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An optimization model for volunteer assignments in humanitarian organizations

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ABSTRACT

One of the challenges facing humanitarian organizations is that there exist limited decision technologies that are tailored specifically to their needs. While employee workforce management models have been the topic of extensive research over the past decades, very little work has yet concentrated on the problem of managing volunteers for humanitarian organizations. This paper develops a multi-criteria optimization model to assist in the assignment of volunteers to tasks, based upon a series of principles from the field of volunteer management. In particular, it offers a new volunteer management approach for incorporating the decision maker's preferences and knowledge into the volunteer assignment process, thus allowing him or her to closely examine the tradeoffs between potentially conflicting objectives. Test results illustrate the model's ability to capture these tradeoffs and represent the imprecision inherent in the work of humanitarian organizations, and thus demonstrate its ability to support efficient and effective volunteer management.

1. Introduction

Humanitarian logistics is one of the most challenging of the logistics domains [1], yet the field has so far received relatively little attention by logistics academics [2–4]. In particular, although the social sciences, economics, and humanities literature have developed a significant amount of work on humanitarian issues, the associated research produced by the decision sciences and operations management communities tends to be much more limited [5]. There is, nevertheless, important work being done in this area, and its significance is gaining more recognition in the broader academic community. These research efforts tend to focus in four specific areas: inventory management [6,7], demand and capacity planning [8,9], facility location [10–12], and transportation and distribution activities [13–16].

One of the humanitarian logistics challenges, which has not received adequate attention, is the difficulty involved in effectively coordinating large numbers of volunteers [1]. Despite the important role played by volunteers in relief and recovery efforts [17], one of the biggest issues that remains is the mismanagement of volunteers [18]. For example, the lack of organization and the lack of clearly defined roles amongst volunteers involved in the rescue and recovery efforts after a cave-in in Barbados in 2007 were cited as major issues that adversely affected the rescue and recovery efforts [19]. Without proper management of volunteer labor (determining where to send the volunteers, what tasks to assign, etc.), volunteers may even become an obstacle to effective disaster management [20].

A volunteer workforce must be managed differently than traditional sources of labor because volunteers are not paid employees. In this sense, volunteers should be assigned tasks based not just on their abilities but also according to their preferences. In order to address these specific needs, this paper develops a multi-criteria optimization model to help balance the level of task fulfillment against the relative necessity to treat volunteers as a renewable resource. The proposed technique provides a decision maker with the opportunity to examine the tradeoffs inherent in managing volunteer labor and to determine the appropriate allocation of resources to meet the organization's goals.

The paper is organized as follows: a review of the relevant literature related to volunteerism and workforce scheduling is followed by an overview of the defining characteristics of the field of volunteer management in a humanitarian context. The volunteer assignment model is then described, and two complementary solution methodologies are compared with respect to their ability to support the appropriate assignment of volunteers in a multi-criteria context. Finally, the paper provides a discussion of the implications and limitations of the research study, and outlines different future research directions.

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2. Background

While employee workforce management models have been the topic of extensive research over the past decades, very little work has focused on the problem of managing the assignment of humanitarian volunteers. With this in mind, our review of the literature focuses on previous volunteerism and workforce scheduling research in this area.

2.1. Volunteer management

Shin and Kleiner [21] define a volunteer as any individual "who offers him/herself to a service without an expectation of a monetary compensation." Volunteer management research has been an important topic in the social sciences, with research areas including the motives for volunteering [22–24], and the relationship of the demographic characteristics of volunteers (such as education and gender [25,26] or age [27]) to present and future commitment levels.

Volunteer retention and the analysis of why people continue to volunteer are also important topics in the volunteer management literature [28,29]. Some of the volunteer management practices that positively influence the retention of volunteers include recognizing contributions and matching volunteers to appropriate tasks. Gidron [28], for example, cites task achievement and the quality of the work itself as factors that could help better predict volunteer retention. Issues such as matching volunteer preferences and the retention of volunteers and can be very relevant when considering how to most effectively manage a volunteer workforce. Such issues play an important role in the development of our decision support model, as will be shown in later sections.

2.2. Labor scheduling

The topic of labor scheduling is becoming increasingly important as the services sector gains more recognition as a large component of the global economy. Relevant reviews of the state of the art in this field include Bechtold et al. [30] and Alfares [31], among others. In terms of solution techniques, it has been noted that the scheduling literature is heavily skewed toward mathematical programming approaches [32]. The relatively large size of some scheduling problems has led to the development of a number of different heuristic methods as well (see, for example, Goodale and Thompson [33]).

As a whole, the operations management literature includes several different application areas related to labor assignment problems. For example, since their inception, scheduling and staffing methods have been applied to areas ranging from airline crew staffing [34] to nurse scheduling [35,36]. In the field of disaster management, Janiak and Kovalyov [37,38] have studied scheduling problems where tasks must be executed by human resources in areas contaminated with radio-active materials. In their model, the authors studied single worker problems with the objectives of minimizing maximum lateness or total weighted completion time.

In the context of scheduling volunteer labor, a search of the literature resulted in three specific articles. The first of these articles, by Gordon and Erkut [39], develops a model to schedule volunteers for an annual music festival. The authors adopt an integer programming formulation that incorporates volunteer preferences and constraints into the model, but they do not explicitly consider the issue of labor shortages. In the case of humanitarian organizations, volunteer labor plays a significant role in the provision of relief aid and assistance for longer-term recovery [20]. However, volunteer labor shortages can become an issue as a result of volunteer mismanagement and high levels of volunteer turnover. A volunteer management optimization model should thus explicitly incorporate the issue of labor shortages in order to help organizations keep shortages to a minimum and increase the effectiveness of their efforts.

The second volunteer scheduling article, by Sampson [40], proposes a goal programming model in the context of optimizing the assignment of reviewers for an academic conference. Sampson's model does consider labor shortages along with volunteer preferences. The goal programming formulation minimizes a series of costs that quantify task shortages, undesired assignments, and the under-utilization or over-utilization of volunteers.

