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Discrete Optimization

Selective vehicle routing for a mobile blood donation system

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ABSTRACT

In this study, a mobile blood collection system is designed with the primary objective of increasing blood collection levels. This design also takes into account operational costs to aim for collection of large amounts of blood at reasonable cost. Bloodmobiles perform direct tours to certain activities to collect blood, but at the end of each day, they bring the collected blood to a designated depot to prevent its spoilage. The proposed system consists of the bloodmobiles and a new vehicle called the shuttle that visits the bloodmobiles in the field on each day and transfers the collected blood to the depot. Consequently, bloodmobiles can continue their tours without having to make daily returns to the depot.

We propose a mathematical model and a 2-stage IP based heuristic algorithm to determine the tours of the bloodmobiles and the shuttle, and their lengths of stay at each stop. This new problem is defined as an extension of the Selective Vehicle Routing Problem and is referred to as the SVRP with Integrated Tours. The performances of the solution methodologies are tested first on a real data set obtained from past blood donation activities of Turkish Red Crescent in Ankara, and then on a constructed data set based on GIS data of the European part of Istanbul. The Pareto set of optimum solutions is generated based on blood amounts and logistics costs, and finally a sensitivity analysis on some important design parameters is conducted.

1. Introduction

Blood donation logistics can be classified under the medical supply transportation problems as a healthcare logistics problem. Although blood transfusion is one of the most critical operations in various medical interventions, blood is a very limited resource. Since blood cannot be produced synthetically, donations constitute the only source. Worldwide average demand for blood is reported by WHO (World Health Organization, 2013) as 92 million units per year whereas the regular blood donors make up only 5 percent of the world population. Effective use of bloodmobiles may be helpful in raising the number of donors and their donation frequencies. Since bloodmobiles can also reach potential donors who have limited time and limited means of transportation, these vehicles can attract more donors than fixed donation points. Red Crescent and Red Cross Societies all over the world share virtually the same organizational structure for their blood collection units. These units consist of mainly fixed points (such as blood centers, hospitals and clinics) and bloodmobiles. Bloodmobiles are motor vehicles (usually bus or large van) containing necessary equipment for the blood donation procedure. Blood drives involving bloodmobiles usually take place in public places such as colleges and churches. These drives aim to reach at many donors that may not be planning to make a blood donation otherwise.

In this study, we propose a new cost efficient and easy-to-implement mobile blood collection system based on the practices of Turkish Red Crescent (TRC). Since TRC is a member of the International Federation of Red Cross and Red Crescent Societies (IFRC), these practices can easily be extrapolated to other national Red Cross and Red Crescent organizations due to IFRC's guidelines. The application of guidelines can differ from organization to organization, but a well-designed global model can be adopted by any organization.

There is a continuous demand for blood that needs to be met through donations. However, mobile blood collection is not the major part of blood collection in the world (including Turkey). In fact, most donations are taken at fixed locations. The structures and operational mechanisms of fixed locations and mobile systems used by TRC for its blood collection activities can be summarized as follows:

- *Fixed locations*: Regional Blood Centers (RBC), less developed Blood Centers (BC) and supporting facilities known as Blood Stations (BS) are the three types of fixed locations. RBCs are capable of performing every blood related action, such as collection, analysis, storage, and distribution. The coordination of activities in BCs and BSs are also among the responsibilities of RBCs. BCs, which are more common, can also perform basic analysis and storage whereas, BSs

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support only the collection and temporary storage of blood. Each mobile unit is assigned to either a RBC or BC, thus mobile blood tours are originated from these centers. In the system that is described by Sahin, Sural, and Meral (2007) there are 7 RBCs, 23 BCs and 34 BSs in Turkey.

- *Bloodmobiles*: In Turkey, bloodmobiles provide service at pre-arranged temporary locations such as governmental organizations, municipalities and certain public events, where the potential number of donors is large. Pre-determined locations are visited by bloodmobiles according to a weekly schedule. Locations and dates for mobile blood collection are usually determined by the host organizations and TRC. TRC assigns collector teams to these host organizations on the designated days. Blood collection at a designated point is a whole day activity including traveling, set-up and collection times. That is, a blood mobile cannot visit multiple locations on any given day. Due to the perishable nature of whole blood, the collected blood needs to be sent to the closest RBC/BC for analysis and storage within a maximum of 24 hours after its collection. To prevent spoilage, bloodmobiles return the collected blood to their assigned RBC/BC (depot) at the end of each day.

This paper proposes a new and more efficient mobile blood collection system that also utilizes a transporter vehicle, called the shuttle, in addition to the regular bloodmobiles. The main purpose of the shuttle is to visit all the bloodmobiles in the field at the end of a collection day and bring the collected blood to the depot. This approach enables the bloodmobiles to continue their tours without having to return to the depot every day. The problem is the determination of both bloodmobile and shuttle tours and the duration of stay for the bloodmobiles at each stop along their respective routes. Even though, this new system is designed based on the current practices of TRC it can be implemented by other Red Crescents and Crosses directly or with small modifications in their current system. For instance, in their study Doerner and Hartl (2008) describe Austrian Red Cross' bloodmobile tours as a combination of fixed bloodmobile locations and shuttles serving these bloodmobiles.

