An optimization model for humanitarian relief volunteer management

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ABSTRACT

One of the challenges of humanitarian organizations is that there exist limited decision technologies that fit their needs. It has also been pointed out that those organizations experience coordination difficulties with volunteers willing to help. The purpose of this paper is to help address those challenges through the development of a decision model to assist in the management of volunteers. While employee workforce management models have been the topic of extensive research over the past decades, no work has focused on the problem of managing humanitarian relief volunteers. In this paper, we discuss a series of principles from the field of volunteer management and develop a multi criteria optimization model to assist in the assignment of volunteers to tasks. We present an illustrative example and analyze a solution methodology where the decision maker exercises his/her preferences by trading-off conflicting objectives. Conclusions, limitations, and directions for future research are also discussed.

Keywords

Humanitarian Logistics, Multi Criteria Decision Making, Optimization, Volunteer management

INTRODUCTION

It has been pointed out that humanitarian logistics is one of the most challenging logistics domains (Ratliff, 2007). However, the field of humanitarian logistics has so far received limited attention by logistics academics (Kovács and Spens, 2007). While the social sciences, economics and humanities literatures have developed a significant amount of work on humanitarian issues, this has not been the case for the decision sciences and operations management communities (Altay and Green, 2006).

Different authors have identified a series of specific challenges faced by the field of humanitarian logistics (Thomas and Kopczak, 2005, Kovács and Spens, 2007). More specifically, Ratliff pointed out that there are limited information and decision technologies that clearly fit the needs of humanitarian relief organizations (Ratliff, 2007). The author also made the claim that one of the challenges of humanitarian logistics is that there are significant coordination difficulties with large numbers of volunteers all trying to help. We strongly believe that the development of decision support technologies could help address some of the deficiencies identified in the literature. For these reasons, our paper is aimed at developing a multi criteria optimization model to assist in the assignment of humanitarian relief volunteers to tasks.

The remainder of this paper is organized as follows: A review of the literature related to volunteering and to workforce scheduling is followed by an overview of different defining characteristics of the field of volunteer management in a humanitarian context. Next, we outline the model developed for our study and present a solution methodology that can assist in the assignment of humanitarian relief volunteers. Finally, we conclude with a discussion of the implications and limitations of our research study, and outline future research directions.

LITERATURE REVIEW

The literature in the area of humanitarian logistics consists primarily of handbooks and general procedures developed by Non-Governmental Organizations that are aimed at structuring operational activities in humanitarian efforts. As pointed out by Beamon and Kotleba, very little is available in terms of quantitative analysis of humanitarian relief logistics operations (Beamon and Kotleba, 2006). For example, while employee workforce management models have been the topic of extensive research over the past decades, no work has focused on the problem of managing the assignment of humanitarian relief volunteers. Accordingly, our review of the literature focuses on previous volunteerism and workforce scheduling research.

Volunteer Management

Shin and Kleiner (2003) define a volunteer as any individual "who offers him/herself to a service without an expectation of monetary compensation". Volunteer management research has been an important topic in the social sciences. The different areas that have been researched include the motives for volunteering, i.e, the reasons why people volunteer (Bussell and Forbes, 2002, Allison et al., 2002, Cnaan and Goldberg-Glen, 1991). Opportunities for personal growth, recognition, achievement, and a desire to contribute to the community are some of the incentives for volunteering cited by past research. Another topic that has been studied in the past involves the demographic characteristics of volunteers, such as education and gender, and their relationship to present and future commitment levels (Van Vianen, 2008, Lammers, 1991).

The area of volunteer retention and the analysis of what practices encourage renewed volunteerism and why people continue to volunteer is also an important topic (Hager et al., 2004, Gidron, 1984). Some of the management practices that positively influence the retention of volunteers include recognition activities and matching volunteers to appropriate tasks. Gidron (1984), for example, cites task achievement and the quality of the work itself as some of the variables that could better predict volunteer retention.

