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An empirical comparison of relocation strategies in real-time ambulance fleet management

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A B S T R A C T

In order to ensure an adequate service to the population, Emergency Medical Services (EMS) rely on a given number of ambulances strategically located over the territory they serve. The arrival of calls to EMS being highly uncertain and dynamic, it may happen that at some point, the vehicles available to respond to these calls no longer cover properly all regions, even if the coverage was carefully planned initially. Relocation of ambulances may therefore be required during the day in order to achieve better performances. Some models tackling relocation have been proposed in the literature and it has been shown that using such strategies can help to improve overall performances. However, relocation generates movements that produce undesirable consequences from both economical and human resources management standpoints. Questions therefore arise: Is the relocation worth the effort? And if so, what form should it take? Unfortunately, this issue has not been investigated much up to now. This study thus focuses on evaluating and analyzing relocation strategies, and reports extensive simulation experiments allowing to analyze the performance of these strategies when the system faces different levels of workload. Our empirical study confirms that dynamic strategies dominate static ones and quantifies the improvements achieved with respect to service level, but also shows that such improvements are obtained at the expense of significant relocation costs.

1. Introduction

Emergency Medical Services (EMS) are critical elements of modern healthcare systems. In such systems, EMS are in charge of the pre-hospital component which consists of basic medical care and transportation activities performed from the reception of an emergency call to the release of the patient either in the care of a hospital or healthcare facility, or at the site of the incident if the patient does not require additional care. To provide this service to the population, EMS use a fleet of ambulances they locate strategically over the region they serve. However, even if the location of ambulances has been carefully planned in the initial static deployment/location plan, the uncertain nature of emergency calls, with respect both to their arrival times and their locations, may lead to a degradation of service level. Indeed, when some ambulances are dispatched to serve calls, the territory protected by the EMS will need to be covered with a reduced size fleet. Consequently, some areas of the region may be left without a proper coverage. For this reason, some corrective actions are generally required during the day in order to maintain or restore a good performance. One of the possible corrective actions is the relocation of ambulances.

Many studies dealing with ambulance fleet management show that the adoption of a relocation strategy can help improve the system performance, at least for their specific context. Although it is clear that the relocation of ambulances represents an interesting mean to maintain or restore a good service level, it also generates vehicle movements that lead to undesirable consequences from both economical and human resources management standpoints. Some questions therefore arise: Is relocation worth the effort? And if so, what form should it take? Unfortunately, this issue has not been investigated much in the literature. Indeed, Nair and Miller-Hooks (2009) observed that many studies consider the development of relocation strategies, but none of them really seem

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to assess the benefits and drawbacks of using such strategies over more classical and static location ones. Nair and Miller-Hooks (2009) therefore focus on the evaluation of a relocation strategy based on the results obtained solving a linear programming model. In this case, the use of linear programming requires a number of assumptions to be able to consider the different sources of randomness. Moreover, the strategy proposed by the authors is again only compared to the static case. In our opinion, even if it represents an interesting first step in the analysis of location and relocation strategies in a more realistic context, there is still a lot of work to do in this field.

The aim of this paper is to further the study of location and relocation strategies by performing a comparative analysis of different location and relocation strategies. This analysis seeks to quantify the benefits and drawbacks resulting from considering different dynamic strategies over more classical static ones. It also compares these strategies over various contexts with respect to workload. To conduct the analysis in a more realistic context, we have used a flexible and generic simulation model that was recently developed and presented in Kergosien, Bélanger, Soriano, Gendreau, and Ruiz (in press). Indeed, simulation can help in dealing more adequately with different stochastic aspects inherent to EMS that cannot be addressed easily in the formulation of mathematical models. The contribution of this paper is therefore twofold. First, we define and formalize four fleet management strategies that take into account the dynamic aspect of the problem, and model them using a common framework. Secondly, we perform the detailed analysis of their respective benefits and drawbacks over varied scenarios on a real-life context.

The paper is organized as follows. A brief literature review on location and relocation strategies is presented in Section 2. In the third section, the different fleet management strategies considered in this study are defined and the underlying mathematical models are presented. Finally, in the last sections, the simulation model designed to analyze and assess each of these strategies is briefly presented, followed by the results of extensive simulation experiments and their analysis. A discussion on potential research avenues concludes the paper.

