. (2012) to dynamic situations, where the availability of drivers, the need for evacuation and the accessible routes are constantly changing over time. This also raises the question of accurate data collection during a disaster. While some data could be collected in advance, as in Zhong et al. (2023), a relevant part of the data can only be collected once the disaster has hit. To use the proposed approaches efficiently, future research should therefore focus on the collection and integration of this data during a disaster.

With the large variety of models for task allocation, decision-makers have an extensive choice for the combination of different objectives and parameters included. Although most authors approached this question in a relatively similar way using linear programming with the objective of maximising (minimising) the (un)fulfilled tasks or maximising (minimising) the volunteers' (dis)satisfaction (Table 1), the models vary in their focus and emphasis different criteria. While there are still future directions to extend these models from a theoretical perspective, it is questionable whether these extensions would add significant practical value. Therefore, instead of extending existing models, future research could focus on tackling the problems with techniques other than linear programming that account for dynamic environments and also provide solutions for larger instances in a short time.

Some authors have already addressed the managerial implication e.g. by extending their model as in Sperling and Schryen (2022). Answering the question of how to obtain the input data, particularly regarding the volunteers' skills, preferences, and time availability, as presented in Xue et al. (2024), could also simplify the integration of models into real applications. Another approach that could enhance practicality is to give volunteers some degree of choice, as in Schmidt and Albert (2022). To bridge the gap between theory and practice, future research could focus on comparing the usability and practicability of different approaches in disaster situations and proposing "best practises" for future development of DSS.

Regarding the allocation to queues, further research could include different service times based on the volunteers' skills. In particular, if the queues represent specific tasks, as in Mayorga et al. (2017) and Paret et al. (2021), the service time per volunteer may depend on skills and experience (as in Urrea et al. 2019). In addition, the (re)allocation of volunteers to queues may also include set-up times (which can also depend on skills or whether the volunteer is assigned to the queue for the first time). Furthermore, especially when dealing with people as customers as in Zayas-Cabán et al. (2020), Ozen and Krishnamurthy (2020) or Abualkhair et al. (2020), future research could address the question of fairness between queues with different priorities and thresholds to balance urgency and equity.

CONCLUSION

In this paper we presented a structured literature review of models to support decision-makers in coordinating volunteers in a disaster's aftermath. We identified 31 articles dealing with decisions ranging from predicting the number of volunteers needed to assigning them to tasks and queues. While the literature on task allocation is relatively extensive (Table 1), there is still a lack of research, particularly in the areas of prediction, training, and teams. Moreover, a variety of articles present a deterministic model in which the number, availability, and skills of volunteers and the exact demand is known in advance. This assumption may not hold true in reality, making it difficult for emergency managers to apply these models in the real world. By integrating the two areas of OR/MS and information systems more closely, future research could focus on both the scientific contribution and practical implementation. In particular, the development of versatile models that can be applied to a variety of disaster situations could increase their practical value and facilitate their application.

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