Optimization of volunteer labor assignments

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Abstract

Labor is a crucial resource in most organizations. In not-for-profit, public, and government services, it is common for labor to include unpaid volunteers. This article demonstrates how the volunteer labor assignment (VLA) problem is markedly different from traditional labor assignment (TLA) problems such as labor scheduling. One core difference pertains to the cost structure of labor, where TLA problems seek to minimize labor costs, yet labor costs for volunteers are usually trivial. Another difference is the assumed size of the labor pool: TLA typically assumes sufficient labor to cover task requirements, whereas the VLA labor pool is limited by the number of volunteers that can be recruited. These and other distinctions coming from the volunteerism literature are described and confirmed with empirical data. One important finding is that volunteers who were not utilized had a reduced propensity to volunteer in the future. These VLA distinctions are incorporated into an integer goal program. Empirical data are used to demonstrate how VLA assumptions produce solutions that are significantly different from solutions coming from TLA assumptions. Sensitivity analysis is described, as are applications in other VLA contexts.

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1. Introduction

The very existence of many not-for-profit, public, and even some government organizations depends on volunteer labor (Whitford and Yates, 2002). Volunteerism is a major factor in many economies. For example, a survey of volunteerism in the United States estimated that in 1998 alone, 109.4 million individuals contributed a total of 19.9 billion hours (Shin and Kleiner, 2003). The economic worth of those volunteer hours depends on the estimate of equivalent wage. Nevertheless, the contribution of that volunteer labor is certainly at least in the hundreds of billions of dollars.

Research has been published about managing volunteer labor from sociological and economic perspectives. Operations management research literature addresses many topics pertaining to labor management, such as labor scheduling, but with almost no references to volunteer contexts. One might suppose that volunteer labor assignment (VLA) problems are the same as traditional labor assignment (TLA) problems. We will show that this is not the case.

The purpose of this research is to demonstrate how labor assignment problems involving volunteers are markedly different from traditional labor assignment problems (involving paid labor). This will be accomplished in stages. First, we review literature which defines volunteerism and which characterizes the major themes and traditions of published labor assignment research. Second, specific assumptions inherent in traditional labor assignment problems are compared with assumptions of volunteerism that come from volunteerism research literature. The differences in assumptions lead to suppositions about the behavior of
volunteer labor that results from desirable or undesirable assignment conditions.

Third, we confirm those suppositions with empirical data, and propose corresponding goals which define “good” VLA problem solutions. Fourth, a VLA mathematical formulation (goal program) is derived to incorporate the goals. Fifth, empirical data are used to demonstrate how optimal VLA solutions are significantly different from the solution that results from optimizing under TLA assumptions. Sensitivity analysis is briefly discussed, followed by an application of the approach to time-dependent contexts. The final section summarizes.

2. Background

The research literature defines volunteerism a few different ways. At a most basic level, a volunteer is “...an individual who offers him/herself to a service without an expectation of monetary compensation” (Shin and Kleiner, 2003, p. 63). However, that is not to say that the volunteers receive no compensation. As Shin and Kleiner (2003) point out “...their service brings intangible rewards.” These intangible rewards include recognition, skill development, and the good feelings of altruism. For the present research, we do not consider “paid” volunteers such as military recruits or Peace Corps volunteers (Conway, 2003). Formally compensated volunteers can probably be appropriately modeled using paid labor models.

Penner (2002) is a little more precise in the definition he uses: “Volunteerism involves long-term, planned, prosocial behaviors that benefit strangers, and usually occur in an organizational setting.” This is more restrictive than other definitions, but provides some useful contextual conditions for the present research. In this research, we do focus on volunteerism in organizational settings, since we are concerned with organization management. We also make assumptions that there are some “long-term” volunteer issues to manage. A long-term view motivates us to consider the impact of the present use of volunteer labor on future labor availability. Also, we assume a context in which the volunteer activities are “planned,” at least over a specified horizon.

2.1. Volunteerism research

“Volunteerism” research is published primarily in social sciences journals. Topics studied include why people volunteer (Anderson and Moore, 1978; Knowles, 1972), the demographics of volunteers (Gillespie and King, 1985), and why they continue in voluntary service (Lammers, 1991; Rubin and Thorelli, 1984). Additional volunteerism research comes out of the economics discipline (Govekar and Govekar, 2002), including models that focus on volunteer supply (Freeman, 1997) and demand (Emanuele, 1996) functions.

Volunteerism has generally not been represented in operations management literature. For example, a search of Journal of Operations Management abstracts since 1980 revealed not even one article with the term “volunteer” or “volunteerism” in the abstract. However, the operations management literature is rich with studies of TLA problems.

2.2. Labor assignment research

Much of the traditional “task assignment” literature focuses on assigning tasks to workstations in manufacturing or data processing settings, with the objective of maximizing throughput by minimizing bottlenecks (Billionnet et al., 1992; Park, 1990; Rachamadugu, 1991; Shin, 1990). Other literature considers the assignment of labor to workstations, which is in essence an assignment of labor to tasks (Davis and Mabert, 2000; Dube and Elsayed, 1979). Often, the labor assignment is dynamic, with the workers moving from one workstation to another according to production requirements (Bobrowski and Park, 1993; Treleven and Elvers, 1985).

There has been relatively little published research specifically about labor task assignment in service businesses. However, much services research has been published in the area of labor scheduling, which is an assignment of labor to time periods (Bechtold et al., 1991). Most of the labor scheduling research assumes a single task being scheduled (Easton and Rossin, 1996; Mason et al., 1998; Thompson, 1992). However, some labor scheduling research also includes determining labor task assignments (Loucks and Jacobs, 1991; Love and Hoey, 1990; Ritzman et al., 1976).

