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Optimal re-organization of a hemodynamics units system: A case study

Fabio Lazzaroni, Giovanni Righini *

Dipartimento di Informatica, Università degli Studi di Milano, Via Bramante 65, 26013 Crema, Italy

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ABSTRACT

We consider some optimization problems arising from the re-organization of a regional health care system concerning the treatment of patients affected by acute myocardial infarction (AMI). The study is focused on the reorganization of the system operations during the nights and the weekends that are the most critical periods. This requires to optimize both strategic and tactic level decisions, where conflicting objectives must be taken into account because several stake-holders are involved. For all optimization problems considered we present integer linear programming models and we provide computational results obtained in a case study for the province of Milan.

1. Introduction

1.1. The context

Acute myocardial infarction (AMI) is the most common cause of mortality in the world. In Italy it hits about two hundred thousands persons every year, causing 8% of deaths in the population aged between 35 and 74 [1]. The economic implications are not less impressive than the social ones: every angioplasty treatment costs about 9500 Euros.

Organizing a regional health care system in order to provide effective treatment to patients affected by AMI is not a trivial task. First of all, it involves several stake-holders with different and often conflicting objectives. Second, it requires both strategic level decisions, needed to set up the system, and tactic level decisions to exploit the available resources optimally.

Additional complexity comes from the need to re-organize an existing health-care system, which may be even more complex than establishing a new one from scratch. This is especially challenging when re-organization is deployed with the objective of reducing public expenditure to make the whole system economically sustainable, while meeting the high expectations patients have based on their past experience of an effective but economically unsustainable system.

The main strategic level decision concerns the optimal number and location of hemodynamics units that are actually needed. When re-organizing an existing system, an important insight is whether the current number of units can be reduced or not and to what extent without harming the level of service. A related strategic problem is how to optimally manage the transient from the current configuration of hemodynamics units to a final one with fewer units, so that the level of service remains acceptable during the transient.

Before answering these strategic level questions, however, one needs to determine how the available resources can be exploited optimally in any possible configuration. In other words, the optimization of tactic problems is needed in order to be able to correctly evaluate the consequences of strategic decisions.

Looking at the health-care system from a tactic decisions viewpoint, the main operations to be optimized concern patients' transportation and duty assignment to the hemodynamics units.

Emergency medical service systems use ambulances to transport AMI patients to hemodynamics units where specialized personnel is present or available on call. It is also common that some patients reach hospitals with private means; in this case they are either admitted to the units of the hospitals they have reached or they are carried to different hemodynamics units by ambulances.

While the decision-maker at a strategic level is only the regional administration, at a tactic level there are at least three different stake-holders: patients, physicians and hospital managers. They share the common goal of making the whole system efficient and effective but they also have some different constraints and objectives.

Patients are mainly interested in intervention timeliness, because in case of AMI there is a strong correlation between the time elapsed between the event and the treatment and the

* Corresponding author.
E-mail address: giovanni.righini@unimi.it (G. Righini).

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probabilities of surviving and recovering [2]. For AMI patients every minute counts. The medical personnel requires an even distribution of the workload to the hemodynamics units, in order to avoid overload periods. Hospital administrators require their units to work with a load as close as possible to their capacity, because this maximizes the revenues obtained for the treatments provided. All these objectives are inter-connected with one another and their optimization cannot be pursued separately.

1.2. The case study

In this paper we consider a case study concerning the city of Milan and its surrounding province: our study is related to the optimization and re-organization of the operations of hemodynamics units during the nights and the weekends. These are the most critical periods in a week, because they are characterized by the most unfavorable ratio between demand and resources.

In this case study we address several optimization problems, presented hereafter from those related to tactic decisions (patients transportation, duty assignment, demand allocation) to those related to strategic decisions (re-definition of number and location of hemodynamics units, transient optimization), because the ability to optimize the former ones is a prerequisite for addressing the latter ones.

The main motivation that triggered the study is the need to compare two possible ways of organizing the available resources. Currently, in the nights and the weekends hemodynamics units do not have specialized personnel on duty, but they rely upon physicians who are available on call. Each patient is carried to the hemodynamics unit that is closest to his domicile and an available physician of that unit is called in the meantime; in this scenario (Scenario 1 from now on) the bottleneck in most cases is the intervention time of the physician, who must drive from his domicile to the hospital. In an alternative scenario currently under evaluation (Scenario 2 from now on) some units are on duty and the patients are carried to the closest one among them, where a physician is present; in this case the ambulance travel time is the bottleneck. Therefore the problem arises to assign night and weekend duties so that the ambulance travel time is as small as possible.