In the third article, Kaspari [41] also proposes a goal programming model that maximizes volunteer's preferences. The two-phase model helps assign volunteers in a bike sharing program. In the first phase, the model determines whether a feasible assignment exists and identifies potential task shortages. In the second phase, the model makes the actual assignment of the volunteers while maximizing their preferences.

In contrast to this other work, our research is focused specifically on the management of volunteers within a humanitarian context. The original idea of scheduling volunteers in this context was first suggested by Falasca et al. [42] in a preliminary form. The contribution of this research is therefore to fully develop a comprehensive assignment model that directly incorporates the relative preferences of the decision maker within the specific constraints and characteristics of humanitarian organizations.

Although our work is similar to that of Sampson [40], in that it incorporates both labor shortages and volunteer preferences into the scheduling process, it extends this previous work in a number of important ways. First of all, we do not assume that volunteer labor costs are insignificant. In many cases, humanitarian organizations will pay *per diem* allowances and cover the transportation of volunteers. For example, after the 2004 Indian Ocean earthquake and tsunami, many NGOs flew in and paid per diems to volunteers from different parts of the world to assist and provide psychosocial support [43]. Similarly, in the case of the Sudanese conflict, NGOs have used local volunteers who receive per diems and incentives [44]. From a modeling perspective, this issue implies that actual scheduling costs should not exceed the available scheduling budget.

Our proposed model also takes the possibility of multiple possible work locations into account, since humanitarian and development aid organizations typically carry out their social missions at different locations simultaneously [45,46]. For example, professionals from different fields of medicine participate in international humanitarian service missions. These volunteers are typically dispersed simultaneously to different sites as members of multidisciplinary teams [47]. A humanitarian volunteer management model should thus consider volunteers' preferences with respect to the location of their assignments.

Similarly, many humanitarian organizations allow their volunteers to sign up either as individuals or as a group [48,49]. That is an aspect that has not been considered in past volunteer scheduling research. For this reason, our proposed model supports the assignment of groups of volunteers, such as corporate or family groups, rather than just individual volunteers. Volunteer groups can help humanitarian organizations accomplish a great deal of work. Groups can be fairly large, as in the case of corporate volunteer groups. Those types of groups can effectively handle certain tasks and can have a major impact in helping achieve recovery goals. In the months following Katrina, for example, groups of volunteers from across the country helped address critical needs in the disaster area such as debris clean-up [50].

Most importantly, however, our proposed solution methodology differs from that of Sampson [40] in its ability to support and explicitly consider the tradeoffs between resource utilization and task fulfillment. For example, our approach easily allows decision makers to visualize the relative impact on volunteer satisfaction of requiring a particular minimum level of task completion, or to determine the relative cost associated with satisfying a given percentage of volunteer preferences. This is accomplished by incorporating the decision makers' expertise into the model itself, through the use of fuzzy membership functions that represent their preferences for each objective. These membership functions provide a simple approach for exploring the consequences that different decisions can have on the outcome of the scheduling process. As such, they can help improve the effectiveness of the decision making process.

3. Characterization of a humanitarian volunteer management model

The primary strategic goals of a humanitarian organization are typically different than those of a for-profit business. Rather than focusing on maximizing revenues, a humanitarian organization will usually seek to improve operations and better support its social mission (i.e., to save lives and alleviate suffering). Even though an objective such as minimizing expenditures may still be relevant for such an organization, they will often balance such concerns against the underlying importance of effectively serving their clients.

Another important difference between the for-profit and humanitarian models has to do with the skills and composition of the labor force. Table 1, adapted from Sampson [40], summarizes how volunteer management problems, in general, differ from paid labor problems with respect to various decision model attributes. These distinctions suggest the need for a mathematical modeling formulation that is significantly different than the traditional formulations for business problems.

Traditional business models assume that the labor force has the required skills to complete a task. In the case of volunteer-driven humanitarian organizations, however, there may be few volunteers who have the required skill levels to complete certain tasks. Alternatively, there also may be volunteers with specialized skills that are either not recognized or not utilized appropriately. In the aftermath of the 2004 tsunami, for example, numerous skilled volunteers from all over the world came together to work for the common good. It was later pointed out that the skills of many of these volunteers were not used as effectively as possible and that "a large number of volunteers became disenchanted because of the lack of organization" [51].

The volunteer labor pool may also include groups of individuals such as fraternal social organizations who have a desire to be assigned tasks as a single group. Faith-based organizations, for example, can help mobilize committed groups of volunteers [52]. Although such groups may agree to be split up, there is a limit to the extent to which this can be done without having a negative impact on the overall satisfaction of the individual volunteers. Furthermore, research has found that organizations that allow groups to volunteer together can be more successful in recruiting [53].

Table 1
Comparison of paid labor and volunteer labor scheduling models.

Model attribute	Paid workforce	Volunteer workforce
Key objective	Maximize profits by minimizing labor costs	Maximize task completion by minimizing shortages
Key constraint	Demand level	Volunteer labor size
Labor pool size constraint	Sufficient/unconstrained	Size of committed labor
Labor costs	Non-zero	Low yet still non-trivial
Labor preferences	Employees' shift preferences may be considered	Volunteers' time and task preferences must be considered
Shortages	Not an issue	Shortages must be balanced among time blocks, tasks and locations

Traditional labor assignment research also typically assumes that a sufficient labor pool is available for the tasks at hand. In contrast, humanitarian organizations frequently depend on a large number of volunteer workers with limited time availabilities in order to accomplish their missions. Unfortunately, the future may become even more challenging for such organizations: it has been claimed that even though the amount of work required in the volunteer sector is growing, the number of available volunteers is not increasing at a comparable rate [24]. It is thus increasingly important for humanitarian and other non-profit organizations to efficiently manage the available volunteer workforce and successfully recruit and retain their volunteer bases.