In many ways, assignment of labor to tasks and assignment of labor to time periods are treated similarly in problem formulations. Labor demand is indexed by time period and/or task. Labor may have preferences and/or availability for specific time periods and/or tasks. Conditions may exist that limit the combination of assignments for either times or tasks: the number of consecutive time assignments may be limited by labor rules (e.g., Loucks and Jacobs, 1991), and the assignments of workers to specific cohorts of tasks might be limited due to safety concerns (e.g., Rachamadugu, 1991).
A primary area where time and tasks assignments differ is in simultaneity: a worker can be assigned to multiple tasks if they are at different time periods, but usually not to multiple tasks if they are at the same time period. However, this constraint is not universal to all scheduling problems, since some workers can complete more than one task at a time (Dube and Elsayed, 1979).

In volunteer contexts, we will show that the task assignment component is crucial since the quality of task assignment impacts future propensity to volunteer. We will consider labor assignment both with and without a time dimension. However, since labor scheduling is much more prevalent in services literature than labor task assignment, we will focus our attention on comparing VLA assumptions with TLA assumptions presented in the labor scheduling literature.

2.3. Labor scheduling research

A variety of articles have been published on labor scheduling since the mid-1970s. Our literature search has not revealed any labor scheduling research articles specifically about not-for-profit or volunteer contexts. The closest related article found was on “Yield Management for the nonprofit sector” by Metters and Vargas (1999). Interestingly, they observed: “The most striking difference between the for-profit and nonprofit models is that of the objective function” (Metters and Vargas, 1999, p. 217). We will consider this issue of objective function distinction in our derivation of a mathematical formulation below.

Without references about volunteer labor scheduling, we will instead review research about “traditional” labor scheduling involving paid employees. The purpose herein is not to provide a general survey of labor scheduling literature, but rather to provide a summary of major themes and approaches taken in the research. Those themes will then be considered in a volunteer organization (VO) context.

A good summary of labor scheduling research to that time was a 1991 article by Bechtold, Brusco, and Showalter. That article provides valuable observations about the research field. First, they observe that labor scheduling can be classified into three categories: days-off scheduling (scheduling which days specific employees take off during each work week), shift scheduling (determining employee work schedules over a daily planning horizon), and tour scheduling (identifying how many employees assume weekly shift schedules, i.e., “tours,” in order to meet task demand). Research involving tour scheduling is more prevalent than shift scheduling or days-off scheduling, and includes a companion problem of determining the feasible set of tours to consider (Easton and Rossin, 1991). The following is an example of a typical tour scheduling problem (Bechtold et al., 1991). It is intended to be representative of the types of traditional labor assignment problems that are described in the literature.

Typical tour scheduling (an example of TLA):

\[
\begin{align*}
\text{minimize} & \quad \sum_j x_j \\
\text{subject to} & \quad \sum_j a_{t,j} x_j \geq r_t, \quad \forall t \\
& \quad x_j \geq 0 \text{ and integer, } \forall j
\end{align*}
\]

where \( j \): tour index, \( j \in (1, \ldots, J) \); \( t \): time period index, \( t \in (1, \ldots, T) \); \( x_j \): number of employees assigned to tour \( j \); \( r_t \): number of employees required to work during time period \( t \); \( a_{t,j} \): 1 if time period \( t \) is included in tour \( j \), otherwise 0.

The objective function equation (TLA-1) minimizes the total number of labor hours scheduled. The constraint equation (TLA-2) assures that we have enough employees to meet task demand. Equation (TLA-3) assures non-negative integer decision variables.

Minimizing the total labor hours scheduled is a common TLA objective function (e.g., Mabert and Showalter, 1990; Mason et al., 1998), although others objective functions exist (Bechtold et al., 1991). Objective functions that also represent costs minimization include: minimize the number of employees scheduled (Baker et al., 1979; Easton and Rossin, 1991; Hung, 1994), minimize labor costs (Easton and Rossin, 1996; Jaumard et al., 1998; Lauer et al., 1994), minimize over-staffing (Loucks and Jacobs, 1991; Love and Hoey, 1990), and maximizing the utilization of employed labor (Jacobs and Bechtold, 1993). These are all highly correlated with minimizing total number of labor hours.

TLA problems may involve other objective function elements. For example, articles have been published that described the superiority of a “customer service” objective function which recognizes that excessively utilized labor leads to degradation in service levels (Goodale et al., 2003; Thompson, 1995). In those situations, the idea is to schedule more than the minimum required labor amount \( r_t \) so that customers can receive better service than expected (e.g., shorter
wait times), leading to increased customer retention and increased profits.

Much of the published research involving labor scheduling is about ways of solving the problem, since it is an integer program that generally requires heuristic solution techniques (for a comparative survey of solution techniques, see Thompson, 1992 or Bechtold et al., 1991). Also, a myriad of variations of labor scheduling have been studied, which we do not have space to review here. However, the variations tend to have common assumptions, which we will show to be different from common assumptions of volunteer labor assignment problems.

3. Distinctiveness of VLA

As with traditional labor scheduling, we recognize that there are a wide variety of VLA contexts to consider. Nevertheless, the volunteerism literature reveals assumptions that tend to be common across volunteer contexts. This section highlights assumptions of VLA that differ markedly from the typical assumptions of TLA. These distinctions lead to suppositions that are confirmed with empirical data in the subsequent section. These distinctions prescribe a mathematical formulation which is quite different from typical TLA formulations.

3.1. Labor Assignment Issue #1: Variable cost of labor

- Typical TLA assumption: Labor represents a non-trivial variable cost at any level.
- Typical VLA assumption: Variable cost for committed labor is negligible, and variable cost beyond committed labor is non-trivial.

Labor is a major cost in most non-volunteer organizations. In the prior section, we showed how minimizing labor costs is the central theme in published instances of TLA, and variations of labor cost minimization are the common objective functions. Countless industry examples have shown that controlling labor costs is central to assuring the profitability of service organizations (Hueter and Swart, 1998; Swart and Donno, 1981).