A critical aspect of Scenario 2 is the frequency with which the units are on duty and the frequency with which they receive patients. The former is particularly critical from the viewpoint of the medical personnel, since intense work duties during nights and weekends are especially demanding [3]. The latter is of particular concern for the hospital administrators who need to keep the demand high. Hospitals equipped with hemodynamics units get a revenue from the regional administration for each patient they treat; therefore the patients-to-hospitals allocation policy may have very significant implications on hospital budgets; hospital managers would not adhere to any agreement on duties assignment if this could imply a loss for their hospitals. Hence the design of the night and weekend duties schedule and the patients allocation policy must be decided so that not only the level of service provided to patients is best possible but also the economic consequences of replacing Scenario 1 with Scenario 2 are acceptable for all hospitals involved.

At a strategic level increasing pressure for the optimal use of scarce public funds asks for rationalizing the whole health care system [4], which may imply a decrease in the number of hospitals providing the same service in different locations of a same territory. For this purpose we studied optimal configurations with fewer hemodynamics units than today. This is a strategic level problem, because the decisions must be taken with a long time horizon in mind [5]. We deal with the location and the scheduling aspect of the problem simultaneously and for each number of hemodynamics units we compute the optimal locations and the consequent optimal assignment of duties in nights and weekends. The transition between the current configuration and a chosen final configuration should also take into account costs and levels of service during the transient phase, which is not instantaneous but would certainly require some years. Transient optimization is a rather unexplored branch in mathematical optimization: some papers (see for instance [6]) concern continuous time optimization of physical phenomena and give rise to mixed-integer models, close to control theory. In this paper we study an integer linear programming problem for determining an optimal sequence for hemodynamics units decommissioning.

All decisions mentioned here above are critical for at least two reasons: first, because a better territorial configuration of hemodynamics units and a better duties assignment may easily result in shorter travel times and in more lives saved; second, because the economical impact of these decisions on the public budget is very relevant. However the problems mentioned above are all combinatorial in nature and they translate into complex (*NP*-hard) discrete optimization models. This prevents from computing provably optimal solutions by hand and it calls for the use of suitable mathematical optimization techniques. Fortunately, the available technology provides useful tools for this purpose. In particular, besides the obvious need for gathering data on populations and territories in geographical information systems (GIS), powerful solvers for integer linear programming models are also available. Integrating mathematical optimization solvers within geographical information systems is a modern and effective way to build up decision support systems providing insight to decision-makers in charge of optimizing services where location and transportation are crucial, including emergency health-care services.

Paper outline. We refer to Scenario 2 and we optimize its organization in order to allow for a sound comparison with Scenario 1. Our study was developed in five different steps that correspond to Sections 2–6 of this paper. They correspond to five optimization problems, that are addressed from tactic to strategic level.

Section 2 is concerned with the minimization of the travel time from any point of the territory to the closest hemodynamics unit on duty in any time shift. Obviously the travel time depends on the number K of units simultaneously on duty, which is a parameter to be set in the decision process. The aim is to have a quantitative evaluation of the trade-off between the service cost, measured by K, and the service level, measured by the travel time. Two objective functions are used to represent the patients' viewpoint: one is the maximum transportation time from the domicile of a patient to the closest unit on duty; the other is the average transportation time, which depends on the spatial distribution of the population.

In Section 3 we consider a secondary objective function that consists in maximizing the minimum distance in time between two consecutive duties of a same unit. This is important to make the rotation fair and the change from Scenario 1 to Scenario 2 more easily acceptable for the medical personnel.

In Section 4 we take into account the managerial and financial constraints of the problem. Ideally the shift from Scenario 1 to Scenario 2 should not provoke relevant changes in the average number of patients treated per unit of time in each hemodynamics unit and hence it should have no impact on the hospital budgets. However, this is not guaranteed in general because it depends on hospital locations and the spatial distribution of the demand. Therefore the desired partition of the demand must be obtained by a proper allocation of patients to hospitals, which is not necessarily optimal from the patients' viewpoint. Hence our aim is to study the trade-off between the level of service and the balance in the assigned demand.

Sections 5 and 6 are devoted to strategic level decisions. In Section 5 we study the effect of closing one or more hemodynamics