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Reorganizing an existing volunteer fire station network in Germany

Dirk Degel*, Lara Wiesche, Sebastian Rachuba, Brigitte Werners

Ruhr University Bochum, Faculty of Management and Economics, Chair for Management, esp. Operations Research, Germany

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ABSTRACT

Volunteer fire departments have been founded to ensure public safety in case of fire and to provide support for professional firefighters. Most of the current stations date back to the beginning of the 19th century. Today, volunteer fire departments face numerous challenges, such as reduced number of following young volunteers or decreasing public budgets. We quantify these effects and identify different alternatives, such as relocating or closing of stations to minimize the impact on rescue service supply. Based on comprehensive case studies in Bochum, Germany it is apparent that these recommendations provide an excellent toolset for a prospective planning approach.

1. Introduction

Emergency services such as fire, emergency or police departments must provide high levels of service in order to ensure public safety. In Germany, local fire departments are responsible for fire fighting, rescue and emergency medical services (see e. g., Degel et al. [1]). These services are performed by professional and/or volunteer firefighters, depending on the size of the community. When considering large-scale disasters in particular, there is a need for additional support by volunteers because professionals need back-up capacity in case of mass casualty incidents (see e. g., Rauner et al. (2012) [2]). In this paper, we focus on urban regions and consider the volunteer fire department as additional supply to support professionals. The presented approach is of remarkable importance also for rural areas with few or no professional fire departments. In Germany [3] and other countries, such as the United States and Australia [4,5], a rapidly decreasing number of young volunteer firefighters is observable during the last years which leads to serious recruitment problems. Additionally, financial constraints and limited public budgets force municipalities to extensive savings and to efficiently utilize their resources. In the field of emergency services, it is difficult to realize these savings because the quality of the rescue service supply must be guaranteed in any case. Rescue service supply means a supply of the general public through firefighters as fast as possible, or more specifically in our case, support of volunteer firefighters. Based on these observations, the following research questions are formulated: Facing a decreasing number of volunteers and limited budgets, how can a volunteer fire station network be reorganized? Which alternatives and options such as closing and/or relocating stations can be used in order to minimize the impact on rescue services supply? Subsequently, which of these possible actions can be recommended and what is their impact on the current situation and the service quality?

The remainder of this article is structured as follows: Section 2 provides a problem description focusing on how the quality of rescue service supply can be evaluated by incorporating different performance criteria for location problems. In Section 3, we identify a necessary or basic level of rescue service supply using a mathematical optimization model similar to a modified Set Covering Location Problem (SCLP). An evaluation of a real world situation for the city of Bochum (federal state North-Rhine Westphalia, Germany) discusses the status quo according to different criteria. Based on two further optimization models (covering models, Sections 4.2 and 4.3) we analyze which stations could be closed or relocated in order to keep the resulting negative effects on rescue quality as low as possible. Reasonable alternatives to reorganizing a deteriorated situation are discussed and evaluated in Section 4.3, providing a detailed analysis based on parametric variations of a modified covering model. Finally, Section 5 summarizes the presented results and provides an outlook for further research.

2. Problem statement

Volunteer fire departments play a significant role in providing rescue supply in case of a fire, emergencies, large-scale events or even large-scale disasters (see e. g., Rauner et al. (2012) [2]). The volunteers' interests have to be carefully taken into account in a

* Corresponding author. Tel.: +49 234 32 24101; fax: +49 234 32 14267.
E-mail addresses: or@rub.de, dirk.degel@rub.de (D. Degel).

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planning approach (Falasca and Zobel (2012) [6]). In urban areas, volunteers extend the existing supply of professional firefighters and provide back-up assistance. In smaller cities and especially rural areas, the nearest professional fire station may be unable to reach some associated demand regions within reasonable time, giving volunteers an even higher importance.

To support in identifying optimal locations for fire stations or rescue services, a rich field of optimization models exists in literature. Recent surveys of models for emergency response have considered various key aspects (e. g., Farahani et al. (2012) [7], Li et al. (2010) [8], and Brotcorne, Laporte and Semet (2003) [9]). On a more general level, Başar, Çatay, and Ünlüyurt (2011) [10] provided a detailed taxonomy for emergency service stations location problems. Farahani, Steadie Seifi, and Asgari (2010) [11] surveyed papers with a special focus on multiple criteria facility location problems. In general, different criteria have to be considered to measure the quality of an existing location network and to integrate various stakeholders interests (e. g., Badri et al. [12]). In most of the existing papers, the important criterion is the ratio of requests served within a certain time standard to all requests. Particularly, many papers discuss timeliness as a criterion of major importance (e. g., McLay, Mayorga [13]). This time threshold only accounts for the first rescue or emergency vehicle arriving at the scene. Especially in urban areas, volunteers provide only additional support to emergency medical services or professional firefighters. Setup times for volunteers are long and include the time required to reach the station. In most cases, they are unlikely to be the first arriving emergency vehicle at a site. Thus, the locations of the volunteer fire stations should allow volunteers to arrive as fast as possible at a site measured in terms of the average time to serve all emergency calls or in terms of the maximum travel time to serve each individual call (e. g., Araz et al. (2007) [14]). In view of the fact that the number of volunteers is declining and budgets are limited, changes of the existing structures are inevitable leading to the close of stations in the worst case. When the closing of stations is unavoidable, the effects on travel times should be minimized.

