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An optimization based on simulation approach to the patient admission scheduling problem using a linear programing algorithm

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ABSTRACT

Background: As patient's length of stay in waiting lists increases, governments are looking for strategies to control the problem. Agreements were created with private providers to diminish the workload in the public sector. However, the growth of the private sector is not following the demand for care. Given this context, new management strategies have to be considered in order to minimize patient length of stay in waiting lists while reducing the costs and increasing (or at least maintaining) the quality of care.
Method: Appointment scheduling systems are today known to be proficient in the optimization of health care services. Their utilization is focused on increasing the usage of human resources, medical equipment and reducing the patient waiting times. In this paper, a simulation-based optimization approach to the Patient Admission Scheduling Problem is presented. Modeling tools and simulation techniques are used in the optimization of a diagnostic imaging department.
Results: The proposed techniques have demonstrated to be effective in the evaluation of diagnostic imaging workflows. A simulated annealing algorithm was used to optimize the patient admission sequence towards minimizing the total completion and total waiting of patients. The obtained results showed average reductions of 5% on the total completion and 38% on the patients' total waiting time.

1. Introduction

It is common-knowledge that in the last decade there has been an increasing demand for health care services. Among others, this arises from an ageing population and an increasing awareness for preventative care. On the other hand, the world economic situation is leading to a reorganization of healthcare systems. At a macro level, what is noticeable is a centralization and decrease in the number of public healthcare providers [1]. In practice, and mainly in the department of medical imaging, this reflects an inability of healthcare providers to respond to an ever increasing demand. As the patient's length of stay in waiting lists increases, governments are looking for strategies to control the problem. In Portugal, to diminish the workload in the public sector, conventions were created with private providers in which patients can access examinations without losing the benefits of the National Health Service (SNS, from the Portuguese Serviço Nacional de Saúde). However, the growth of the private sector is not following the demand for care. In this context, new management strategies have to be considered to minimize the patient length of stay in waiting lists, while reducing the costs and increasing the quality of care.

The study of workflows attempts to understand the process and remove components, without added value, which delay the service and introduce complexity that ultimately may result in errors. The opportunities that this type of study has in medical imaging are significant, given that the majority of workflows in medicine have yet to be consistently described [2], which is also the case for medical imaging.

Appointment scheduling systems are today known to be proficient in the optimization of health care services. Their utilization is focused on increasing the usage of human resources, medical equipment and reducing the patient waiting times. This paper considers the appointment scheduling problem in an imaging clinic.

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The considered imaging clinic provides services on Computed Tomography (CT), MRI, Radiology (RX), Orthopantomography (OT), Densitometry (PX), Mammography (MG) and Ultrasound (US). Appointments are requested by the patient either by phone or in person. At the moment of request the patient appointment is scheduled for a day and time according to the timetable availability and patient's preference. The size of the time block, i.e. processing time, is defined according to the modality. The aim was to improve the patients' admission scheduling in order to minimize the patients' waiting time, and increase patient throughput. Thus, the problem studied herein considered elective patients and was modeled as a static, multi-stage/multi-server system, with processing times estimated according to the type of clinical examination and defined as a probability distribution. A discrete-event simulation model integrated with an optimization technique was used to minimize the patients' waiting time and increase patient throughput.

This paper is divided in eight sections. In the first section, the problem object of study is presented. In the second section, the problem is defined and the state of the art is reported. In the third section, the case study is described. In the fourth section, the resources' and tasks' characterization parameters are presented. In the fifth section, the modeling approach is explained and the simulation technique described. In the sixth section, the optimization algorithm with which the results were obtained is presented. In the seventh section the optimization results are interpreted and presented. Section eight draws conclusions on the results and foresees future work.