Each of these areas of research reinforces the observation that volunteers play a vital role in the provision of assistance in humanitarian relief situations. The manner in which they do so, and the specific characteristics of their participation in relief efforts play an important role in the development of our model, as will be shown in later sections.

Labor Scheduling

Several articles have been published on labor scheduling as the topic has become gradually more important due to the prevalence of the services sector. However, volunteer management, in general, has not been discussed in the operations management literature.

Previous research can be categorized by type of model, by solution methodology and by application area. Relevant reviews of the state of the art include Alfares (2004) and Bechtold et al. (1991), among others. With respect to the solution methods and techniques, it has been noted that the literature is heavily skewed towards mathematical programming approaches (Ernst et al., 2004). In addition, because of the size of some tour scheduling problems, different heuristic methods have been developed (See Goodale and Thompson (2004)).

The operations management literature includes several different application areas related to labor assignment problems. Since their inception, scheduling and staffing methods have been applied to areas ranging from airline crew staffing (Kohl and Karisch, 2004) to nurse scheduling (Parr and Thompson, 2007, Azaiez and Al Sharif, 2005). However, a review of the literature related to labor scheduling research specifically focused on not-for-profit or volunteer contexts resulted in only one specific article. Sampson (2006) developed an optimization model for labor assignments in the context of an international meeting. In addition, the author illustrated ways in which the volunteer management problems are different from typical paid workforce assignment problems.

In the disaster management field, Janiak and Kovalov studied scheduling problems where tasks need to be executed by human resources in areas contaminated with radio-active materials (Janiak and Kovalyov, 2006). In their model, the authors studied single worker problems with the objectives of minimizing maximum lateness or total weighted completion time. The idea of modeling individual volunteer preferences, for example, was not considered. Another somewhat related article by Metters and Vargas also discusses issues related to nonprofit organizations from a quantitative decision modeling perspective (Metters and Vargas, 1999). The authors extended yield management concepts to the nonprofit sector by developing a heuristic to assist in pricing decision making. Their technique was demonstrated at a nonprofit child care center. One of the key attributes of their model is the idea that profit maximization is not the most important goal.

Overall, while employee scheduling has been the topic of extensive research over the past decades in the business literature, no work has focused on the problem of optimizing the assignment of humanitarian relief volunteers.

CHARACTERIZATION OF A HUMANITARIAN VOLUNTEER MANAGEMENT MODEL

This section provides a brief overview of the different defining characteristics of volunteer management in humanitarian organizations. We first explore what characteristics make a humanitarian decision model different from a traditional business model, and then analyze some additional ideas from the field of volunteer management that played an important role in the development of our model.

Differences between traditional business models and humanitarian models

A key difference between traditional business models and humanitarian models is that of the objective function. Rather than maximizing revenues, the objective function for a humanitarian organization should support its social mission (i.e., to save lives and to alleviate suffering).

Another important difference between traditional business models and humanitarian models is related to the skills of the labor force. Traditional business models assume that the available labor force has the required skills to complete a task. In the case of humanitarian organizations, one must take into consideration that some volunteers may not have the required skill levels to complete certain tasks. For that reason, humanitarian organizations must avoid inefficiencies in the management of skilled volunteers. In the aftermath of the 2004 tsunami, for example, numerous skilled volunteers came together to work for the common good. Those individuals came from all over the world but it was pointed out that the skills of many of the volunteers were not used to the maximum: “A large number of volunteers, became disenchanted because of the lack of organization (…). Some highly-skilled volunteers were asked to perform repetitive jobs” (Anonymous, 2005).

