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Innovative Applications of O.R.

Simulation modelling for contracting hospital emergency services at the regional level

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ABSTRACT

Hospital emergency services are closely connected to demographic issues and population changes. The methodology presented here helps to assess the effects of the forecasted demand changes on the next-year emergency unit workloads. The objective of the study is to estimate the expected volume of emergency hospital services, as measured by the number and costs of medical procedures provided to patients, to be contracted by the Polish National Health Fund (NFZ) branch at the regional level to cover the forecasted demand. A discrete-event simulation model was developed to elaborate the credible forecasts of the *function components*, the fundamental elements of the contract values granted by the NFZ for emergency departments for the following year. Emergency department-level data were drawn from the NFZ regional branch registry to perform a statistical analysis of emergency services provided to patients in 17 admission units and emergency wards in 2010. The model results indicate that the predicted increase in two age groups, i.e., the youngest children and the older population, will have different effects on the number and value of hospital emergency services to be considered in the contracting policy. There is potential for a discrete-event simulation to support strategic health policy decision making at the regional level. The value of this approach lies in providing estimates for the what-if scenarios related to the prognosis of changing acute demand.

1. Introduction

This paper describes the part of the project that aims to study the demand for emergency hospital care within the context of services provided by admission units (AUs) and emergency wards (EWs) located in the Lower Silesia region in Poland. The main objective is to assess the volume of services, which is measured by the number and costs of medical procedures, to be contracted by the National Health Fund (NFZ) in hospital AUs and EWs to satisfy the next-year demand for emergency medical treatment at the regional level.

The demand for service reflects the relationship between the price and the quantity demanded. Typically, if the price decreases, the demanded quantity increases. In Poland, as in other European countries, most healthcare is contracted by the NFZ, which is financed by obligatory health insurance contributions from every working citizen. This legal system excludes the possibility of the regulatory role of a price mechanism because healthcare is provided to patients free of charge at the point of delivery. In the case of elective hospital care, the supply and demand relationship is rationed by waiting lists and the distinctly defined measures are available. For example, Martin, Rice, Jacobs, and Smith (2007) use *outpatient referrals* and *decisions to admit* to measure the demand side, and *outpatients seen* and *inpatients admissions* to measure the supply side, respectively. The emergency medical services (EMS) are provided without limits for every patient who requires medical assistance and there is no possibility to separately estimate demand and supply sides. The numerous literature on predicting acute demand assumes that the emergency needs of the population are correctly modelled by the exogenous random arrival process. This process describes also the supply side, because the emergency demand is recognised only if it is registered in the system. The challenge is to forecast how this process changes over time and to measure the influence of the spatial and the demographic factors on the volume of emergency patients.

There are many obstacles that significantly hinder the process of acute healthcare demand–supply analysis. When studying emergency demand, information regarding *the acute events arising process* is unavailable because it is only possible to study events that are reported to the healthcare system. In fact, between the emergence of a need for service and notification of such an event to the public healthcare system, some information is dispersed. On the one hand, there are patients who decide to seek help in private health system or completely resign from applying for benefits. On the other hand, some patients consider hospital AUs as

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alternatives to general practitioners, which increases the number of non-emergency cases treated by the emergency system.

The demand for acute hospital services is more variable than is demand for other categories of health services and the precise mix of treatments to be delivered under an *acute contract* is difficult to predict. Variability is displayed in the seasonal variations of arrival rates, in the treatment requirements of individual patients and in the variety of treatment options for the same diagnosis. The observed variability occurs for many reasons, such as seasonal illness, summer/winter outdoor incidents, fluctuations depending on time of day, day of the week and season-specific periods. The patient's free choice of a healthcare provider makes forecasting even more difficult. In the case of acute events, patients usually select the closest available emergency department (ED) that offers the required service; however, sometimes the patients' preferences cause them to travel to a facility located in a neighbouring area. Additionally, EDs serve students, temporary workers, tourists, and visitors who live outside the region and who are not included in demographic statistics. Furthermore, demand for emergency services is strongly driven by a broad range of random factors. Uncertainty relates to the unpredictable nature of acute events, particularly in terms of time, place and type of emergency care needed.

The NFZ, when contracting *ex ante* AU/EW health services, specifies a lump sum payment based on the number of patients treated and the services provided in the previous settlement period. It means that the NFZ, the purchaser, has to assess in advance the expected volume of health services to be contracted with the service provider for the next year. This mechanism resembles the so-called *naïve forecast*, which assumes that recent periods are the best predictors of the future. The problem with this approach is that random fluctuations are tracked as faithfully as are other fundamental changes, seasonal trends are ignored and it is not possible to consider more complex relationships between demographic trends and the demand for emergency care.