VOs are operationally unique primarily in the employment of volunteer labor. The variable cost of volunteer labor is not always zero (Emanuele, 1996), but it is usually low enough to make reducing labor cost a non-issue. Instead, the focus of VOs is often increasing the commitment of volunteers, both new volunteers and time commitment of current volunteers (Freeman, 1997).

The research literature discusses a concept that we term “committed labor” (CL), which is the finite amount of labor the volunteer has agreed or will agree to volunteer (Cnaan and Amrofell, 1994, p. 344). Another way to characterize “committed labor” is as that amount of work effort the volunteers are willing to contribute. CL can be viewed as both an individual and collective measurement. CL for an individual is the amount of time the volunteer is personally willing to give to the VO. Collective CL is the total amount of committed labor from the group of volunteers.

In reality, individual CL is a probabilistic cost function, but often characterized by a point estimate. We may ask someone how many hours he or she is willing to contribute over a given period of time. The response might be “I can give two hours next week,” which is to say “I can give two hours without incurring a cost that would prevent me from volunteering” (Cnaan and Amrofell, 1994). If the VO subsequently requests 3 hours of labor, the individual may refuse, or may agree but with a decreased enthusiasm. Decreased enthusiasm can cost the VO in terms of decreased future CL. Therefore, the VO can have more aggregate CL by not requiring time contributions greater than each individual’s CL estimate.

VLA Supposition #1. Use of current volunteer labor up to CL maintains or increases future CL, but use beyond CL decreases future CL.

3.2. Labor Assignment Issue #2: Employment of labor

- Typical TLA assumption: The amount of labor employed should be minimized, subject to adequately meeting demand.
- Typical VLA assumption: Unassigned committed labor may represent a cost, implying a possible advantage of using more labor than less labor.

As discussed in the prior section, TLA models represent labor as a cost that should be minimized. Excess labor is normally avoided in TLA, but allowed in order to comply with shift or tour restrictions (such as minimum shift length) or to provide a higher service level. The primary objective of most TLA formulations is to meet demand with a minimum amount of excess labor.

VOs might also be interested in minimizing labor utilization; however, this is less of an issue since labor
costs up to \( CL \) are trivial. In some cases, it may be detrimental to not use committed labor. Volunteers are frequently motivated by a desire to help others and contribute to the community (Gillespie and King, 1985), which will only be fulfilled by being engaged in the volunteer activity. Research has shown that volunteers who participate in meaningful activities are more likely to be committed to ongoing volunteering (Ryan et al., 2001). The volunteer work experience tends to encourage additional volunteering (Smith, 1994). Therefore, having a volunteer participate in a perhaps non-essential task that is perceived as meaningful may lead to increased committed labor. Conversely, failing to utilize a volunteer at a desired level may be result in lower future commitment.

**VLA Supposition #2.** Utilized volunteer labor is more likely to volunteer in the future than unutilized volunteer labor.

### 3.3. Labor Assignment Issue #3: Task assignment and future labor availability

- Typical TLA assumption: Future labor availability is not significantly influenced by current task assignment.
- Typical VLA assumption: Future committed labor is a function of current task assignment.

One would assume that employees in a traditional paid employment situation have preferences for task assignments. However, employee preferences for task assignment are not generally modeled in TLA literature. Some TLA models consider employee qualifications for specific tasks (e.g., Loucks and Jacobs, 1991), but that is modeled as an assignment constraint, not as a measured preference.

Other TLA formulations consider employee time preferences and availability (e.g., Baily and Field, 1985; Love and Hoey, 1990; Miller et al., 1976; Thompson, 1996; Warner, 1976), but not task preferences. Our review of labor scheduling and other TLA research literature did not show any that modeled task assignment as having any influence on future labor availability. As will be discussed below, published TLA models assume that available labor is sufficient to meet demand during any given planning horizon.

Under VLA, the availability of labor is limited by the ability to recruit and retain volunteers. Volunteer involvement has been described in research literature as being dependent on task assignment (Govekar and Govekar, 2002, p. 37). One study showed that the top two factors in volunteer satisfaction are the task being considered important and interesting (Hedrick, 1983). Another study showed that task assignment (being challenging, interesting, and requiring responsibility) is the most statistically significant predictor of volunteer service beyond initial training (Lammers, 1991, p. 138). In another study, prior experience that was similar to the volunteer experience was the most frequently cited motivation of volunteers (Rubin and Thorelli, 1984, p. 232).

There is an implied need for fit between the volunteer and the assigned tasks (Freeman, 1997). Assigning volunteers to tasks that are considered to be meaningful is positively correlated with greater commitment and frequency of volunteering, which effect was not realized when the task was less engaging (Ryan et al., 2001, p. 636). In other words, the perceived quality (i.e., being meaningful, engaging, etc.) of task assignment under VLA makes a difference in future CL (Smith, 1994, p. 251).

**VLA Supposition #3.** The level of future volunteer CL is directly related to the perceived quality of the present task assignment.

### 3.4. Labor Assignment Issue #4: Availability of labor to meet task demand

- Typical TLA assumption: Labor is sufficiently available to cover task demand.
- Typical VLA assumption: The availability of committed labor is finite and may not cover task demand.

For TLA, labor is generally assumed to come from a labor market which is either infinite or at least sufficient for task demand (e.g., Easton and Mansour, 1999; Lauer et al., 1994; Loucks and Jacobs, 1991; Love and Hoey, 1990; Mabert and Showalter, 1990; Mason et al., 1998; Thompson, 1992; Warner, 1976). TLA formulations that determine staffing levels do not generally assume constraints on labor availability. Instead, constraints such as Equation (TLA-2) are imposed to assure that all task demand is met. Even TLA papers that allow labor shortage (e.g., Easton and Rossin, 1996) do so to minimize the probability of overstaffing, not because of real or implied limits on labor availability. Also, most TLA formulations assume a constant variable labor cost for any staffing level, even though that would be more realistic to assume an increasing marginal cost.