In addition, traditional labor assignment research typically assumes that a sufficient labor pool is available. On the other hand, humanitarian organizations rely heavily on the use of volunteers to implement their humanitarian efforts. Those organizations typically depend on a large number of volunteer workers with limited time availabilities to accomplish their missions. The future will be even more challenging: it has been claimed that even though the amount of work required in the voluntary sector is growing, the number of available volunteers is not increasing at a comparable rate (Bussell and Forbes, 2002). Therefore, it is important for humanitarian and other non-profit organizations to manage efficiently the available volunteer workforce in order to successfully recruit and retain their volunteer bases.

The table below was adapted from Sampson (2006) and discusses how humanitarian volunteer management problems differ from paid labor problems with respect to various decision model attributes. Most of those distinctions were confirmed by Sampson with empirical data and determine a mathematical formulation that is different from traditional formulations for business problems.

Model Attribute	Paid Workforce	Humanitarian Volunteer Workforce
Objective	Maximize profits by minimizing labor costs	Maximize task completion by minimizing shortages
Key constraint	Required tasks	Committed labor
Labor pool size constraint	Assumed to be sufficient or unconstrained	Determined by size of committed labor
Labor costs	Non-trivial	Low yet still non-trivial
Labor preferences	Some models consider time preferences	Models must consider volunteers' time and task preferences
Task labor shortages	Not an issue	Shortages need to be balanced among tasks

Table 1. Comparison of labor assignment perspectives (Adapted from Sampson (2006))

A model for humanitarian organizations must ensure that the resources available be used efficiently. In addition, such a model must try to make sure that enough volunteers are available at all times while taking into account individual preferences in such a way that volunteers are treated fairly. The discussion above reveals that the modeling of the volunteer scheduling problems requires the consideration of multiple objectives. Specifically, the volunteer management problem needs to be formulated so as to select a configuration of schedules that balances the trade-off between available resources and volunteer preferences.

Additional considerations from the field of volunteer management

Any such model must also take into consideration other hypotheses from the volunteer management literature that were empirically tested and verified by Sampson (2006). Those considerations are discussed below.

- The level of future committed labor (CL) is directly related to the current assignment of tasks. Consequently, a volunteer management model should take into consideration and satisfy as much as possible the volunteers' preferences for task and time block assignments.
- The use of volunteer labor up to level of CL will maintain/increase future CL. On the other hand, use of volunteer labor beyond CL will decrease future CL. In this respect, a volunteer management model should avoid over utilization of volunteer labor.
- Utilized volunteer labor will be more likely to volunteer in the future than unutilized volunteer labor. In this sense, a model should provide solutions that avoid non-utilization or under utilization of volunteer labor, whenever possible.
- Task demands in excess of current CL will result in shortage costs. This postulate simply indicates that a volunteer management decision model should maximize task completion making use of volunteer labor as much as possible in order to avoid shortages.

The characteristics discussed above imply the need for a mathematical formulation that is intrinsically different from traditional business decision models.

PROPOSED MODEL

Our volunteer management model is presented as a bi criteria integer programming model with binary (0,1) and general integer variables. The two objectives are structured as follows: In the first objective, we are interested in minimizing task shortages. The first objective function thus minimizes total shortage costs. Shortage costs represent a penalty and occur when a certain time block remains unassigned. In addition, the model takes into consideration individual time and task preferences (e.g., a request to have a certain day or time block off) so that volunteers are treated fairly. For that purpose, the second objective function minimizes the number of undesired assignments. Taken together, these two objectives contribute towards the overall mission of saving lives and alleviating suffering while using resources more efficiently and effectively.

Data Elements

The reader should note that most volunteer data may be available from existing computerized Disaster Management software systems. Such systems are available to help humanitarian organizations structure the data they collect and can also allow organizations to use different types of decision models. The Sahana Volunteer Management Project developed by the Humanitarian FOSS Project@ Trinity, for example, is a free and open source humanitarian software module for Sahana that allows the users to coordinate the contact information, skills, assignments and availability of volunteers and responders (TheHumanitarianFOSSProject@Trinity, 2008). Other types of data that should be stored and retrieved, in support of the model, include more specific preferences of volunteers (in terms of tasks and time blocks). The model data elements are presented below.