In the context of providing relief in the aftermath of a disaster, a humanitarian organization may often have limited time to decide how to allocate their volunteer labor. This implies not only that the timing of task assignments is important, but also that the organization may not have the ability to gather large amounts of data about the specific capabilities of their volunteers. Although it would be relatively quick and easy to collect the preferences of volunteers with respect to performing particular tasks, or working during specific periods of time, the data may simply not be available to support Sampson's [40] approach of judging the "cost" to each individual of an undesired assignment, or the "cost" of too many or too few assignments, let alone to individually decide how many assignments are "too many" or "too few" for a given volunteer. Even in the case of longer-term humanitarian operations, when there may be more opportunity to collect and characterize the backgrounds and specific preferences of volunteers, the underlying motivation of those volunteers to provide their time and skills in order to improve the well-being of others would make the relative "cost" of an additional hour of work relatively unimportant to them. With this in mind, the *number* of undesired assignments becomes a more appropriate performance measure, in support of volunteer retention for humanitarian workers, than the overall associated cost of these assignments, regardless of the time-critical nature of the humanitarian context.

Although some humanitarian volunteers may be expected to provide their own meals and housing, the actual monetary cost of assigning a volunteer could also be an important consideration if a *per diem* or basic housing allowance is provided, as discussed above. Although such costs would typically be limited compared to the labor costs of a for-profit business, the limited budget of a volunteer-driven organization can potentially make them an important factor in the organization's decision making process. Any schedule of task assignments in a humanitarian organization should therefore also consider actual budget constraints as a part of the model.

In summary, humanitarian organizations must not only ensure the efficient and effective use of available resources, but also take into account the volunteers' preferences so that they feel that they are treated fairly and can be retained as potential future labor. This implies that modeling the scheduling of volunteers for such organizations requires the consideration of multiple objectives. It is also important for decision-makers in humanitarian organizations to have the flexibility to consider and understand the trade-offs that exist between those different objectives because of the limited resources that are typically available to humanitarian organizations.

4. Proposed model

Our volunteer management model is designed to assist in the assignment of both individual volunteers and volunteer groups to tasks. The model, which is a bi-criteria integer programming model with binary and general integer variables, is presented as follows:

4.1. Objective functions

The first objective function in the model represents total shortage costs, which are given by task shortages and which occur when a given time block remains unassigned. The second objective function represents the number of undesired assignments, which allows the model to take individual time and task preferences into consideration (e.g., a request to have a certain time block off), so that volunteers feel that they are treated fairly and continue to volunteer in the future. Taken together, these two objectives allow an organization to craft a schedule that balances the immediate labor requirements to carry out its social mission against the need to retain volunteers for future periods.

4.2. Decision variables

There are two sets of decision variables in the model:

$x_{ijkl} = 1$ if volunteer or group i is assigned time block j and task k at location l, 0 otherwise.

y_{jkl} = the shortage of volunteers (number of persons) for time block j of task k at location l.

A solution to the volunteer management problem is thus the assignment of different volunteers (individual volunteers or volunteer groups) to particular time blocks for each of the required tasks at the different locations. We represent this solution by a set of binary variables that assume a value of 1 if an individual volunteer (or volunteer group) is assigned a certain time block to perform a determined task, and a value of 0 otherwise. The second set of integer-valued variables represents the associated shortage of volunteers (in terms of number of persons) for each specific time block, task, and location.

4.3. Data sets

V = The set of all volunteers (individuals or groups).
T = The set of all time blocks in the scheduling period.
K = The set of all tasks.
L = The set of all locations.

4.4. Parameters

n_i = The total size of volunteer group i ($n_i = 1$ for individuals, 2 or greater for groups).

e_{jkl} = The total number of volunteers (number of persons) required for time block j of activity k at location l.

d_{jkl} = Task shortage cost for time block j of task k at location l.

$\bar{v}_i$ = Maximum number of time blocks assigned to volunteer or group i.

$\underline{v_i}$ = Minimum number of time blocks assigned to volunteer or group i.

u_i = Maximum number of undesired time blocks assigned to volunteer or group i over scheduling period.

w_i = Maximum number of undesired tasks assigned to volunteer or group i over scheduling period.

p_{jkl} = Maximum shortage of volunteers (number of persons) for time block j of task k at location l.

$a_{ijl} = 1$ if volunteer or group i prefers not to be assigned time block j at location l, 0 otherwise.

$b_{ik} = 1$ if volunteer or group i prefers not to be assigned task k, 0 otherwise.

f = Available budget for the scheduling period.

c_{jkl} = Cost of utilizing a volunteer for time block j of task k at location l.

4.5. Model formulation

The general model formulation is thus presented as follows:

$$\text{Min} \sum_{j\in T}\sum_{k\in K}\sum_{l\in L} d_{jkl}y_{jkl} \tag{1}$$

$$\text{Min} \sum_{i\in V}\sum_{j\in T}\sum_{k\in K}\sum_{l\in L} a_{ijl}n_i x_{ijkl} + \sum_{i\in V}\sum_{j\in T}\sum_{k\in K}\sum_{l\in L} b_{ik}n_i x_{ijkl} \tag{2}$$

st

$$\sum_{i\in V} n_i x_{ijkl} + y_{jkl} \ge e_{jkl}, \quad j\in T,\ k\in K \text{ and } l\in L \tag{3}$$

$$\sum_{i\in V}\sum_{j\in T}\sum_{k\in K}\sum_{l\in L} c_{jkl}n_i x_{ijkl} \le f \tag{4}$$

$$\underline{v_i} \le \sum_{j\in T}\sum_{k\in K}\sum_{l\in L} x_{ijkl} \le \bar{v}_i, \quad i\in V \tag{5}$$

$$\sum_{j\in T}\sum_{k\in K}\sum_{l\in L} a_{ijl}x_{ijkl} \le u_i, \quad i\in V \tag{6}$$

$$\sum_{j\in T}\sum_{k\in K}\sum_{l\in L} b_{ik}x_{ijkl} \le w_i, \quad i\in V \tag{7}$$

$$y_{jkl} \le p_{jkl} \quad j\in T,\ k\in K \text{ and } l\in L \tag{8}$$

$$\sum_{l\in L} x_{ijkl} \le 1, \quad i\in V,\ k\in K \text{ and } j\in T \tag{9}$$

$$x_{ijkl}\in\{0,1\}, \quad i\in V,\ j\in T,\ k\in K \text{ and } l\in L \tag{10}$$

$$y_{jkl} \ge 0 \text{ and integer}, \quad j\in T,\ k\in K \text{ and } l\in L \tag{11}$$

The first objective function, (1), minimizes the total cost of task shortages. These shortage costs are related to resource maximization; they can be treated as a penalty function so that unfilled schedules are considered less optimal than those which are filled. The model will, therefore, make use of volunteer labor as much as possible to satisfy task demands.