2. Location decisions in EMS management

Three main types of location decisions arise in real-time management of ambulance fleets. First of all, at the beginning of their work shift, one needs to determine the initial location of ambulances. This location is referred to as the vehicle initial standby site or home base. Then, after completing a mission, a vehicle needs to be sent back to a given standby site. The repositioning problem thus consists in determining where to send a newly idle vehicle. Finally, relocation decisions are concerned with the modification of a vehicle standby site over its work shift. Multi-period relocations occur at given and fixed times over the planning horizon. Dynamic relocations rather occur when the system state justifies it. Decisions can then be taken based on compliance tables, which a priori defines relocations to perform for each possible state, or determined in real-time.

Few years ago, most of the work assumes that the location of given ambulances will remain unchanged for the entire planning horizon. The set of standby sites where ambulances will be positioned while waiting to be dispatched to respond to emergency calls is determined in the planning phase. This problem is commonly known as the static location problem. Once implemented, the corresponding location plan will remain unchanged, i.e. each ambulance will return to its designated standby site after completing a mission. Repositioning decisions are thus selected according to a pre-determined location plan. To better take into account the variation of the demand pattern throughout a day, the planning horizon can be divided into several time periods and a static location problem can be solved either for each period or over the whole planning horizon. This problem is generally addressed at the tactical level as opposed to the operational level of the problem considered in this paper. Static location problems are reviewed in Sections 2.1 and 2.2.

Nevertheless, as discussed in the introduction, under certain circumstances it may be beneficial to change ambulance locations or home bases during a day, using dynamic repositioning and relocation strategies, in order to take into account the evolution of the situation faced by the EMS. Doing so, one hopes to achieve a better service level to the population. Both dynamic repositioning and relocation strategies are discussed in Sections 2.3 and 2.4, respectively. Note that all dynamic problems described hereafter consider a single period planning horizon.

2.1. Single-period static location problem

Several approaches and models have been proposed to determine either the number and the location of ambulances required to achieve a given service level or, alternately, the location of a given ambulance fleet in order to maximize the system performance. Toregas, Swain, ReVelle, and Bergman (1971) were the first to explicitly formulate the ambulance location problem considering the widely used notion of coverage. Their model, the *Location Set Covering Problem*, seeks to determine the number of vehicles needed and their location in order to ensure that all demand zones can be reached (or covered) within a given time limit. The number of vehicles required to achieve such a coverage can however be very large and totally unrealistic in many practical contexts. Considering these practical limitations, Church and ReVelle (1974) therefore formulate the *Maximal Covering Location Problem* which aims to maximize the population covered by a given vehicle fleet. From these two seminal models, a significant number of models have been proposed to address the static location problem, among which we can cite the *Maximum Expected Covering Location Model* (Daskin, 1982, 1983), the *Maximum Availability Location Problem* (ReVelle & Hogan, 1989), and the *Double Standard Model* (Gendreau, Laporte, & Semet, 1997) to name but a few. ReVelle (1989), Marianov and ReVelle (1995), Brotcorne, Laporte, and Semet (2003), Goldberg (Başar, Çatay, & Ünlüyurt, 2004Bélanger, Ruiz, & Soriano (2012), Aboueljinane, Sahin, & Jemai (2012), and Aboueljinane et al. (2013) present interesting surveys of the numerous models applied to emergency vehicle location, focusing mainly on the field of mathematical programming, but also on those of simulation and queueing theory. Farahani, Asgari, Heidari, Hosseininia, & Goh (2012) also review covering problems in facility location, which are directly related to EMS location problems. Since the focus of this work is on relocation strategies, we will not review further the literature on the single-period static location problem and refer the interested reader to the good surveys listed above for details on the different models proposed to address it. The remainder of this section will instead be devoted to the description of the multi-period static location problem as well as the main dynamic repositioning and relocation strategies with a particular attention to the objective pursued.

2.2. Multi-period static location problem

Multi-period relocation strategies consider that the demand pattern may fluctuate throughout the day due, among others, to population movements (e.g. early morning, morning commute, mid-day, evening commute, evening, night, etc.). A workday is then divided into several time periods, according to the various demand profiles, and different location plans are established a priori for