Connecting Social Networks and Scheduling Networks: An application to the Red Cross

Mariana Escallon-Barrios, Reut Noham, and Karen Smilowitz
Industrial Engineering and Management Sciences, Northwestern University // marianaescallon2023@u.northwestern.edu, noham.reut@northwestern.edu, ksmilowitz@northwestern.edu

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Motivation

The mission of the American Red Cross, *to prevent and alleviate human suffering in the face of emergencies by mobilizing the power of volunteers*[1], applies not only to those impacted by large-scale disasters, but also to those affected by local disasters, such as house fires and flooding. At the American Red Cross of Chicago & Northern Illinois, volunteers respond to over 1,400 local disasters each year, providing assistance for food, clothing, shelter, and other services. The Red Cross has two primary objectives for disaster response: (i) respond quickly to clients and (ii) provide a meaningful experience to engage all volunteers. The first objective is simple to measure, but is often at odds with the second. One can ensure a quick response by dispatching volunteers with a strong reputation. Such a policy could limit engagement of new volunteers. While engagement is difficult to measure, data from the last five years shows that 20% of volunteers respond to 80% of incidents, leaving opportunities to improve the participation of 80% of volunteers. In this work, we combine social network analysis and network optimization to better understand volunteer behavior and use this understanding to develop scheduling policies to increase engagement and effective responses.

Problem Statement

Disaster response volunteers sign up for shifts pn a schedule through a Red Cross web application, Disaster Cycle Services Operations (DCSOps). When an incident occurs, dispatchers (volunteers themselves) use this DCSOps schedule to identify and deploy response volunteers to the event. The Red Cross believes strongly in using DCSOps to enable volunteers to schedule themselves, thus "owning" their experience, rather than more common top-down volunteer scheduling approaches featured in the operations research literature (e.g., Falasca et al. (2011)). Analysis of response and scheduling data (Fox et al. (2015)) suggests that this process results in a mismatch between the

number of volunteers scheduled for a shift (supply) and the likelihood of an incident (demand). With insufficient coverage, responses can be delayed and dispatchers then rely on known volunteers to respond, resulting in the 80/20 split in response. In this work, we utilize social network analysis to characterize patterns in volunteer scheduling and response behavior and use these insights to develop scheduling policies to engage a wider range of volunteers, ensure a quick response, and maintaining schedule autonomy for the volunteers.

Social Network Analysis

Using social network analysis approaches, we study schedule, dispatch and response data over a five-year period with over 800 volunteers and 7,000 incidents, identifying challenges and opportunities.

— *Time slot preferences lead to supply / demand mismatches.* Analysis of a multi-level network between volunteers and time slots supports the finding of Fox et al. (2015) that popular time slots (greatest supply) are not necessarily the time slots with the highest likelihood of incidents (greatest demand).

— *Engaged volunteers sign up in self-formed groups.* Using a Separable Temporal Exponential Random Graph Model (STERGMs) and proximity timelines, we observe evidence that a subset of volunteers sign up in groups and that many such volunteers have response rates over 60%. According to Ellis (2005), organizations with group volunteers are more successful in engaging volunteers.

— *Engaged volunteers sign up consistently by day of week or time of day.* Using Exponential Random Graph Models (ERGMs), we explore the extent to which volunteers show evidence of consistent scheduling patterns either by time of the day or day of the week. We find that volunteers with more consistent scheduling patterns tend to have higher response rates.

The social network analysis highlights an opportunity to address schedule imbalance; such as creating formal mechanisms to allow new volunteers to join such groups. New volunteers could also benefit from schedule consistency; however, any changes to the scheduling process should ensure that all volunteers can continue to sign up in recurring patterns.

Scheduling Network Optimization

With insights from the social network analysis, we propose a hybrid team-based scheduling model (similar to full team scheduling in some regions). Under a hybrid model, a small subset of volunteers are assigned to teams led by experienced volunteers. Our proposed hybrid approach to scheduling volunteers is comprised of (1) recurring slots reserved for teams (shown in two colors in Figure 1 for two teams) and (2) a large number of "open" slots for the remaining general volunteers to select in DCSOps as is currently done. Finding the appropriate balance of slot designations between teams and general volunteers is critical to ensure the success of the new volunteers in

teams and the continued engagement of general volunteers. Such designations should recognize the characteristics of volunteers (e.g., likelihood of a positive response to a dispatcher call) and time slots (e.g., likelihood of an incident occurring) determined through analysis of DCSOps data.

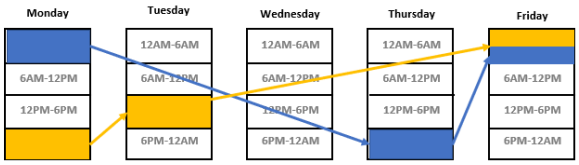


Figure 1 **Path-based representation of team schedules: each color represents a different team schedule over a five-day period**

Given space constraints, we do not present the scheduling model, but rather we highlight several key factors related to modeling and solution approaches. The overall objective is to develop a hybrid scheduling tool to increase the engagement of the volunteers by providing an overall meaningful experience while ensuring that all time slots are sufficiently covered. Unlike traditional slot-assignment models, we model the teams' schedules as paths through a temporal network. The use of path-based formulation allows us to account for schedule consistency and schedule-dependent response rates for the groups. Figure 1 shows two possible team schedules, represented by paths of assigned day/time slot combinations. While the yellow path consists of a mix of time-of-day slots (morning, late afternoon and evening), the blue path demonstrates consistency with two morning slots (Monday and Friday). This consistency may be valuable for the volunteers on a team; however, the cost of removing these time slots for general volunteers can be relatively high. The path scheduling variables also allow us to capture the impact of uncertainty. Importantly, the problem has both exogenous sources of uncertainty (e.g., whether an incident occurs is independent of scheduling decisions) and endogenous sources of uncertainty (e.g., a volunteer's likelihood of positively responding to a call may be a function of prior scheduling decisions). If teams are scheduled routinely in undesirable time slots, the response rate of volunteers may decline, see Sampson (2006)).

The structure of the schedule plays an important role in the formulation of the objective function that aims to attain appropriate coverage and high satisfaction of all volunteers. We use a max-min approach to attain a balance coverage developing metrics to capture the value of a schedule, in terms of schedule consistency and the likelihood of response opportunities to engage volunteers. We analyze the change in the preferences of the general volunteers when we eliminate some time slots and limit their scheduling options. We consider this impact when deciding which time slots to assign to teams.

Since enumerating all paths *a priori* is intractable, we employ a column generation approach to iteratively add candidate paths to the model, adapting approaches to the unique objective and constraints of this model. We show that even with a simplified objective function of maximizing the minimum expected coverage of a time slot, solving the max-min model through column generation is problematic. Incorporating the change in preferences of a volunteer when a time slot is not available, affects the coverage of the schedule and increases the number of nodes in the network in an exponential way. To handle this challenge, we develop a heuristic that combines dual variable information with our knowledge of desirable schedule characteristics from the social network analysis. For the pricing problem, we apply a bidirectional DP approach that allows us to reduce the size of the network.. This algorithm not only works well with the simplified objective function, but it can also be adapted to add complexity for more detailed variants of the objective function. We will present computational tests to highlight the potential for team scheduling.

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Notes

[1]American Red Cross Mission Statement; `www.redcross.org/about-us/who-we-are/mission-and-values.html`