With our system, both the bloodmobiles and shuttles can be mobilized in the sense that, we decide on the points to be visited by the bloodmobiles, and durations of these visits as part of the solution output. As another example, American Red Cross (2012) performs same dedicated bloodmobile tours periodically and announces them in their website, expecting donors will visit these vehicles. This is very similar to what TRC does in its current practice, before the introduction of the new system suggested by the authors. Therefore, American Red Cross can update its tours using the structure that is going to be described in this paper, in order to achieve higher blood collection amounts by visiting the local activities with high expected number of visitors and employing shuttles to collect the blood. In brief, the system and the results reported in this paper can easily be adopted by other blood collecting organizations around the world including Austrian and American Red Cross organizations.

New system requires determining stops of bloodmobiles, the duration of stay for the bloodmobiles at each stop along their respective routes and finally the sequence of visiting these stops (i.e. tours) for both bloodmobiles and the shuttles. To the best knowledge of the authors', there is no study in the literature that simultaneously considers all these issues. The most closely related problem in the literature is the Selective Vehicle Routing Problem (SVRP) suggested by Chao, Golden, and Wasil (1996). The node selection and route determination tasks in SVRP correspond to the selection of the stops and routes of the bloodmobiles. However, our problem also requires deciding on the length of stay of each bloodmobile at the nodes along its route, and the daily routes of the shuttle to transfer the collected blood at the bloodmobiles in the field to the depot. Since SVRP does not include a mechanism that would simultaneously optimize the bloodmobile and shuttle tours, our model stands out as a new problem that can be considered as an extension of SVRP. Thus, we name it as the Selective Vehicle Routing Problem with Integrated Tours (SVRPwIT).

The rest of the paper is organized as follows: Section 2 presents a formal definition of the research problem followed by a review of the related literature. Section 3 proposes a mathematical model for this problem. In Section 4, the performance of the mathematical model is tested first on a real data set obtained from past blood donation activities in Ankara, and then on a constructed data set based on GIS (Geographical Information System) data of the European part of Istanbul. Section 5 proposes a 2-stage IP based algorithm as a more efficient technique to solve larger problems. Computational times and optimality gaps of this algorithm are compared with the exact solutions also in this section. Finally, the paper is concluded in Section 6, with a summary of the study and possible future research directions.

2. Problem definition and related literature

2.1. Problem definition

We design a new mobile blood collection system motivated from the current Red Cross and Red Crescent applications. In addition to the daily bloodmobile visits, the new system also allows 2- or 3-day stay-overs at any given point, while still conveying the collected blood to the depot in a timely manner to avoid its spoilage. The new system also proposes more frequent and better utilized bloodmobile tours over a weekly schedule. The routes are not limited to special, large-scale events. Quite contrarily, even smaller towns and suburban places can be visited to increase the collected blood volumes.

The proposed system of any given depot consists of its current bloodmobiles and an additional shuttle. The bloodmobiles start their tours at the beginning of the planning horizon and they may remain in the field without having to return to the depot until the last day as long as there are unvisited points with blood potential. They visit several potential locations once they leave the depot and spend at least one day at each location. Since blood collection is a whole day activity, a bloodmobile cannot visit multiple locations on any given day. If the estimated blood potential of a location is significantly high, a bloodmobile can stay there 1 or 2 more days. With the help of the new shuttle service, the unnecessary daily trips of bloodmobiles between the collection points and the depot are eliminated. Instead, the collected blood is transported to the depot by the shuttle, which visits every bloodmobile in the field at the end of each day. The only exception to this is the end of a bloodmobile tour at which time the bloodmobile returns to the center with its collected blood making a shuttle visit unnecessary. An illustration of integrated shuttle and bloodmobile tours is shown in Fig. 1. Fig. 1a depicts the potential stops of the bloodmobiles and the depot, and Fig. 1b shows the tours of three bloodmobiles, where the self-loops correspond to stay-overs. In Fig. 1c, the node labels indicate the days that they are visited by a bloodmobile. Finally, Fig. 1d –f shows a set of potential shuttle tours belonging to the first, second and third days of the planning horizon.

This new system aims to utilize bloodmobiles efficiently, in the sense of increasing the frequency of bloodmobile tours and reducing the operational costs of mobile blood collection system. The main decisions are:

- the locations selected among possible candidates for bloodmobiles' visits,
- the length of the stay at each location visited by bloodmobiles,
- tours of both bloodmobiles and shuttles based on bloodmobile locations on each day of the planning horizon.

The two objectives are maximizing the collected blood amount and minimizing the transportation costs of the vehicles. Since the tours need to be defined between stops that are chosen among potential places, our problem can be classified as a variant of Selective Vehicle Routing Problem, which is discussed in the following section.