Decision Variables

The solution to the volunteer management problem is the assignment of different volunteers to a time block of each required task. We represent this solution by a set of binary variables that assume a value of 1 if a volunteer is assigned to a certain time block to perform a determined task, and a value of 0 otherwise.

x_{ijk} = 1 if volunteer *i* is assigned to time block *j* of task *k*, 0 otherwise

y_{jk} = Integer variable that represents the shortage of volunteers (number of persons) for time block *j* of task *k*

Data Sets

V = The set of all volunteers

T = The set of all time blocks in the scheduling period

K = The set of all tasks

V^{jk} = The set of volunteers available for time block *j* and who can perform task *k*

V^{m} = The set of volunteers who are willing to work time blocks of length *m* (in hours)

K^{i} = The set of tasks that volunteer *i* is able to perform

T^{i} = The set of time blocks that volunteer *i* is available to work

T^{mk} = The set of time blocks of length *m* for task *k*

Parameters

f = Available budget for the scheduling period

z = The total length of the scheduling period

c_{ijk} = Cost of utilizing volunteer *i* for time block *j* of task *k*

d_{jk} = Task shortage cost for time block *j* of task *k*

$\overline{v}_i$ = Maximum number of time blocks to assign to volunteer *i*

$\underline{v}_i$ = Minimum number of time blocks to assign to volunteer *i*

u_i = Maximum number of undesired time blocks assigned to volunteer *i* over scheduling period

w_i = Maximum number of undesired tasks assigned to volunteer *i* over scheduling period

p_k = Maximum shortage of volunteers (number of persons) for task *k* over scheduling period

a_{ij} = 1 if volunteer *i* prefers not to be assigned to time block *j*, 0 otherwise

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

e_{jk} = Number of volunteers required for time block j of activity k

Model Formulation

The actual model formulation is presented as follows:

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

$$\text{Min} \sum_{i\in V}\sum_{j\in T} a_{ij} x_{ijk} + \sum_{i\in V}\sum_{k\in K} b_{ik} x_{ijk} \tag{2}$$

st

$$\sum_{i\in V^{jk}} x_{ijk} + y_{jk} \geq e_{jk}, \quad j\in T, \text{ and } k\in K \tag{3}$$

$$\sum_{i\in V}\sum_{j\in T}\sum_{k\in K} c_{ijk} x_{ijk} \leq f \tag{4}$$

$$\underline{v}_i \leq \sum_{i\in V} x_{ijk} \leq \overline{v}_i, \quad j\in T, k\in K \tag{5}$$

$$\sum_{j\in T^i} a_{ij} x_{ijk} \leq u_i, \quad i\in V \tag{6}$$

$$\sum_{k\in K^i} b_{ik} x_{ijk} \leq w_i, \quad i\in V \tag{7}$$

$$\sum_{j\in T} y_{jk} \leq p_k, \quad k\in K \tag{8}$$

$$x_{ijk} \in \{0,1\}, \ y_{jk} \geq 0 \text{ and integer}, \quad i\in V, \ j\in T, \text{ and } k\in K \tag{9}$$

$$f \geq 0 \tag{10}$$

$$e_{jk} \geq 0 \text{ and integer}, \quad j\in T, \text{ and } k\in K \tag{11}$$

The first objective function, (1), minimizes total shortage costs. Total shortage costs represent a way to model the idea discussed in the previous section that task demands in excess of current CL will result in task shortages. The model will thus try to make use of volunteer labor as much as possible in order to satisfy task demands. In this way, 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.

Objective function (2) minimizes the number of undesired time block assignments. Undesired assignments are calculated by having each volunteer specify which time-blocks and which tasks they would rather be assigned, and then by minimizing the number of time blocks and tasks they are assigned to that were not requested in the first place.