To reduce the complexity of defining the model's parameters, an average overall cost could be used for each individual task and time block at each location. The inclusion of the cost parameter, d_{jkl}, however, provides the organization with the flexibility to define, *a priori*, different tasks (such as those which directly impact the health and well-being of affected individuals) that may have more relative importance within the schedule.

Objective function (2) minimizes the total number of undesired task and time block assignments. Undesired assignments are calculated by having each volunteer or group specify which time-blocks and locations as well as which tasks they would rather be assigned to, and then by minimizing the number of time blocks and tasks assigned that were not requested in the first place. In theory, this objective could be augmented by having individuals state the extent to which they would prefer not to be assigned a given task, and an additional parameter could then represent the cost of an undesired assignment. As discussed above, however, the actual *number* of undesired assignments will be more relevant in a humanitarian context, and thus we adopt the simpler model representation.

Constraint set (3) ensures that an appropriate number of persons is assigned to each time block and task at each location, in order to satisfy the workload requirements determined by the decision maker. Consequently, the right hand side of constraint set (3) represents the desired service level for each task and time period. Constraint (4) makes certain that the actual schedule costs (such as *per diem* allowances) do not exceed the available budget.

Constraint set (5) ensures that volunteers are assigned an adequate number of time blocks. As discussed in previous sections, a volunteer management model should provide solutions that help decision makers avoid both over-utilization and under-utilization of volunteer labor. We include the minimum and maximum number of time blocks as a constraint in our model, rather than as part of the objective function (as in Sampson [40]), because we are not associating costs with individual undesired numbers of assignments. Instead the model simply requires the collection of the maximum (and/or minimum) amount of time that a volunteer would like to contribute, in the context of stating preferences for tasks and time blocks.

Constraints (6) and (7) place upper bounds on the number of undesired assignments for each individual or group, in terms of both time blocks and tasks assigned over the scheduling period. These constraints help limit the number of undesired assignments to a reasonable level, even if significantly more emphasis is placed on minimizing task shortages (objective (1)) than on maximizing volunteer satisfaction (objective (2)). Similarly, constraint (8) places an upper limit on the shortage of volunteers per task over the scheduling horizon. This not only helps balance task shortages among tasks but also bounds task shortages at an "acceptable" upper level in instances where the satisfaction of volunteer preferences is more important. The decision maker can thus use this set of constraints to balance the use of volunteer labor among different tasks. Constraint (9), on the other hand, ensures that a volunteer is not assigned to more than one location per time block. Constraints (10) and (11) complete the formulation by enforcing non-negativity, integrality, and binary conditions.

The reader should note that the constraints presented above could be modified (e.g., an organization might use different time block lengths) or additional constraints could be added to incorporate more specific organizational policies. For example, an organization might want to incorporate constraints that take into consideration the seniority of volunteers or include constraints to assign certain volunteers specific tasks they were assigned in the past. The resulting size of a typical problem is fairly large, however, and will usually contain over a thousand binary and integer variables, as well as several thousand constraints.

5. Solution approaches

We now solve the problem at hand by using two complementary methodologies to assist in the assignment of humanitarian volunteers. Taken together, these techniques can help the decision maker consider and examine the tradeoffs between the objectives of (1) minimizing task shortages and (2) minimizing undesired assignments.

5.1. The efficient frontier approach

A traditional method for representing alternative solutions to bi-criteria optimization problems involves constructing the efficient frontier [54].

5.1.1. Generating the efficient frontier

We can generate the efficient frontier for our volunteer management model in a pre-emptive fashion by first minimizing objective function (1) (the overall cost of task shortages) with respect to the original model's constraints. We combine the resulting solution, z^{shortage}, with a relaxation parameter β (where, initially, $\beta = 1$), and set the following new constraint within the model:

$$\sum_{j\in T}\sum_{k\in K}\sum_{l\in L} d_{jkl}y_{jkl} \le \beta z^{\text{shortage}} \quad (12)$$

The efficient frontier can then be generated by repeatedly solving the problem of minimizing objective (2) (the overall number of undesired assignments) for incrementally larger values of β, and plotting each consecutive solution, $z_\beta^{\text{undesired}}$, against the corresponding task shortage for the current β: $z_\beta^{\text{shortage}}$. The smallest possible number of undesired assignments would then be represented by $z^{\text{undesired}}$.

This methodology first minimizes shortage costs to achieve as much coverage as possible and then focuses on minimizing the number of undesired assignments. As shown in Fig. 1, minimizing the number of undesired assignments without incurring any additional shortage costs (i.e., $\beta = 1$) generates a result at the lower end of the efficient frontier. As β is subsequently increased, shortage costs start to increase while the number of undesired assignments go down.

Fig. 1 below illustrates the result of applying this approach to the assignment of tasks at a South American development aid organization that implements development programs for at-risk population groups. The data set included twenty six volunteers and two volunteer centers over the course of fifteen workdays. Different constraints were incorporated into the model including a maximum and minimum number of assignments per volunteer, a maximum number of undesired assignments per volunteer, a budget constraint as well as a series of constraints that were designed to balance labor shortages across the different workdays and centers. The resulting model contained around 1350 decision variables and the algorithm was implemented using the Risk Solver Platform from Frontline Systems, Inc. Each iteration took between 5 and 24 s to solve using a computer with a 2.53 GHz Core Duo processor.