There is a large number of approaches available that attempt to forecast EMS demand and estimate the volume of services needed to cover the population needs, namely, regression modelling, time-series analysis, queuing theory-based models and simulation modelling. From among these methods, simulation seems to be well suited to tackle the problems of emergency hospital care, which is a highly complex system and a valid analytical model would in itself be very complex. Brailsford (2007) suggests that there are three main reasons for the popularity of simulations among healthcare researchers: the uncertainty and variability of healthcare systems forces the use of stochastic approaches; it is difficult or even impossible to model the complexity of healthcare organisations with analytical methods; and the key role of human factors can easily be implemented using a simulation methodology. The advantage of simulation approach stems from its flexibility as well as its ability to handle the variability, uncertainty and complexity of dynamic systems. Simulation is particularly useful when problem exhibits significant uncertainties, which give rise to stochastic analysis. It is also an ideal tool for performing "what-if" analysis, e.g. what effect would forecasted demographic changes have on the expected volume of emergency health services?

The overall aim of the project is to use a simulation approach to assess the impact of the forecasted demographic changes on the expected volume and costs of treated emergency patients, to be subsequently considered by the NFZ when entering into the next year's contract. The study includes an assessment of monthly dependent patterns of demand for emergency services. The general idea of the study was described by Mielczarek and Uziałko-Mydlikowska (2012b). The purpose of this paper is to present the first stage of the research. The challenge was to develop a simulation model that could be used to estimate the expected volume of emergency health services, as measured by the quantity of medical procedures and the overall costs of servicing the treated patients, to be contracted by the NFZ at the regional level, given the assumptions on forecasted demand. The next phase of the project will examine demographic trends across the population in the region and, using a Monte Carlo simulation and a regression model, explore the relationship between the changes in the population of the region and the number of acute services provided by the AUs and EWs. The valid forecasts might enable the Health Fund decision makers to accurately plan future supply and to improve the equity of access to emergency health services across the whole region.

2. A taxonomy of healthcare simulation models: a demand perspective

There are many taxonomies of healthcare simulation models in the literature. Brailsford (2007) divides the models into *human body, operational models of healthcare units* and *strategic, system-level models*. Jun, Jacobson, and Swisher (1999) address the problems encountered by healthcare clinics and systems of clinics and survey the application of discrete-event simulation (DES) modelling in two areas: *patient flow* and *allocation of resources*. Some reviews classify models into *epidemiology, health and care systems operation, health and care systems design*, *medical decision making* (Lagergren, 1998) and *extreme events planning* groups (Mielczarek & Uziałko-Mydlikowska, 2012a). In this paper, healthcare simulation models are classified into three groups depending on the purpose for which the process of analysing and estimating the demand is to be carried out.

The first models, called *Group 1* (*improvements*), are focused on the current work of service providers. These models are used for resource allocation, staff scheduling, admission planning, and managing patient flows in healthcare units. They are concerned with identifying bottlenecks and suggesting system improvements. They also help to formulate an overall diagnosis of system performance. To achieve these tactical and operational goals, it is necessary to obtain knowledge about the level, variability and uncertainty of demand. Arrival schedules are usually defined based on historical data or on-site empirical observations. The classical problem formulation is usually as follows: how to change the operation of the system to satisfy the output measures given certain levels and characteristics of the demand. The models concentrate on the units providing the healthcare services and try to identify improvements to the internal organisation of the unit assuming a certain level and structure of the demand. The layout of the conceptual model is consistent with the diagram presented in Fig. 1.

Performance measures depend on the system under study. Emergency system models usually calculate response-time intervals or response-time threshold, although McLay and Mayorga (2010) proposed measures related to patient survival rates. Models of clinical settings usually concentrate on patient waiting time, cancellations and the utilisation of resources (i.e., time of utilisation of operating theatres, bed occupancy, exam room usage). Models from Group 1 may concern (a) different clinical settings, such as operating theatres, outpatient clinics, ambulatory care units or diagnostic departments, (b) complex centres such as multi-unit hospitals or multi-facility outpatient centres, or (c) treatment processes such as radiation therapies. Group 1 is extensively covered in the academic literature, and some illustrative examples are given below.

The simulation approach has been used to improve the efficiency of orthopaedic trauma theatres (Bowers & Mould, 2004) and operating rooms (Persson & Persson, 2009; Steins, Persson, & Holmer, 2010) given the stochastic patient arrival and surgical