Routing for Rural Health: Optimizing Community Health Worker Visit Schedules

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Abstract

Community health worker programs provide healthcare to those living outside the financial and physical reach of the standard health infrastructure. These programs are particularly prevalent in low resource regions. Frequently such programs involve community health workers making household visits across a significant geographical area. We suggest that this problem can be posed as a formal routing and scheduling problem, and to use techniques developed from solving the travelling salesman problem with time windows. In addition, household visits can generate a series of future follow up visits, a feature not often handled in the combinatorial scheduling and routing literature. We present the basic problem and outline potential research directions.

Worldwide, community health worker (CHW) programs provide access to health information and interventions for people outside the financial or physical reach of the standard healthcare infrastructure. Such programs include the Lady Health Worker program in Pakistan, the Millennium Village Projects' CHWs in Africa and Bangladesh Rural Advancement Committee's (BRAC) CHW programs in multiple countries. Though there is a large amount of variation between different CHW programs, many involve a community health worker making household visits in order to provide health education, dispense common over-the-counter medication, or perform limited medical procedures.

There is encouraging evidence that community health workers are associated with positive improvement in community health. For example, recent work by Baqu et al. (2008) found that in a large randomized trial, community health workers were associated with an improvement of over 30% in neonatal survival rates in Bangladesh. Yet in this intervention, each community health worker was responsible for roughly 4000 people, and 20% of children failed to receive a single post-natal visit, let alone the recommended three visits in the week. In addition, Baqu and colleagues report that CHWs "attended less than 5% of all births because of their high workload, travel distances, and difficulties in receiving timely notification of deliveries."

In this and a number of other CHW programs, community health workers need to visit a large number of households, separated by non-trivial distances. There are many household visit types, such as regular check ups, prenatal visits, and visits to dispense pneumonia medication. These visit types come with different time granularity scheduling constraints: regular checkups can occur almost anytime, prenatal visits should be at regular intervals, and a pneumonia patient must be visited frequently over a short time course. In addition, different visit types will take different mean durations of time to complete. Depending on the focus of the CHW program, different visits will have different priorities. In several programs, like the Bangladesh study, CHWs have too many visits to accomplish. In such cases, each day a CHW is faced with a limited amount of time and a large number of potential household visits to do, each of which is associated with different priorities. The CHW must reason about uncertainty over travel and visit duration, the relative proximity of households, and the relative timing constraints of different visits.

This is an incredibly complex problem to solve when there is not enough time to do all the visits, and to our knowledge, typically CHW visit scheduling is done in an ad hoc way, either by the community health worker herself, or by program administrators. In these limited resource situations, there is a significant potential for optimization to help use CHWs' time in the most efficient manner to improve prioritized health outcomes for the community they serve. Given this, we propose posing CHW household visit scheduling as a formal schedule and routing optimization problem.

We first frame CHW scheduling and routing as an instance of multiple traveling salesman problems with time windows, and then discuss additional problem features, including one that may lead to novel scheduling research.

Problem Formulation

To provide continuity of care, and build relationships between a community health worker and the individuals she serves, we first assume that community health workers are responsible for a fixed set of households. A simple approach for doing this is to iteratively step through the community health workers and assign the nearest household to the CHW's home at each step. This ensures that all CHWs are responsible for the same number of households, but does not consider total work time for each CHW, which is a function of the household locations and associated household

visits.

If we then seek to minimize the total time of each CHW to cover all the visits to households within her jurisdiction, while satisfying the time window constraints for each visit, then this problem becomes N instances of the travelling salesman problem with time windows (TSPWTW). This is a well studied problem that is formally hard: the travelling salesman problem is NP-complete.

The community health worker visit scheduling problem also possesses a number of additional features not captured with the standard TSPWTW formulation, such as: varying visit type priorities, varying visit durations and travel cost, patients missing their visit by being out, and differing numbers of households in need of visitation. Related problems, such as package delivery, have overlapping features, but as these features complicate the problem, part of our future work will be to identify which subset of the problem features are most important for creating useful schedules.

One fairly unusual feature of the CHW scheduling problem is that, beyond a patient not being home, a single visit may trigger a sequence of additional visits, each with their own timing constraints. For example, discovering that a child has pneumonia will necessitate the introduction of several new visits over the next few days. To our knowledge there is little routing work which formally considers the possibility of visits triggering a set of additional visits or tasks.

Related Research

Routing and scheduling problems are ubiquitous in the real world, and the research progress made in solving them has lead to a wide number of impressive success stories. For example, Etah Dairy in Uttar Pradesh, India, used route optimization to save thousands of dollars and also reduced the amount of milk ruined by long trips in hot weather (Sankaran and Ubgade 1994). In solid waste collection in New York, route optimization over 72,000 stops allowed fewer trucks to be used, at a savings of approximately 1 million dollars a year (Golden, Assad, and Wasil 2002).

The most similar problem to CHW visit scheduling is for home health care service, such as for visiting nurse associations. Steeg and Schröder (2007) used a heuristic approach to optimize routing, and tested their results on a periodic vehicle routing problem with time windows benchmark problem in the literature. Sachidanand et al. (1997) focused on creating a system for the Visiting Nurses Association in Alabama, and were particularly interested in making a user friendly tool that could be deployed. Both these approaches assume the number of visits is static. Aside from this work and some commercial systems, such as OptiTime[1] and Ankota[2], there appears to have been little work on home health visit schedule-routing.

Varakantham and Smith (2008) consider a scheduling problem where tasks have durational uncertainty and can trigger follow up tasks. However, they assume that the number of visits is known in advance (in other words, they assume they know how many tasks are triggered, instead of assuming this is a stochastic variable available only at run time). In addition, their solution is not for multiple location problems, which is a key aspect of the CHW problem. Of course, one alternate to considering triggered events is just to reschedule each day: whether it is preferable to explicitly consider the potential for triggered follow up events when planning, or to simply reschedule each day will depend on the time to compute a schedule, and if it is feasible to frequently redistribute schedules to health workers.

Current Work

We are currently working with a set of anonymized household locations from a Millennium Village in Africa. To start we will partition the households into a set of subregions. We will assume a single visit type, and solve each CHW's schedule as a TSPWTW problem. We will then compare the solution to scheduling by choosing households randomly each day from the pool of visits whose time windows are valid during a given day: we are not suggesting this is how CHWs choose their visits, but this is a simple baseline to compare to in the absence of pre-existing data on the routes followed by community health workers. We hope later to work with CHW program administrators to produce good schedules that meet their needs: such schedules may include some of the additional features identified above, and draw on the related literature in home health care scheduling.

Our ultimate goal is to create a scheduling system that could be used by existing[3] mobile phone programs devised to assist community health workers. We believe that optimizing scheduling may help overburdened community health workers have the greatest impact on health outcomes.

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[1] http://www.opti-time.com/en/improve-home-services.asp

[2] http://www.ankota.com/

[3] http://groups.google.com/group/ict4chw