2. Problem definition and literature review

2.1. Environmental factors

The first reference to the Admission Scheduling (AS) problem is from Bailey [3] and dates from 1952. In this work, the problem was addressed as a queuing system with the objective of minimizing patients' waiting time. Bailey concluded that the best solution for the problem was to schedule patients in regular intervals, equal to the average consultation time. The AS problem definition was first addressed by Cayirli and Veral [4] and is briefly described hereafter. AS problems consider the finding of an appointment schedule in a healthcare environment for which an objective function, considering one or multiple performance measures, is optimized. If AS is considered as a queuing system, these performance measures have an essential role as, in queuing systems, issues are often related to the patient. The problem definition is primarily divided into two main categories: static and dynamic. It is considered a static problem when all the decisions are made *a priori*. This means that the proposed appointment system does not consider the system current state. Static problems are the most common type of problems in healthcare environment [3,5–7].

In contrast to this, in a dynamic problem the appointment system is reviewed based on its current state [8–11]. In both categories, problems are further defined according to environmental factors defined in the following sub-sections, namely: number of stages – number of tasks required to complete the process, number of servers – number of available resources with competences to complete the same task, patient tardiness and processing times.

2.1.1. Number of stages

(i) *Single-stage:* system where patients queue for a single stage. The majority of the studies in literature represent single-stage problems. Schemes, illustrating single-stage systems, are provided in Fig. 1(a) and (b).

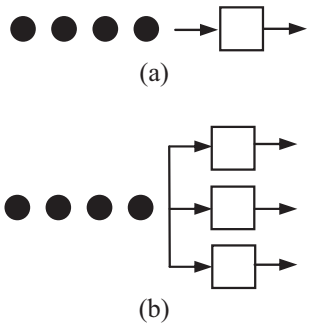

Fig. 1. Queuing system: (a) single-stage/single-server system; (b) single-stage/multi-server system.

(ii) *Multi-stage:* system where patients queue for multiple stages, such as registration, examination and checkout. Schemes illustrating multi-stage systems are provided in Fig. 2(a) and (b). A multi-stage system was considered by Garg et al. [5]. In this work, a hospital scenario was studied and the patient pathway was modeled to consider different phases of care, such as acute, treatment and rehabilitation. In the workflow modeled by Granja et al. [12], three stages were considered in the patient's pathway in radiology: admission, examination and billing. Chen et al. [13] considered four stages in their analysis of surgery admission. Connelly and Bair [14] explored the potential of discrete event simulation in the operations analysis in an emergency department. In their work, a multi-stage system was considered as each patient was modeled as a set of instructions that define a series of individual activities that must be completed in a given order before the patient leaves de emergency department.

2.1.2. Number of servers

(i) *Single-server:* appointment system regards a specific server. Schemes illustrating single-server systems are provided in Fig. 1(a) and Fig. 2(a). They are the most predominant in literature [15,16]. Even if not considered the best option to define the problem, this choice is related to the human background of the problem. The doctor–patient relation is highly considered in quality measures. Always being sent to the same doctor is highly valued by the patient. Therefore, most models consider independent queues for each doctor.

(ii) *Multi-server:* more than one server with the same capabilities is considered in the appointment system [17–20]. The scheduling algorithm decides to which server each patient

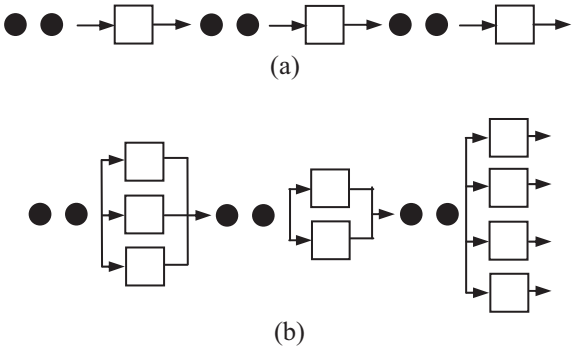

Fig. 2. Queuing system: (a) multi-stage/single-server system; (b) multi-stage/multi-server system.

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