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A generic method to develop simulation models for ambulance systems

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ABSTRACT

In this paper, we address the question of generic simulation models and their role in improving emergency care around the world. After reviewing the development of ambulance models and the contexts in which they have been applied, we report the construction of a reusable model for ambulance systems. Further, we describe the associated parameters, data sources, and performance measures, and report on the collection of information, as well as the use of optimisation to configure the service to best effect. Having developed the model, we have validated it using real data from the emergency medical system in a Brazilian city, Belo Horizonte. To illustrate the benefits of standardisation and reusability we apply the model to a UK context by exploring how different rules of engagement would change the performance of the system. Finally, we consider the impact that one might observe if such rules were adopted by the Brazilian system.

1. Introduction

The reuse of models is a topic of considerable interest in healthcare because, although most care delivery systems are specifically designed for the local context, many share common design elements. As an example, emergency departments share common operational principles but the configuration, management and layout of one department will differ from another. In this paper, we use an example from emergency medicine – ambulance control – as an exemplar with which to explore the question of reuse and standardisation of models.

Ambulance services are attractive to model for a number of reasons. First, the start and end of each task is well defined, tasks are self-contained and take place over short periods of time. Moreover, the processes lend themselves to a logistic analysis well-suited to modelling. This is not the case for all medical services, many of which are open ended, run concurrently with other medical interventions and stretch over long periods of time. Second, as we shall see, although there are many dimensions of uncertainty to modelling an ambulance service, these dimensions can be partitioned with relative ease and changed when moving from one ambulance service to another.

The ability to expand a model by interfacing it to another, even off-the-shelf, model is a third feature of reuse and standardisation. The geographical spread of ambulance services provides an opportunity to explore geographical information systems (GIS) and thus to extend a model's applicability from one city to another. Fourth, the high number of variables

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and the random nature of demand make the analysis for decision-making a combinatorial problem with a high number of alternatives and renders deterministic methods unattractive.

Finally, setting appropriate metrics is a case of assessing complex trade-offs, rather than applying measures that have been derived from first principles. For instance, an ambulance in front of every house would minimise the response time (the elapsed time from the call to the arrival of an ambulance on the scene), but at prohibitive cost. To satisfy such demand with a high quality service, it is required a redundant system, with a low utilisation of resource in consequence. Meanwhile, system managers are pressed to operate the system within cost constraints, which implies maximising the utilisation of resource.

For all these reasons, simulation modelling is an attractive way of analysing such scenarios. Section 2 surveys the vast literature on modelling and simulation that has been applied to ambulance services. However, most Discrete Event Simulation (DES) models are built for a specific city in order to analyse a specific aspect of the system, making reuse hard if not impossible.

In this paper, we propose a generic DES modelling for ambulance services. The proposed modelling is comprehensive and emphasises the use of modular approach in order to build generic models. The methodology describes in detail, all stages we usually take during a simulation analysis of an Emergency Medical System (EMS). As a basis, we have taken a specific model [1,2] and generalised it to capture features of other systems. Section 3 describes ambulance services in generic terms, the overall structure of the model and the associated parameters, the data sources and collection, and the construction of an optimising loop around the simulation. In Section 4 we explain the validation of the model and the results are discussed in Section 5, with a short conclusion to clarify the findings (Section 6).

2. Literature review

Ambulance services have been analysed in a variety of ways, including queuing theory and hypercube models [3–9], mixed integer programming [10,11], stochastic optimization [12] and dynamic programming [13]. By contrast, simulation modelling presents a high cost of implementation, but gives a more detailed description of the system [3] and allows the analysis of dynamic effects [14,15]. These features make the simulation approach a powerful decision-making tool for analysing such systems.

Simulation models have been used to analyse ambulance services since the '60s [16–20]. Since then, there have been many studies focused on a particular city or region.

Fujiwara et al. [21] analysed deployment policies for Bangkok, Thailand, combining a simulation model informed by a location model (a mathematical programming model). Meanwhile, Henderson and Mason [22] built a simulation model to refine the solutions proposed by a queue model for the ambulance service of Auckland, New Zealand.

Kock and Weigl [23] used simulation to analyse ambulance logistics in Austria, with the main objective of comparing centralised and decentralised policies of transportation for the Austrian Red Cross. Su and Shih [24] developed a simulation model of the ambulance service system of Taipei, Taiwan and used it to explore alternative scenarios that might improve the operation of the system.

Wu and Hwang [25] built a wide-ranging simulation model to analyse the ambulance system of Tainan, Taiwan. This model was used to estimate the threshold for expanding the ambulance fleet and to evaluate ambulance-dispatching strategies during large public events such as concerts and marathon races.

Silva and Pinto [2] developed a model to analyse the ambulance service of Belo Horizonte, Brazil. The model was used to analyse two aspects of the service: its response to increased demand and what expansion of the fleet would be needed to reduce the average response time significantly.

Meanwhile, Berchi et al. [14] proposed a five-step methodology to planning the ambulance service system of Milan, Italy. The proposed method was used to estimate the preferred locations of ambulances depots and number of ambulances.

More recently, Aboueljinane et al. [26] developed a simulation study to improve the system of Val-de-Marne department, a small administrative district located in the southeast of Paris, France. Zhen et al. [27] proposed a simulation optimisation method in order to evaluate the performance of ambulance deployment and relocations plans. The authors run a demo example using the system of Shanghai, China. Morohosi and Furuta [9] built and applied a simulation model to a large-scale ambulance system in the Tokyo metropolis.

It will be noted that many of these exercises involved another mathematical technique in conjunction with the simulation model. Morohosi and Furuta [15] applied the MEXCLP (maximum expected covering location problem) location model to ambulance data in Tokyo metropolis and they verified the assumptions of the model via simulation. Aringhieri [28] took this further by developing a hybrid approach that integrated Agent Based Simulation (ABS) and Discrete Event Simulation (DES) to analyse the ambulance service system, again in Milan. The author states that the model is quite flexible and could be used in other cities of Lombardy. Zhen et al. [27] proposed a simulation-optimisation method in order to evaluate the performance of ambulance deployment plans. The authors used a genetic algorithm to guide the search process. The key point is that simulation within a geographical context has been routinely demonstrated, but geographic reusability remains an elusive, but attractive goal.

More broadly, the application of simulation modelling and other OR techniques to healthcare has been widely discussed in the literature. This is driven by such factors as the increasing and aging population, especially in urban centres [29,30] with a knock-on effect for ambulance services. Comparisons with manufacturing and military usage have revealed a signif-