For VLA, the system is typically constrained by the amount of committed labor (Caan and Amrofell, 1994, p. 344). When volunteer recruitment is performed prior
to scheduling, the availability of labor is assumed to be exogenous to the scheduling problem. When all committed labor is exhausted, the alternatives are: (a) to recruit more committed labor, (b) to shift to a paid labor pool, or (c) to limit task accomplishment to that which can be performed by committed labor (Freeman, 1997; Govekar and Govekar, 2002). In any case, there is a cost associated with task demand that exceeds committed labor.

**VLA Supposition #4.** Task demand in excess of committed volunteer labor results in a non-trivial shortage cost.

Distinctions between TLA and VLA perspectives will be summarized in the final section (Table 4). In the next section, we will confirm these VLA suppositions with empirical data. Our mathematical model will then build on those suppositions, and allow us come up with a VLA solution that is different from what would emerge from a typical TLA approach.

### 4. VLA empirical study

In this section, we present a case study to illustrate the VLA distinctions presented in the prior section. This will allow us to show how the VLA suppositions are manifested. We do not claim that this situation is globally representative of all VLA situations, but rather that it is illustrative of phenomena that occur in many VLA contexts. A subsequent section will describe other contexts with similar VLA characteristics.

The VLA context we studied involves individuals volunteering to review research papers for an international academic conference. That context was selected for study largely due to access to the volunteer data. The conference received 674 research papers to review, with multiple reviews needed for each paper. Reviewers are asked to read the assigned papers and provide comments with a recommendation of accept, marginal accept, or reject. The conference program committee then uses those recommendations to decide on the inclusion of papers in the conference program and proceedings.

The conference organization had no budget for paying reviewers, and thus relied completely on volunteer labor. To facilitate this process, the organization recruited volunteers from organization members, past conference participants, authors of submitted research papers, and others. In all, 796 people volunteered, of which 749 provided valid review assignment preferences in time to be considered. The conference was organized into 18 research tracks, which represent 18 somewhat distinct functional areas. Each research paper was submitted to a specific track according to the paper topic and content. The number of papers in each track varied (mean = 37.4, standard deviation = 20.8).

Volunteers had the opportunity to indicate their preferences for reviewing papers submitted to various tracks. Any given track could be selected as a first choice, second choice, or third choice (allowing multiple tracks in each category). In addition, volunteers specified the number of papers they would be willing to review, which is a measure of CL.

The next section will describe an optimal assignment of volunteers to tracks. However, due to the timing of data availability, the implemented volunteer assignment was performed in a sub-optimal manner. Some volunteers were allocated to tracks manually by the conference Program Chair, and others were allocated on a first-come first-serve basis by Track Chairs. Nevertheless, volunteers’ specified review limits were respected, and track preferences were accommodated to a large degree.

This non-optimized assignment of volunteers turned out to be fortuitous because it provided a variety of assignments that allowed us to confirm the VLA hypothesis from the prior section. Some volunteer assignments were quite in line with volunteer preferences, and others were not. At the end of the review process, volunteers were surveyed as to their experience in the review process relative to their originally stated preferences. In all, 449 volunteers (out of the full 796) responded to the ex post survey.

#### 4.1. Validation of suppositions

The volunteer survey asked questions about the review assignments relative to the original volunteer commitment. Results are given as they pertaining to specific suppositions (from the prior section). For each supposition and empirical observation, we state a corresponding goal to be included in the mathematical formulation.

**VLA Supposition #1** (Use of current volunteer labor up to CL maintains or increases future CL, but use beyond CL decreases future CL). As mentioned, no volunteer was asked to review more papers than they originally committed to. However, the survey included the question: “For you, what effect would asking you to review more papers than you originally said you would have on your future volunteering?” Of the 444 volunteers who responded to this question, a full 42.6% said it would have a negative effect, discouraging
them from volunteering in the future. Only 14.6% said that it would have a positive effect, encouraging them to volunteer more in the future. The net effect is clearly negative, implying that even though the cost of volunteer labor is trivial, there is a non-trivial cost to exceeding CL.

Goal #1. Avoid excess use of volunteer labor.

VLA Supposition #2 (Utilized volunteer labor is more likely to volunteer in the future than unutilized volunteer labor). For whatever reasons, 109 volunteers wound up getting no review assignments, and 41 of the 109 responded to a survey question about their likelihood of volunteering again in the future (see Table 1, where \( A_v \) is the number of review assignments for volunteer \( v \), \( CL_v \) is the number of reviews volunteer \( v \) said he or she would do, and \( N \) is the number of respondents in each given sub-group).

Observe that 39.0% of the unassigned respondents said they were less likely to volunteer to review again the subsequent year. Contrast this with reviewers who received one or more assignments (2.0%), and those who received the number of review assignments they asked for (1.8%). Interestingly, those who received one or more assignments but less than the volunteered number were not significantly different from those who received the volunteered assignment quantity. These data indicate that the cost for non-assignment primarily occurs for those who receive no assignment.

The “satisfaction” column of Table 1 shows mean scores for a survey question asking how satisfied volunteers were with the number of reviews they received (on a very dissatisfied −3 to +3 very satisfied scale). Note that the unassigned volunteers had a negative satisfaction mean. For sub-assigned volunteers (i.e., where \( 0 < A_v < CL_v \)), the mean satisfaction rating was positive but lower than the mean for fully assigned volunteers.

Goal #2. Avoid non-utilization of volunteer labor.