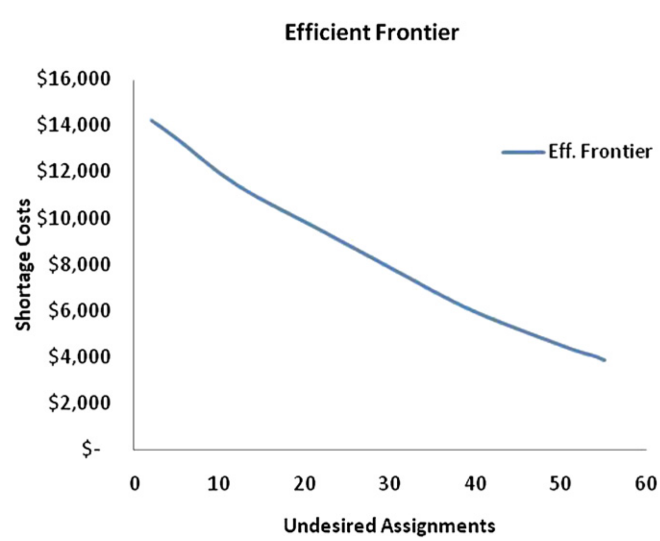


Fig. 1. Efficient frontier results.

There are two extreme situations represented in these results. The first one (corresponding to objective (1) $= z^{\text{shortage}}$) is concerned with guaranteeing task coverage and requires minimizing shortage costs as much as possible ($\beta = 1$) given the labor that is available. This solution would be appropriate, in general, in a humanitarian response or recovery situation where the immediate-/time-critical need to offer assistance for disaster survivors will outweigh most other considerations (it would be safe to assume that in such situations most volunteers would be less worried about the quality of their schedules and would be more focused on working as hard as possible).

The second scenario, on the other end of the curve (and corresponding to objective (2) $= z^{\text{undesired}}$), would be more appropriate to scenarios in which the long-run completion of tasks is the ultimate goal, such as mitigation or post-crisis recovery stages or a development aid scenario like the one in the case study. In this alternate scenario, it would not be a significant issue to let some staffing needs go unmet in the short-term, in order to have volunteers come back in future periods. That is, a decision maker could decide to have some time blocks uncovered in order to improve volunteer morale and reduce volunteer turnover.

5.1.2. Balancing conflicting objectives

In general, the decision maker will need to balance the two extreme scenarios presented in Fig. 1 to best fit the current situation and the current needs. Since our volunteer management optimization model contains two goals, the decision maker could use a goal programming formulation. This methodology would require the decision maker to specify a target value for each specific goal. The resulting goal program would contain a set of divergence variables in the objective function associated with the two goals previously described. The goal programming methodology would then minimize the deviation from those target goals.

However, there are some specific limitations related to this approach that justify the proposal of an alternative solution methodology. In the first place, the goal programming methodology would require the decision maker to come up with specific target values for the different goals. However, specifying appropriate single point estimates can be difficult for decision makers in humanitarian contexts [55].

The second key limitation is that the goal programming approach may result in inefficient solutions. Fig. 2 displays goal programming results for our volunteer management case study using different combinations of target goal values.

Six different target values per objective were used for a total of 36 problem scenarios. Overall, only 15 of the goal programming scenarios resulted in five solutions that were roughly equivalent to the efficient frontier solutions. On the other hand, because of suboptimal target values, 21 of the goal programming scenarios (i.e., 58% of the total number of scenarios) resulted in goal programming solutions that would be considered inefficient when compared to the efficient frontier results.

The results above help illustrate how the selection of certain target values for our two objectives initially might lead to an inefficient scheduling decision. For example, if the decision maker specified a target value of 20 undesired assignments and target shortage costs equal to $10,000, then the solution would near the efficient frontier. However, if the decision maker specified a target value of 40 undesired assignments and target shortage costs equal to $10,000, the goal programming methodology would minimize the deviation from those target goal values and the resulting solution would be suboptimal when compared to the efficient frontier solutions. The decision maker may therefore need to repeat the process using different target values, in order to ultimately determine a more efficient solution. The efficient frontier-based approach, on the other hand, can make it easier to directly identify an optimal solution, providing decision support in a more user-friendly and straightforward manner.

Another approach to identifying an appropriate balance between the objectives would be to have the decision maker specify his or her relative preference for one objective over the other, in the form of providing a weight for each objective function (w_1 and w_2, for objective functions (1) and (2), respectively). The problem could then be reformulated as a single objective integer program, and solved to indicate the position on the efficient frontier that corresponds to the suggested weights.

The two original objective functions (shortage costs and undesired assignments) are each defined in terms of a different unit of measurement. Consequently, this approach would require an additional step, such as reformulating each objective in terms of its percentage deviation from optimal. Such a reformulation, combined with the relative weighting scheme, would result in the following new objective function:

$$\text{Min}\ \alpha\left(\frac{\left(\sum_{j\in T}\sum_{k\in K}\sum_{l\in L} d_{jkl}y_{jkl}\right) - z^{\text{shortage}}}{z^{\text{shortage}}}\right) + (1-\alpha)\left(\frac{\left(\sum_{i\in V}\sum_{j\in T}\sum_{k\in K}\sum_{l\in L} a_{ijl}n_i x_{ijkl} + \sum_{i\in V}\sum_{j\in T}\sum_{k\in K}\sum_{l\in L} b_{ik}n_i x_{ijkl}\right) - z^{\text{undesired}}}{z^{\text{undesired}}}\right) \quad (13)$$

where $\alpha = w_1/(w_1 + w_2)$ represents the normalized weight assigned to objective (1). Upon solution of this new single objective problem for a given set of weights, the resulting values of objective (1) and objective (2) could then be plotted on the efficient frontier to help the decision maker identify the relative extent of the tradeoffs that the chosen weighting scheme represents.