Fig. 1 illustrates the two different levels analyzed in the following sections. In a first step in Section 3, we focus *a priori* on travel times in order to consider an average or minimum level of quality. Minimizing the average travel time per emergency call (equivalent to the minimization of the total travel time) can result in longer travel times to some regions with lower demand in the outskirts. The average time can be interpreted as public benefit or as the goal of the firefighters' management. Minimizing the maximum travel time yields the time required to serve any individual victims' request as soon as possible in a worst case scenario.

In a second step in Section 4, the resulting effects of relocating or closing facilities are measured *a posteriori*. Different (proxy) criteria are considered in order to discuss major effects without focusing on costs explicitly; the number of stations and relocations of existing locations are considered to estimate resulting cost effects. This

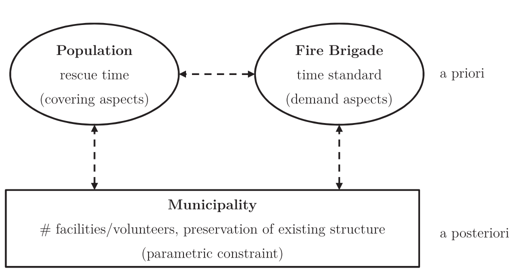

Fig. 1. Structural interdependencies among different criteria.

approach allows for the quantification of the impact of closing stations on rescue service supply and various interests in the presence of the mentioned challenges. It helps to find an optimal closing sequence supporting a system transformation from a given status quo to a basic level of supply, keeping the quality losses small. Overall, this study intends to provide strategic decision-support and evaluation of alternatives which can be considered as a prospective planning approach (see Chevalier et al. (2012) [15]). The following sections cover the two main aspects within an evaluation of the status quo (Section 3) and lastly, reorganizing or closing some of the existing stations (Section 4).

3. Locating volunteer fire stations–basis service level

The first step of this analysis identifies a required number of stations to ensure that each demand region can be reached within a given time standard from at least one volunteer fire station. The focus here is to determine a feasible solution; the prior discussed objectives will be integrated later on. Based on a modified SCLP, the number of necessary locations is calculated with a preference for using existing stations only. This aids to identify the minimum number of required stations which are needed in order to ensure a basic level of supply. The optimal solution of the basic level model is evaluated in terms of maximum and average travel times and the resulting level of coverage which is compared to the current situation, the status quo. The latter criterion allows to analyze aspects of availability of volunteers. Further, this allows to estimate the effects of a decreasing number of volunteers and thus fewer required stations.

3.1. Required number of volunteer fire stations

The demand nodes i and all potential location sites for volunteer fire stations j are summarized in the index sets $i \in I$ and $j \in J$ with $I = J$. Additionally, several subsets of J are introduced. The subset $\mathcal{F}$ (*fixed*) summarizes indices of either joint locations of volunteer and professional firefighters or newly built volunteer fire stations, which are considered as *fixed*. In this context, fixed means that these locations cannot be closed or relocated. The second subset $\mathcal{E}$ (*existing*) contains all indices of existing volunteer fire stations which can be closed or relocated, therefore, $\mathcal{F} \cap \mathcal{E} \neq \emptyset$. The decision maker can determine unavailable locations for particular scenarios which are summarized in the subset $\mathcal{U}$ (*unavailable*). In general, there are many other available potential sites $j \in J$ not included in one of the subsets $\mathcal{F}$, $\mathcal{E}$ or $\mathcal{U}$. These sites can be used to locate a volunteer fire station, if necessary. In order to calculate the minimum number of required facilities, a basic model for the SCLP [16,17] can be applied with few modifications. The travel times t_{ij} from a demand node $i \in I$ to potential locations $j \in J$ are calculated on the basis of the Euclidean distance d_{ij} and a constant travel speed v: $t_{ij} = d_{ij}/v$ and are assumed to be symmetric. For each demand region, a set of possible sites to locate a volunteer station can be identified as $N_i := \{j \in J \mid t_{ij} \leq T\}$ where T is a legal time standard. The binary variable $y_j \in \{0,1\}$ indicates whether a volunteer station is located at site $j \in J$ ($y_j = 1$) or not ($y_j = 0$). To restrict possible locations to the currently existing sites (if possible), we formulate additional constraints which ensure that only existing locations ($\mathcal{F}$ and $\mathcal{E}$, yet excluding $\mathcal{U}$) are used. Only if the minimum level of coverage cannot be guaranteed with the existing infrastructure, new stations are to be built represented in the model through high penalty costs M in the objective function (1). The following model determines the minimum number of stations required to provide a basic level of supply using the existing structure.