VLA Supposition #3 (The level of future volunteer CL is directly related to the perceived quality of the present task assignment). Interestingly, the survey results show that volunteers assigned to other than their first choice tracks were no less likely to review again than volunteers assigned to first choice tracks. However, nine survey respondents were only assigned papers outside of their track selection, and all but one completed a track-assignment satisfaction question. Even though that is a small sample, those eight were significantly \((p < 0.05)\) less satisfied with their assignments than those assigned in their chosen tracks, even if not to first choices. There appears to be a minor advantage from assigning within track requests for this setting. This advantage may be more pronounced in settings where the various task areas are less similar.

Goal #3. Satisfy volunteer preferences for task assignments if possible.

VLA Supposition #4 (Task demand in excess of committed volunteer labor results in a non-trivial shortage cost). Track Chairs obtained labor for reviews from three sources: (1) volunteers, (2) authors of conference submissions, and (3) other people recruited by the Track Chairs. Filling the review needs with volunteers was easy, since the volunteer list was provided to the Track Chairs. Further, 75% of the reviews assigned to volunteers were completed by the stated review deadline, whereas only 45.8% of the reviews assigned to non-volunteers were completed by the review deadline. A full 22.9% of non-volunteers never responded to the invitation to review, and 23.7% responded by saying they would not do the review.

One might think that authors of conference submissions would be reliable reviewers (due to their expressed interest in involvement in the conference), but that was not the case: only 45.6% of non-volunteer authors completed reviews by the review deadline, compared with 78.8% of authors who volunteered. Non-volunteer authors were even less reliable than those who were neither authors nor volunteers (47.9% finishing by the review deadline). There is a significant reliability cost for using non-volunteers, even if they are authors.
Goal #4. Minimize the shortage of satisfying task demand with volunteers.

We will give this fourth goal particular attention due to the compelling expectation of increasing marginal costs of unmet task demand. When there are multiple task areas and insufficient volunteer labor, there is likely to be a need to balance the task shortage across the different task areas. Given increasing marginal cost of task shortage within each task area, balancing shortages can reduce the overall shortage cost. A few different approaches to task shortage balancing will be considered in the mathematical formulation.

5. VLA optimization and TLA comparison

The formulation presented in this section applies to the reviewer VLA problem described in the prior section, but is applicable to a wide variety of VLA problems, as described in the subsequent section. The formulation embodies the assumptions and suppositions of VLA. This initial VLA formulation is task-focused, and does not include the time dimension. The subsequent section will describe how it can easily be extended to consider time assignments.

We define a decision variable matrix:

\[ A_{v,t} = 1 \text{ if volunteer } v \text{ is assigned to task } t, \text{ otherwise } 0. \]

In the reviewer assignment problem, the “task” categories \( t \) are the 18 tracks (i.e., \( t \in 1, \ldots, 18 \)).

We provide limits on volunteer-task assignments:

- \( L_v \) = lower limit of assignments for volunteer \( v \) without a cost.
- \( U_v \) = upper limit of assignments for volunteer \( v \) without a cost.
- \( U^E_v \) = upper limit on excess assignment (above \( U_v \)) for volunteer \( v \).
- \( U^E_v \) can be considered the amount of overtime allowed for each volunteer.

- \( L_t \) = lower limit of assignment need for task \( t \) without a cost.
- \( U_t \) = upper limit of assignments for task \( t \) (absolute).
- \( U^E_{v,t} \) = upper limit of assignment of volunteer \( v \) to task \( t \).

The reason we have both \( L_v \) and \( U_t \) parameters is according to the need to be flexible in allowing specific task assignments. \( L_v \) corresponds to the \( r_t \) term of the TLA formulation. \( U_t \) recognizes that some tasks can take on additional labor in order to assure that volunteers are appropriately assigned. In other words, we allow for the idea that it is sometimes better to employ more than the minimum number of required workers, in order to give those volunteers assignments they consider meaningful.

The previous section introduced four goals, and thus we will use a goal programming methodology. Goal programming has been used in TLA contexts (e.g., Brusco and Johns, 1995; Easton and Rossin, 1996; Jaumard et al., 1998). For example, Loucks and Jacobs (1991) minimized: (a) excess labor assignments and (b) squared deviations from employee work time targets. Our VLA goal program will be more complex than that, allowing a \([L_v, U_v]\) range of volunteer assignment targets, differing costs outside of those targets, a task assignment range, a non-linear cost for task shortage, and task preference ranks.

We define the following goal deviation variables:

\[ S_v = \text{assignment shortage for volunteer } v. \]
\[ E_v = \text{assignment excess for volunteer } v. \]
\[ S_t = \text{assignment shortage for task } t. \]

Again, no excess task assignments above \( U_t \) are allowed. The goal divergence variables are weighted in the objective function according to the following cost parameters:

\[ CS_v = \text{cost per unit of assignment shortage for volunteer } v. \]
\[ CE_v = \text{cost per unit of assignment excess for volunteer } v. \]
\[ CA_{v,t} = \text{cost of assigning volunteer } v \text{ to task } t. \]

Note that \( CA_{v,t} \) is not relative to a divergence variable, but relative to the \( A_{v,t} \) decision variables, and allows us to model goal #3 (satisfy volunteer preferences). Also, we do not have a \( CE_v \) parameter because we assume that \( U_v \) is a hard constraint.

We previously described the desirability of modeling task shortage as having an increasing marginal cost. Therefore, we define the following general function set:

\[ CS(S) = \text{cost per unit of assignment shortage for task } t. \]

We will describe functional forms for \( CS(S) \) below.