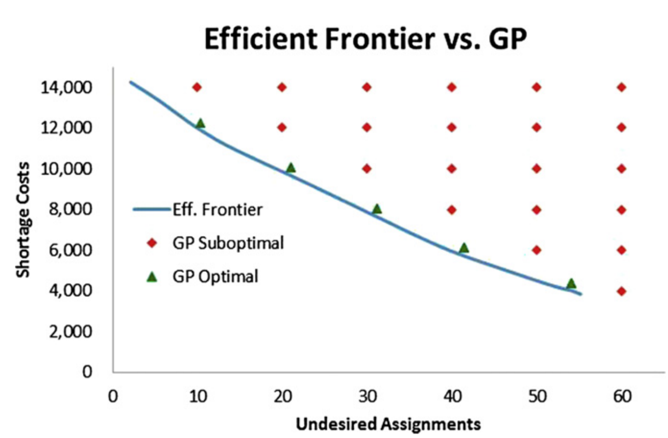


Fig. 2. Comparison of goal programming and efficient frontier results.

Although having the decision maker specify their relative preference between the two objectives of the assignment problem gives them the opportunity to consider a number of different possible outcomes, it can be relatively difficult to quantify these preferences with any degree of accuracy. In order to address this difficulty, we propose a complementary second solution technique that can be used to directly incorporate the decision maker's preferences and knowledge *a priori* and further support decision making in volunteer management settings.

5.2. The fuzzy approach

Fuzzy logic is a form of mathematics that can be used to represent imprecision in a mathematical model's variables [56]. Since its inception by Zadeh [56], several authors have studied different aspects of fuzzy logic theory [57–59]. The work by Kahraman [58] discusses relevant applications and recent developments in the field.

Fuzzy logic has been implemented in traditional labor scheduling settings [60–62]. Tamiz and Yaghoobi [60] developed a fuzzy goal programming model that helps allocate nurses to hospital wards. The authors' model takes into account both hospital objectives and nurses' preferences and divides the different components into hard constraints and fuzzy goals. Topaloglu and Selim [62] also focused on the development of a fuzzy goal programming model for the nurse scheduling problem. The author used fuzzy set theory to deal with uncertainties in the target values of the hospital management and nurses' preferences. Teodorovic and Lucic [61], on the other hand, developed a scheduling model to assign aircrew members to rotations. The authors used fuzzy logic to represent the decision maker's preferences with respect to the assignment of specific crew members to specific rotations.

Fuzzy logic models have also been developed for emergency logistics problems [8,63,64]. Tzeng et al. [64] developed a fuzzy multi-objective programming model for relief delivery to maximize the efficiency and fairness of relief distribution. Tzeng's distribution model focuses on minimizing delivery costs and times, and maximizing demand satisfaction. Sheu [8,63] developed a series of demand management models for emergency logistics operations in large-scale disasters. The author uses fuzzy logic to cluster affected areas into sets, and multi-criteria decision making to rank and prioritize those sets.

Decision-making situations such as disaster scenarios are characterized by large amounts of imprecise information [65] and are typically too complex to be represented using precise quantitative information. Nevertheless, a decision maker may be able to use fuzzy logic in order to arrive at a solution [64]. In this sense, fuzzy logic resembles human reasoning in its use of approximate information to model decisions. The purpose of this section is to discuss the application of fuzzy logic concepts to volunteer management problems in humanitarian contexts.

5.2.1. Fuzzy membership functions

In the proposed volunteer management model, the different objectives for potential schedules can be defined as fuzzy sets. Each fuzzy set can thus be represented by a function that relates each value to a grade of membership. Such a function is known as a membership function. Membership functions are built based on subjective knowledge and are, therefore, dependent on the decision maker and the problem situation. For example, objective (1) can be defined as a fuzzy set called "Acceptable Shortage Costs" which relates the schedule's shortages to a grade of membership in the fuzzy set. An example of a membership function for "Acceptable Shortage Costs" is presented in the figure below.

Fuzzy membership functions, in general, are defined by two parameters: a lower quantity, denoted by l, and an upper quantity, denoted by u. In our particular context, each objective's membership function can thus be formally described by the following formula:

$$\mu_{(o,l,u)} = \begin{cases} 1, & o < l \\ \dfrac{u-o}{u-l}, & l \le o \le u \\ 0, & o > u \end{cases} \tag{14}$$

In the example above, a schedule that results in shortages equivalent to \$12,500 is given a grade of membership of 0.25 in the fuzzy set. The higher the total shortage costs for a particular schedule, the lower the grade of membership, and vice versa. As a result, the objective no longer has a single crisp value but instead is reflected as a value in the membership function.

Fuzzy logic thus provides a formalized framework for dealing with the imprecision intrinsic to our decision problem. Since the representation of knowledge becomes more natural by using fuzzy sets, the decision maker's preferences can be modeled in a more straightforward way. The use of fuzzy logic can help our volunteer management model consider multiple objectives without the need for assigning any weights or selecting any ordered rankings for objectives.

5.2.2. Representing objectives as membership functions

Our complementary solution approach involves using the decision maker's preferences and knowledge with respect to task shortages and undesired assignments in order to build a fuzzy membership function for each of the two objectives in the model. We then use a combination of those membership functions to direct the decision maker to an appropriate point in the efficient frontier, in order to further assist him or her in the volunteer management decision making process.

As was done for a hypothetical decision maker's perception of "Acceptable Shortage Costs" in Fig. 3, we can also construct a membership function for objective (2), i.e., the number of undesired assignments. An example of such a membership function is presented in Fig. 4.

In this case, a total of 60 undesired assignments or more would result in a degree of membership equal to zero while a total number

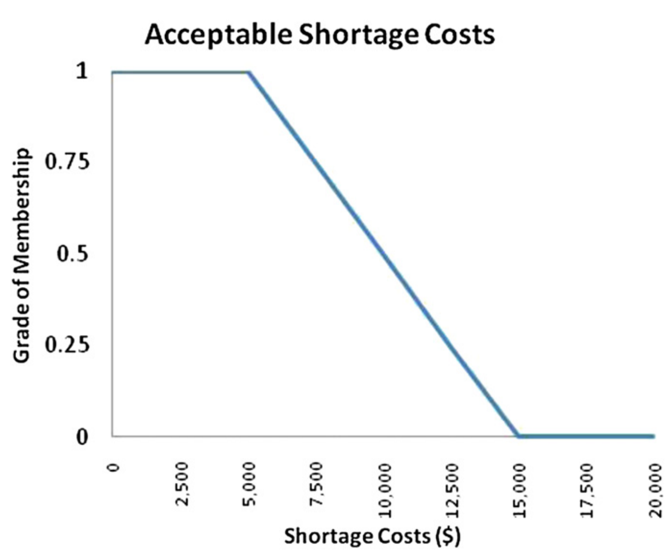


Fig. 3. "Acceptable Shortage Costs" membership function.