Constraint set (3) tries to ensure that an appropriate number of persons is assigned to each time block and task in order to satisfy the workload requirements determined by the decision maker. The right hand side of constraint set (3) represents the set of desired service levels. Constraint (4) makes certain that actual schedule costs do not exceed the available budget level. Constraint set (5) ensures that volunteers are assigned to an adequate number of time blocks. As discussed in previous sections, a volunteer management model should provide solutions that help decision makers avoid both overutilization and non-utilization of volunteer labor. For example, based on the information provided by a volunteer the decision maker might determine that the volunteer should be assigned between 3 and 7 time blocks over the scheduling horizon. The underlying premise is that volunteers should be treated fairly and not be over worked.

Constraint sets (6) and (7) place upper limits on the number of undesired assignments with respect to both time blocks and tasks assigned to each volunteer over the scheduling period. In this sense, since previous research has found that volunteers that are treated fairly are more likely to volunteer in the future, the model should satisfy volunteer preferences for assignments as much as possible. Constraint set (8) places an upper limit on the shortage of volunteers per task over scheduling horizon. As mentioned in the previous section, task shortages should be balanced among tasks in a humanitarian volunteer management model. The decision maker can thus use this set of constraints to balance the use of volunteer labor among different tasks. Finally, constraints sets (9), (10) and (11) enforce non-negativity, integrality and binary conditions.

The reader should note that the constraints presented above could be modified (e.g., an organization might want to use different time block lengths) or additional constraints could be added in order to incorporate more specific organizational policies (e.g., policies that take into consideration the seniority of volunteers). The size of a typical problem is fairly large and would usually contain several thousand binary and integer variables, as well as several thousand constraints.

SOLUTION METHODOLOGY, ILLUSTRATIVE EXAMPLE AND RESULTS

A traditional method for solving bicriteria problems is the efficient frontier method (Winston, 2004). In this approach, a set of optimal (i.e., efficient) solutions must be generated. In our model, we achieve that goal by first minimizing objective function (1) (At this point, we ignore objective function (2)). We then express the resulting solution ($z^{shortage}$) as a function of $\beta = 1$, and set the solution as a constraint. As a result, we have a new constraint in our model:

$$\sum_{j \in T} \sum_{k \in K} d_{jk} y_{jk} \leq \beta z^{shortage} \qquad (12)$$

Next, we proceed to solve the model minimizing the number of undesired assignments, i.e., objective function (2). Objective function (2) is now expressed as:

$$\text{Min } z^{undesired} = \sum_{i \in V} \sum_{j \in T} a_{ij} x_{ijk} + \sum_{i \in V} \sum_{k \in K} b_{ik} x_{ijk} \qquad (13)$$

Note that from (12), the resulting solution ($z^{undesired}$) will now depend on the value of β.

In order to develop the efficient frontier (i.e. a trade-off curve between the two conflicting objectives), we now must repeatedly solve the modified model for different β values greater than 1. Next, we simply need to plot the different combinations of $z^{undesired}$ and $z^{shortage}$ values. Finally, the decision maker will:

1. inspect the tradeoff curve,
2. select the point in the curve that, based on his experience and preferences, most appropriately balances the two conflicting objectives, and
3. implement the corresponding schedule.

We now present computational results from randomly generated instances. In our example, we have 40 volunteers that need to be assigned to a series of tasks over the course of one week. The software used to solve the instances was the Risk Solver Platform from Frontline Systems, Inc. The resulting tradeoff curve is presented below.