A general task-focused VLA goal program is as follows:

**VLA:**

\[
\begin{align*}
\text{minimize} & \quad \sum_v CE_v E_v + \sum_v CS_v S_v \\
& \quad + \sum_v \sum_t CA_{v,t} A_{v,t} + \sum_t CS_t(S_t) \quad \text{(VLA-1)}
\end{align*}
\]
subject to

\[
\sum_t A_{v,t} + S_v \geq L_v, \quad \forall v \quad \text{(VLA-2)}
\]

\[
\sum_t A_{v,t} + E_v \leq U_v, \quad \forall v \quad \text{(VLA-3)}
\]

\[
E_v \leq UE_v, \quad \forall v \quad \text{(VLA-4)}
\]

\[
\sum_v A_{v,t} + S_t \geq L_t, \quad \forall t \quad \text{(VLA-5)}
\]

\[
\sum_v A_{v,t} \leq U_t, \quad \forall t \quad \text{(VLA-6)}
\]

\[
A_{v,t}, S_v, E_v, S_t \geq 0, \quad \forall v, t
\]

\[
A_{v,t} \leq U_{v,t}, \quad \forall v, t \quad \text{(VLA-7)}
\]

The goal program has four elements in the objective function (VLA-1), corresponding to the four goals previously described. Constraints (VLA-2)–(VLA-4) place bounds on volunteer assignment levels and measure divergence from the first two goals. Likewise, (VLA-5)–(VLA-7) set bounds for task assignments. All variables are non-negative integers.

5.1. Base problem parameters

The 749 volunteers specified the number of papers they would be willing to review which we consider to be CL and which are interpreted as \( U_v \) values. Most volunteers specified that they would review one, two, three, or four papers. Some volunteers specified that they would be willing to do “any” number of reviews, which is subject to numerical interpretation. Fifty reviews is perhaps a bit unrealistic; for the sake of modeling, we represent “any” as six. Given that interpretation, the reviews volunteered to review a total of 1830 papers (in specific tracks). For the sake of study, we allow one assignment above \( U_v \), which sets \( UE_v = 1 \).

\( L_v \) could be zero if one supposes that volunteers would be satisfied with no assignment. However, we have shown that providing no assignment comes with a cost, implying that \( L_v > 0 \). For a base case, we will set \( L_v = 1 \), implying that at least one assignment is better than none (which is consistent with our empirical findings).

There were 674 papers to review, spread across 18 regular tracks. Ideally, it is good to have an odd number of reviewers for each paper, to avoid split accept/reject recommendations. Three is a good number of reviewers. However, experience has shown that a sizable percentage of reviewers fail to complete reviews by the necessary deadline. As a result, it is common practice to invite extra reviewers to reduce the need to scramble for reviewers at the review deadline. For a base case parameter, we will set \( L_t \) at \( 4D_t \), where \( D_t \) is the demand (i.e., number of manuscripts to review) for track \( t \). This is the ideal three reviews plus one buffer. That presents a total number of reviews at 2696, almost two-thirds of which might theoretically be handled by the 749 volunteers. (The mean \( U_v \) value was 2.29 and \( \sum_v U_v \) was 1717.) Since the volunteers selected specific tracks, and the number of papers per track varied significantly, it was uncertain a priori whether or not all volunteers could be used.

There is little problem with having excessive reviews for each paper, but for this study we will limit \( U_t \) to \( 5D_t \), which is five reviews per paper. Track Chairs may consider it burdensome to have to sift through excessive reviews in making decisions.

We set \( U_{v,t} = 0 \) for papers in tracks not selected. In this case, we do not limit the number of papers a reviewer reviews in a given track. Therefore, \( U_{v,t} = U_v + UE_v \) for selected tracks, which is the maximum number of assignments for each given volunteer.

5.2. Base cost parameters

As mentioned, individuals listed their track preferences in three categories: first choices, second choices, and third choices. These are coded in a matrix of preferences \( P_{v,t} \) as the choice level of volunteer \( v \) for reviews in track \( t \). For simplicity, we set \( CA_{v,t} = P_{v,t} - 1 \), so that there is no cost for giving someone a first choice, and in increasing cost for giving secondary or tertiary choices.

The values for \( CS_v \) and \( CE_v \) likely vary across individuals, but individual parameter estimates would be very difficult to obtain. For this study, we will settle for approximations that are constant across volunteers. It appears to be slightly more costly to provide excessive assignments than insufficient assignments, but either being significantly more costly than not accommodating preference ranks. We thus use \( CE_v = 10 \) and a slightly smaller \( CS_v = 9 \).
Finally, we specify CS, the cost of not filling tasks. At the simplest level, we might specify CS(S) = K1S, where K1 is a scaling constant. This makes the cost of shortage in one track equivalent to shortage in another track. One disadvantage of this function is that it will not allocate reviews in any systematic way across tracks, other than according to the track preferences of volunteers.

An alternative is to model task shortage as an increasing marginal cost. This is realistic both theoretically and practically. The concept of increasing marginal costs is fundamental to economic theory. In practical terms, when a track leader has to find reviewers, he or she will often use friends and accessible colleagues first, and then acquaintances, then non-acquaintances. In other words, it is increasingly difficult to locate and recruit reviewers.

An increasing marginal cost task shortage function is CS(S) = K2S2, where K2 is another scaling constant. This is good because it attempts to balance the shortage numbers across tracks. However, the tracks have widely varying numbers of papers (i.e., Dt varies in t). That task shortage cost function would give advantage to tracks with many papers. A function that would allocate shortage according to track review needs is CS(S) = K3(S/Lt)2.

5.3. Typical TLA parameters

For comparison purposes, we construct a set of VLA parameters that represent the general TLA problem assumptions as discussed previously. Again, we recognize that TLA occurs in many variations, and simply attempt to capture the common embodiments.

TLA assumes a non-trivial labor cost at any staffing level. Therefore, we set LV = UV, with CSV = −1 so that all staffing up to UV, represents a cost, and CEV = 2 to represent an “overtime” cost for each volunteer. Further, we set UEV = M1, an arbitrary large value, to represent the labor pool being unconstrained. We set CAx,t = 1, to represent the common situation of no explicit preference for task assignment. The constraint to meet all task demand can be represented by using CS(S) = M2S, again where M2 is an arbitrary large value.