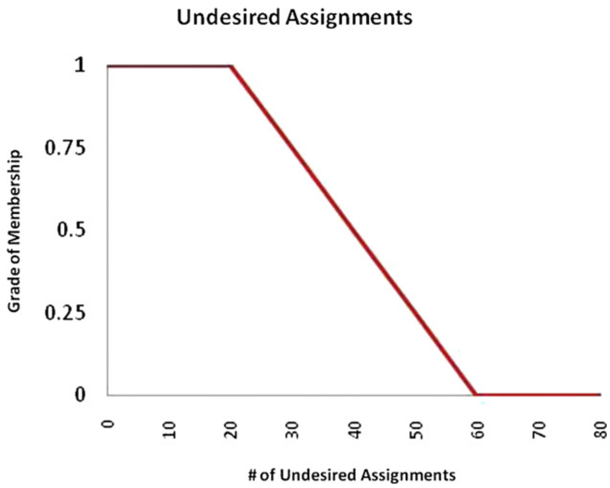


Fig. 4. "Number of undesired assignments" membership function.

Table 2
Two sample schedules.

	Schedule A	Schedule B
Shortage costs	$15,000	$12,500
Undesired assignments	20	50

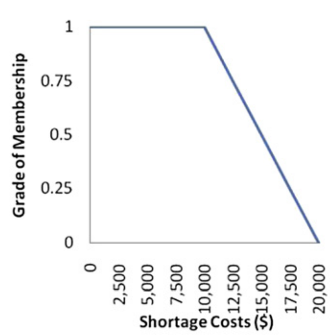
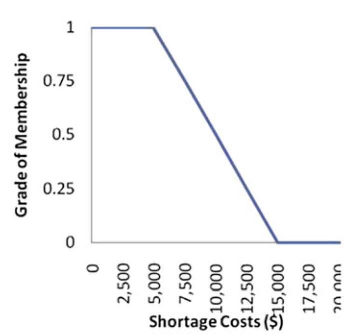
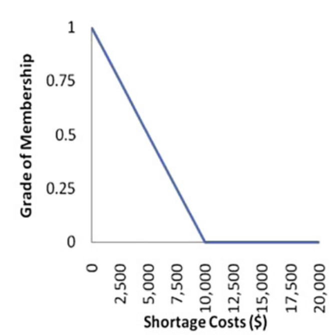
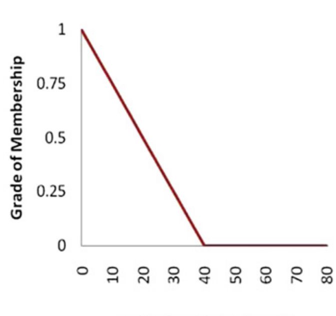
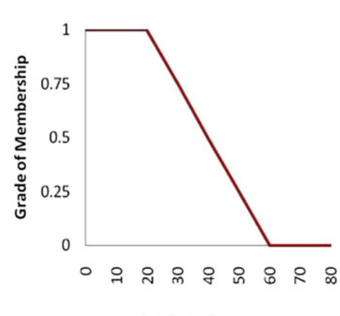
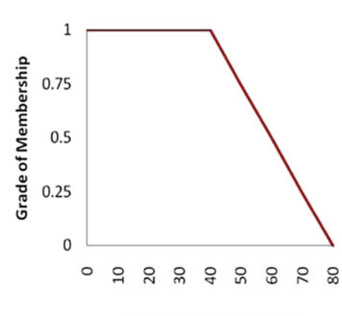
less than 60 would result in consecutively higher grades of membership (until the highest value is reached for 20 and below). A critical issue in this respect is related to the selection of upper and lower thresholds since the values specified by the decision maker will affect the membership grades and, ultimately, the objective function value. In practice, choosing membership bounds arbitrarily may even lead to infeasible multiobjective decision making problems. Different methods have been proposed to overcome this issue (e.g., [58,66]). In this respect, the efficient frontier-based approach can also help the decision maker identify suitable threshold values. For example, visually inspecting the efficient frontier values in Fig. 1 would allow the decision maker to realize that selecting $0 & $2000 as the thresholds for shortage costs might not be feasible.

Given an individual membership function associated with each of the two objectives in the volunteer model, an "overall" objective function can be created to solve the volunteer labor scheduling problem using the fuzzy solution approach. The approach that we take to create such an overall objective function is to calculate the sum the individual grades of membership for each of the two objectives. By maximizing this sum, we can achieve a solution that correspondingly maximizes the decision maker's preferences. Our new objective function is thus expressed as:

$$\text{Max } z^{\text{fuzzy}} = \mu^{\text{shortage}} + \mu^{\text{undesired}} \quad (15)$$

where μ^{shortage} and $\mu^{\text{undesired}}$ represent the result of applying the appropriate membership functions to objectives (1) and (2), respectively.

Table 3
Membership functions related to three alternative humanitarian scenarios.

	Scenario A	Scenario B	Scenario C
Urgency Level	Low	Medium	High
Shortage Costs			
Undesired Assignments			

Consider the two alternative schedules presented in Table 2. Using the membership functions presented in Figs. 3 and 4 we can determine the objective function value for each of these two specific schedules. Schedule A results in an objective function value of $1 + 0 = 1$, while Schedule B results in an objective function value of $0.25 + 0.25 = 0.5$. Since the objective function is the sum of the degrees of membership for each objective, Schedule A would be selected as preferred since it results in a higher objective function value.

5.2.3. Testing and analysis

The following test cases illustrate how this fuzzy approach works in the context of humanitarian volunteer scheduling problems. In order to illustrate the value of the technique, we developed 3 alternative sets of membership functions that represent different humanitarian scenarios.