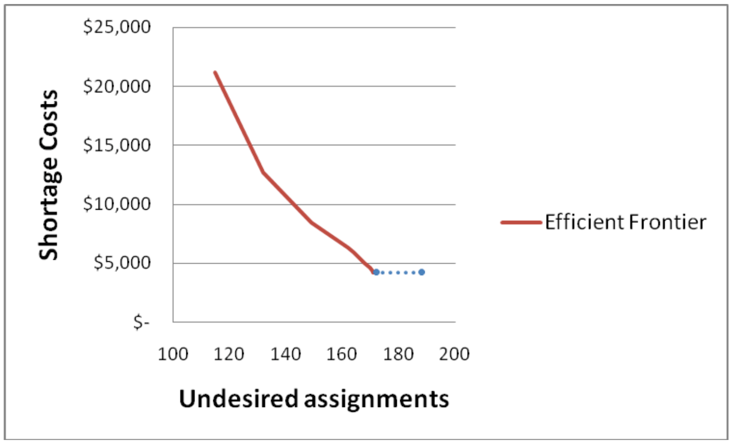

Figure 1. Efficient Frontier Results

The solution methodology first minimizes shortage costs in order to get as much coverage as possible and then focuses on minimizing the number of undesired assignments. As shown in the figure above, minimizing the number of undesired assignments without incurring any additional shortage costs (i.e., $\beta = 1$) results in an initial reduction of that number. Then, as β is subsequently increased, shortage costs start to increase while the number of undesired assignments starts to go down.

As implied above, there are two extreme scenarios. The first one is concerned with guaranteeing coverage and requires minimizing shortage costs as much as possible ($\beta = 1$) given the labor that is available. This solution would be appropriate in a disaster response or recovery situation when the immediate/time-critical need to offer assistance for 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, as soon as possible). The second scenario, on the other end of the curve, might be more appropriate in the mitigation or post-crisis recovery stages where the long-run completion of tasks is ultimately the goal, and therefore in the short-term it would not be a significant issue to let some staffing needs go unmet in order to have volunteers come back in future periods. That is, a decision maker could decide to have some shifts uncovered in order to improve volunteer morale.

Ultimately, based on the context and the types of needs, the decision maker would use his/her experience and expertise to select a point in the curve and implement the corresponding schedule. Our model can thus be used to assist in the management of volunteers and help the decision maker deal with conflicting objectives by providing computer-aided decision support.

CONCLUSIONS AND FUTURE RESEARCH

The purpose of this paper was to help address some of the challenges faced by humanitarian organizations through the development of a volunteer management model. For that purpose, a multi criteria optimization model to assist in the assignment of volunteers to tasks was developed. In addition, we reviewed a series of important principles from the field of volunteer management and discussed how a volunteer labor force model differed from a traditional business model. We also presented a solution methodology and a preliminary analysis of its performance was undertaken.

The multi criteria nature of volunteer management is extremely relevant. On the one hand, humanitarian organizations need to manage volunteers wisely so that they become a renewable resource. On the other hand, these organizations need to keep shortages to a minimum (understanding that additional volunteers may not be available to take up the slack) 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 conflicting objectives. The decision maker will ultimately need to solve this issue based on his or her experience and preferences. An important characteristic of our solution approach is its support for the decision maker to easily consider the impact of tradeoffs between the two conflicting objectives in humanitarian relief, or crisis management scenarios.

The multiple criteria solution methodology presented in our paper has some limitations. In the efficient frontier approach, the decision maker's preferences about the relative importance of each objective are only exercised post-hoc when he or she trades-off objective values on the efficient frontier. Another major limitation of the two-dimensional efficient frontier approach discussed in our paper is the impossibility to reasonably include more than two objectives. Ongoing research is studying the use of alternative techniques such as fuzzy logic to overcome those limitations. Exploring alternative solution methodologies would further strengthen the applicability and importance of this work in the context of providing computer-aided decision support.

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 in order to achieve a certain goals. Past studies that integrate both planning and scheduling decisions include Venkataraman and Brusco (1996) and Thompson (1995), 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.

The volunteer management distinctions and the model formulation are quite general, and can be easily applied to other humanitarian aid contexts. For example, ongoing research is examining the related problem of assigning volunteers for youth counseling in low income neighborhoods of a South American developing country. Future research might also look at ways of adapting the model formulation to meet other humanitarian scenarios.

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