The base VLA and typical TLA parameters are summarized in Table 2. We chose K parameter values to just avoid excess use of volunteers, and thus have the shortage allocation results be comparable across the three candidate CS(S) functions. This is in contrast to the comparative TLA, which assumes sufficient labor to meet all task demand.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base VLA value</th>
<th>Comparative TLA value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV</td>
<td>1</td>
<td>UV</td>
</tr>
<tr>
<td>UV</td>
<td>Given by volunteers</td>
<td>Same</td>
</tr>
<tr>
<td>UEV</td>
<td>1</td>
<td>M1</td>
</tr>
<tr>
<td>CSV</td>
<td>9</td>
<td>−1</td>
</tr>
<tr>
<td>CEV</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Lt</td>
<td>4Dt</td>
<td>Same</td>
</tr>
<tr>
<td>Ut</td>
<td>5Dt</td>
<td>Same</td>
</tr>
<tr>
<td>Ut,t</td>
<td>Uv + UEv if selected</td>
<td>0 otherwise</td>
</tr>
<tr>
<td>CAx,t</td>
<td>x − 4</td>
<td>1</td>
</tr>
<tr>
<td>CS(S)</td>
<td>K1S</td>
<td>M2S</td>
</tr>
</tbody>
</table>

5.4. Solution procedure and results

This problem is an integer program, which normally would be difficult to solve since general integer programming is known to be NP-Complete. However, with a little effort, the formulation can be coerced into a mincost network flow representation, as shown in Fig. 1.

Arc flow bounds are shown in brackets. Most of Fig. 1 is self-explanatory. The one aspect that needs explanation is the representation of the non-linear CS(S) function. This is accomplished by a series of arcs between the “unmet task demand” node and the task nodes. Each arc has a flow capacity of 1 (minimum flow zero), and a cost equal to the first differences of the CS(S) function, so that the commutative arc costs equal the non-linear cost function values. For example, if CS(S) = S2, then arc costs would be calculated as follows:

Arc # | CS(x) | Arc cost = CS(x) − CS(x − 1) |
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1^2 = 1</td>
<td>1^2 = 1</td>
</tr>
<tr>
<td>2</td>
<td>2^2 = 4</td>
<td>2^2 − 1^2 = 3</td>
</tr>
<tr>
<td>3</td>
<td>3^2 = 9</td>
<td>3^2 − 2^2 = 5</td>
</tr>
</tbody>
</table>

and so forth

Thus, the number of arcs in the set with non-zero flows is equal to Sn, with the total cost being equal to the desired CS, value. This technique for including non-linear cost functions in network flow formulations only works if the non-linear cost function is convex, as are all increasing marginal cost functions.

Mincost network flow problems can be solved optimally in polynomial time by a variety of algorithms (Evans and Minieka, 1992). The one we used was devised by Goldberg (1997) and is known to be particularly efficient even for large problems.
5.5. Solution quality metrics

We evaluate solution quality in terms of our four goals, which are as follows.

For goal #1 (avoid excess use of volunteer labor), we measure first and second moments of volunteer assignment excess variables (where $V = |v|$):

$$
\mu(E_v) = \sum_v E_v / V = \text{mean volunteer assignment excess.}
$$

$$
\sigma(E_v) = \text{standard deviation of volunteer assignment excesses.}
$$

For goal #2 (avoid non-utilization of volunteer labor), we similarly measure moments of volunteer assignment shortage variables:

$$
\mu(S_v) = \text{mean volunteer assignment shortage.}
$$

$$
\sigma(S_v) = \text{standard deviation of volunteer assignment shortages.}
$$

For goal #3 (satisfy volunteer preferences for assignments if possible), we measure the mean preference ranking value for solution assignments:

$$
\mu(P_v, t \mid A_v, t > 0) = \text{mean ranking of granted request.}
$$

Goal #4 (minimize the shortage of satisfying task demand with volunteers) can be measured different ways, depending on the task shortage balancing objective.

$$
\mu(S_t) = \text{mean task shortage.}
$$

$$
\sigma(S_t) = \text{standard deviation of task shortage.}
$$

$$
\mu(S_t / L_t) = \text{mean percentage task shortage.}
$$

$$
\sigma(S_t / L_t) = \text{standard deviation of percentage task shortages.}
$$

The one other item we track is $\sum_v A_v, t$, which is the total number of assignments given.

6. Results

Solution results for the base problem and the comparative TLA instance are shown in Table 3. Specific task shortage cost functions $CS_t(S_t)$ are shown.

Observe that the comparative TLA solution forced excess use of volunteer labor in order to fully satisfy task demand, as planned. The VLA solutions avoided excess use of volunteer labor, instead leaving tasks unfilled as necessary. This distinction emphasizes a major difference between the TLA perspective (which tends to focus on meeting organizational needs) and a VLA perspective (which gives more attention to meeting the needs of volunteers).

In no instance did these test data result in volunteer assignment shortage (i.e., $S_v > 0$). This is circumstantial, and would not be expected to occur in general. We eliminated a priori any volunteers who only requested from other “special tracks” that did not have any refereed research papers, since it would be impossible to fill those requests. Nevertheless, it is conceivable that some track would have been extremely popular, with the volunteers for that track not ranking alternative tracks, leaving some volunteers unassigned. As it stands, the system was successful at providing meaningful assignments for all volunteers.

Further, the VLA solutions were quite successful at accommodating volunteers’ top-ranked requests, with only a small portion of assignments being other than top-ranked requests (as shown by the $\mu(P_v, t \mid A_v, t > 0)$ values near 1). The typical TLA approach which did not focus on satisfying labor interests obviously did worse at meeting those interests, with a 1.4889 average rank of
6.1. Sensitivity tests

The reported results used base case parameters. There are an endless number of tests that can be run over different parameter values, representing different weighting of goals, etc. There is not space herein to review those tests in any detail. The natural extension of this research is to explore strategic and managerial implications of VLA as ascertained from solution sensitivity to problem configuration and parameters. The following are a few brief examples.