Scenario A in Table 3 represents a low urgency scenario. In this situation, the decision maker seeks to minimize the number of undesired assignments and is willing to leave a larger number of shifts uncovered to satisfy as much as possible the volunteers' preferences. In contrast, Scenario C represents a high urgency situation in which the decision maker is interested in keeping shortages to a minimum and, therefore, is willing to allow a larger number of undesired assignments. Scenario B represents a combination of the other two scenarios.

The results of our running the multi-criteria optimization model for each of the three scenarios described above (using the same data as in Section 5.1) are shown in Fig. 5. For each scenario, we used equation (15) as the objective function, while all of the model's constraints, parameters, and variables remained unchanged from Section 4.

By superimposing these solutions over the efficient frontier (as previously obtained), it can be seen that each of them lies on the efficient frontier and is optimal for the original problem. The results thus demonstrate the model's ability to represent the imprecision inherent in the work of humanitarian organizations.

The test results also demonstrate how the model can help support volunteer management in different contexts. In this sense, the solution derived from Scenario A (low urgency) is located near the end of the efficient frontier that corresponds to fewer undesired assignments and correspondingly higher task shortages. As the level of urgency increases, the solutions start moving toward the other end of the efficient frontier. The fuzzy model solution derived from Scenario C (high urgency), for example, reflects the decision maker's preference for keeping shortages to a minimum.

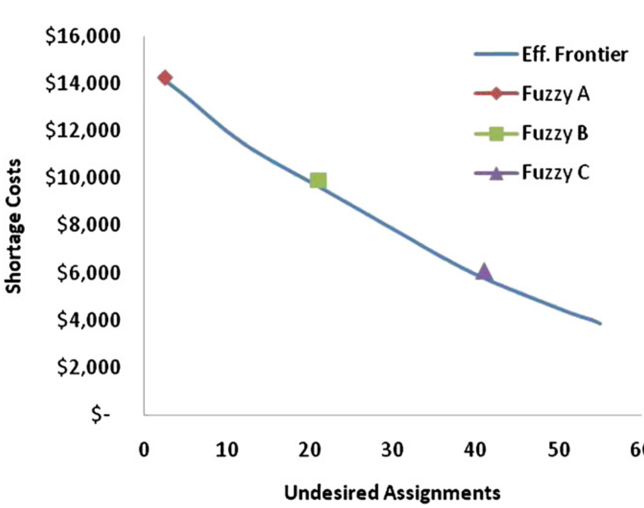


Fig. 5. Plot of fuzzy model results vs. efficient frontier results.

6. Conclusions and future research

The purpose of this paper was to help address a specific challenge faced by humanitarian organizations by developing a multi-criteria optimization model to assist in the management of volunteers. We began with a review of a series of important principles from the field of volunteer management, and discussed how a volunteer labor force model is fundamentally different from a traditional business model. Following a discussion of the model, we presented two complementary approaches to its solution and discussed the importance of directly representing and understanding the tradeoffs inherent in the management of volunteers in humanitarian contexts.

Unlike previous work on volunteer scheduling, this research effort focuses specifically on scheduling in humanitarian organizations. We have included a discussion of specific issues such as labor costs, multiple locations, and group assignments that are important considerations in this particular context. An even more important contribution of this work, however, is the development of an approach by which decision makers can incorporate their expertise into the scheduling model itself, in order to better support examining the tradeoffs between resource utilization and task fulfillment.

As Scholten et al. [67] point out, there exists increasing pressure on humanitarian organizations to become more efficient and effective. On the one hand, organizations must manage volunteers wisely so that they become a renewable resource. On the other hand, these organizations must keep shortages to a minimum in order to increase the effectiveness of their efforts. Therefore, even though the efficient use of resources is important, it may not be enough in the event of a humanitarian crisis. There is thus a clear need to balance these conflicting objectives, and the decision maker will ultimately be required to solve this issue based on his or her experience and preferences. In this sense, the test results illustrate the model's ability to capture these tradeoffs and represent the imprecision inherent in the work of humanitarian organizations, and thus demonstrate its ability to support efficient and effective volunteer management.

It is important to recognize that the multi-criteria solution methodology presented in our paper has some limitations. In particular, with respect to the fuzzy logic approach, one should note that all the membership functions that were used are linear. These membership functions are used in our model because of their simplicity and efficiency with respect to computability. It should be noted that the shape of the membership functions can also be non-linear. Ultimately, the model should utilize the shape that best reflects the decision maker's objectives. Further research with respect to decision makers' preferences would provide more accurate representations of the nature and form (linear, non-linear, or discrete) of those membership functions. In this sense, the effects of non-linear and discrete shaped membership functions on the mapping of solutions merits further examination.

Future research may also look at formulating a combined planning and scheduling model. Workforce planning deals with decisions that are more strategic in nature. In our context, it would involve determining the volunteer workforce levels required by a humanitarian organization to achieve a certain goal. Past studies that integrate both planning and scheduling decisions include Venkataraman and Brusco [68] and Thompson [69], among others. A volunteer workforce planning model would help determine how many volunteers should be recruited, and then this information could be fed into the scheduling model.

In the context of improving decision support for humanitarian organizations, there is also potential to make volunteer data more accessible through existing computerized Disaster Management software systems. Such systems provide the opportunity for humanitarian organizations to structure and store the data that they collect, and may allow the use of different types of decision models. The Sahana Volunteer Management Project developed by the Humanitarian FOSS Project at Trinity College, for example, is a free and open source humanitarian software module for Sahana [70] that allows the users to coordinate the contact information, skills, assignments, and availability of volunteers and responders [71].

The volunteer management discussion and the model formulation in this paper are relatively general, and can be easily applied to other humanitarian aid contexts. For example, in the case of medical personnel who volunteer in the aftermath of a disaster event, it would be possible to further extend this basic model by incorporating additional characteristics into the scheduling process, such as different skill levels. Even though our research is unique in terms of combining efficiency analysis and fuzzy logic to solve volunteer labor scheduling problems, it has broader implications not only for other types of scheduling problems commonly found in service applications but also for all other types of multiple criteria decision making problems.

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