We found it interesting to study the impact of reducing the cost of excess volunteer assignments (CEv) on the task shortage metrics. In particular, as CEv is linearly reduced, we find that Eν increases along an S-curve (i.e., convex followed by concave function). This implies that there is a point of maximum marginal gain in excess assignments from reducing the cost of excess assignments.

Another interesting area of sensitivity tests is with regard to the minimum number of assignments for each volunteer. We used base Lν = 1, which only provides a cost penalty if the volunteer gets no assignments. However, we might have observed a cost for volunteers who say they will review four papers, yet only get one assignment. That could be modeled by setting Lν = Uν, implying that anything less than the specified number of reviews would incur a cost. Interestingly, this also produces μ(Sν) = 0, with all volunteers being fully assigned. This is likely to be distinct to this data set, and may not occur in other VLA contexts.

7. Extension to multi-period VLA contexts

The task-focused approach and formulation can easily be applied in various other VLA contexts. The following are some examples:

- United Way. The United Way serves as an umbrella organization for thousands of local agencies. In addition to soliciting donations, the United Way recruits volunteers that could be assigned to specific agencies by VLA techniques.
- Parent Teachers Associations (PTA). At the start of every school year, local PTA chapters recruit parents to help with various PTA projects during the year.
VLA methods could be used to assign parents to projects.

- Religious ministries. Religious ministries may involve thousands of volunteers to be assigned to hundreds of possible fields of service. In some cases, the assignments are known beforehand. In other cases, volunteers may be asked for assignment preferences or about physical conditions (such as advanced age) that limit the range of possible assignments. VLA methods can be used to make assignments that are in the best interest of the volunteers and the organization.

However, other VLA contexts involve both task and time dimensions, such as the following:

- Olympics. For example, the 2002 Winter Olympics involved thousands of unpaid volunteers being assigned to work in dozens of venues. Volunteers had preferences and skills for specific assignments, and some assignments required specific physical abilities. VLA methods might be used to assign volunteers to venues according to those preferences and position requirements.

- Community Youth Soccer. Youth Soccer utilizes volunteer labor serving as coaches, referees, field preparers, team managers, etc. These tasks differ in volunteer interest and task need. In addition, volunteers may have preferences for working with particular age groups. VLA methods might be used to assign volunteers to teams and games according to those interests and needs.

- Habitat for Humanities (HH). HH organizes projects in many communities to construct homes for the needy. The homes are affordable largely due to using volunteer labor. Individual volunteers likely have skills or interests for particular tasks of the home construction process. VLA methods might be used to assign volunteers to tasks.

- Public television fund raising. Instead of relying on advertising revenues, public television receives much funding from week-long fund-raising campaigns. Volunteers staff call centers during the campaigns. VLA methods might be used to assure that the times of assignment coordinate with volunteers’ availability and preferences.

- Boy Scouts merit badge pow wows. A merit badge “pow wow” is an event in which Scouts can earn badges in specific areas over a one to three day event. Merit badge counselors are volunteers who work with boys on specific badges. VLA methods might be used to assign volunteers to merit badges according to interests and needs.

In these VLA settings, individual volunteers probably should not be given multiple task assignments that occur simultaneously. For example, a soccer referee cannot referee two games at the same time. The task-focused VLA formulation described above can easily be augmented to include a time dimension of assignment. An additional constraint set can assure that no volunteer is assigned to more than one task at a given time period. The volunteers could give preferences not only for task assignment, but also for time-period assignments. Fortunately, this increased formulation complexity does not prevent deriving a (slightly more complex) network flow representation, as depicted in Fig. 2.

The $p$ subscripts represent time periods. The $U_{v,p}$ parameters would be 1 when each volunteer can only be assigned to one task during each time period (or 0 if the volunteer is unavailable during that time period, in which case we would just not create that arc). The $L_{t,p}$ and $U_{t,p}$ parameters set bounds on task demand during each time period; for testing we simply allocate

![Fig. 2. Network flow representation of multi-period VLA goal program.](image_url)
requirements for each task evenly across task time periods. Note that now the task shortage is subscripted by time period, implying that the cost of task shortage is period specific. This is consistent with the cost representation in labor scheduling literature, as well as the services management principle of time-perishable capacity (Fitzsimmons and Fitzsimmons, 2004, p. 23). Excess volunteers during one period do not compensate for insufficient volunteers during another period (although a modified formulation could consider aggregate task shortage costs).

To test the robustness of our conclusions about the distinctiveness of VLA problems versus TLA problems, we repeated the comparative tests with a multi-period problem formulation. Since our empirical data did not have a time dimension, we simulated time periods by assigning specific tasks (i.e., tracks) to specific time periods. We varied the number of simulated time periods as well as the number of periods each task was assigned to. Tasks were represented sequentially across time periods, with the total requirements for each task divided uniformly across time periods for the given task.

The numerical distinction between solutions under VLA and TLA assumptions were again manifested for these multi-period problem instances. This occurred even though multi-period problems are somewhat more constrained than the task-focused problems (due to our limiting volunteers from having more than one assignment during any given time period). Future research might repeat this study using multi-period empirical data.

8. Summary

This research has illustrated ways in which the VLA is fundamentally different from typical TLA. The two perspectives are summarized in Table 4. We were able to incorporate these differences into a goal program that accounts for the peculiarities of VLA. We showed that a TLA solution was different from a VLA solution for the given data set, as well as when we included simulated time-period data.

The VLA distinctions and the VLA formulation are quite general, and can be easily applied to other VLA contexts. Nevertheless, context-specific issues are sure to exist. Future research might look at ways of augmenting the VLA formulation to meet other contextual needs.

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