ISBN-978-989-9121-01-0
LISBON 18th International Conference on "Innovations in Science, Engineering & Technology" (LCISET-22)
Lisbon (Portugal) April 13-15, 2022

Optimization of the Scheduling Process of an Oncology Centre using a Multi-appointment Scheduling Algorithm with Time Window

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***Abstract*:** *The urgency of the cases faced in oncologic centres demands a fast diagnosis to accelerate and establish the choice of the right treatments. A timely access care is a major concern and one of the priorities for these centres since an increase of the patient waiting time can have a medical impact on the patients' health. With limited resources and funding available to satisfy the demand, oncologic centres face particular challenges. In order to overcome these challenges, several specialists focused their attention to study alternative ways to manage. Therefore, more efficient solutions are being adopted to improve the quality of care and ensuring a timely access. One of the identified areas to improve is the scheduling system.*

This paper presents the design and development of a scheduling system focused on the patient that can be applied in different clinical areas, flexible to adapt and focusing on a multi-appointment scheduling problem with time window of patient's medical exams requests. The scheduling problem is assumed as a set of patients to be schedule in a limited number of medical exams slots and each patient should have all its exams' requests schedule in a defined time window. The optimization function is the allocation costs of all patient's requests and the solving aim is its minimization in order to reduce patient waiting time, minimize the time window and maximize the number of exams schedule in the same day or consecutive days for each patient.

For better use, the scheduling system consists in an interface as a front page and a scheduling algorithm model for the optimization. The interface allows the user to register the patient's requests and originates a list which is used as input to the model. The algorithm model consists in schedule the patient's requests entered by the scheduling system user and searching the most optimized order to allocate the patients according to a set of variables and constraints: the number of exams requested per patient, the number of slots available for each exam and the ratio of number of slots available and the number of requests per exam; and scheduling costs: penalty for not scheduling the exam, for scheduling in different days or for not scheduling consecutively.

The case study was developed to optimize a real-world scheduling problem of an oncology centre for a cancer diagnosis and staging in an oncology centre. To evaluate the proposed model, the performance of different settings of the optimized scheduling algorithm is compared with the current manual method of scheduling in the oncologic centre, the first come first served method. The results of the experiments have shown that the proposed algorithm has achieved better results compared to the current method of scheduling in the oncologic centre.

Keywords: *outpatient scheduling, multi-appointment scheduling, oncology.*

1. Introduction

Healthcare systems are currently challenged by several factors, such as the accelerated growth in health expenditure, the impact of demographic changes on the prevalence of chronic diseases and its respective needs, and, on the other hand, the increase of patients' expectations for a quality care delivery. The resources and funding available to satisfy the demand are limited and tends to affect the quality of care provided [1].

The increase of the patient waiting time is an important quality criteria of healthcare systems and its one of the biggest problems in quality deliver because of the potential medical impact on patients [2]. For oncology centres in particular, a timely access care is a major concern and one of the priorities for these centres since the urgency of oncologic cases demands a fast and efficient diagnosis to accelerate and establish the choice of the right treatments [3].

In order to overcome these challenges, more efficient solutions and approaches are being adopted to improve the quality of care. An integrated and multidisciplinary approach has been becoming more popular as it faces the challenges of the healthcare evolution and transformation to a more coordinated care and often transversal to more than one department, aiming to optimize the care delivery and centralize on the patient and it's needs [4].

We develop a scheduling system for a real-world scheduling problem of an oncology centre, that, in the perspective of a care delivery centralized in the patient, optimizes the scheduling of the medical exams requested for each patient, considering the slots available, to guarantee a celerity in the diagnosis and staging process.

2. Literature Review

The literature on appointment scheduling problems is extremally vast and its applications are transversal to all medical fields and all types of scheduling problems, such as outpatient appointments, nurses and physician shifts scheduling or surgery, rehabilitation and home care scheduling.

The comprehensive reviews of Cayirli and Veral [2] and Gupta and Denton [5] are considered the state of the art regarding scheduling in healthcare, providing an overview and guide to develop and design scheduling problems. Most recently, literature reviews regarding integrated and multidisciplinary healthcare on hospital settings [6] and on other medical contexts [4] have also emerged as an answer to the changes on the healthcare paradigm.

Literature on oncology related scheduling problems has been increasing. Though, most studies focus on the treatment phase, being the most common problems, radiotherapy or chemotherapy patient scheduling, such as in [7] and [3], respectively. Our study, instead, focus on a previous phase, the diagnosis and staging. There are some studies that focus specifically on schedule patients in complementary diagnosis tests, such as [8], but not with the goal of schedule the patients' medical exams to reach, in a time window, a cancer diagnosis or staging in a oncologic centre.

Although, to the best of our knowledge, we didn´t find studies with the same characteristics of the problem that we studied: scheduling medical diagnostic and staging tests, such as radiology, nuclear medicine or clinical pathology tests, requested for each patient, in a time window, to have all the information to obtain a diagnosis and choose the most appropriate treatments with the most celerity.

3. Problem description

The patient scheduling problem can be described as the allocation of a set of patient's medical exams' requests, with a limited number of exams' slots available. This study focus on finding the most optimized allocation of patient's requests, in order that each patient should have all its exams' requests schedule in a defined time window. We consider the following scheduling problem characteristics:

- For each patient, there is a set of exams requests.
- For each exam, there is a set of time slots available.
- The time slot granularity depends on the number of days, hours per day and number of slots per hour
- Each patient should have all its exams schedule in a defined time window

The aim of this study is to develop a scheduling system that can be used as a toll to optimize the schedule of medical exams in an oncology centre department, in order to guarantee tree main goals:

- Reduce patient waiting time
- Minimize the time window
- Maximize the number of exams schedule in the same day or consecutive days for each patient

4. Solution methodology

The designed and developed scheduling system consists in two distinct components: the user interface and the scheduling algorithm. The interface allows the user, among other features, to enter the data regarding the patients and exams information. Integrated in the interface, the scheduling algorithm, uses the data as an input to schedule the appointments which results can be shown directly in the interface.

4.1. User interface

The interface was designed using the Model-View-Controller (MVC) architecture, which is based in the separation of the program in tree layers: the model, for all methods related to the data, including, the access to it; the view, that includes all the functions related to visual features; and the controller, that connects the other layers. This architecture reduces the complexity of the code, becoming easier to use and to reuse the code, and allows the design of the program being separate from the logic, reducing the risk of errors [9].

The input data is stored and transferred in the JSON format. This format is considered simpler, easier and faster to use, for example, in reading and writing, essential for transferring the data between the interface and the scheduling algorithm. The JSON files are used in the scheduling system to store the data regarding the patients and its exams' requests but also the exams and its availability.

4.2. Scheduling algorithm

The input data of the scheduling algorithm consists in the data entered in the interface by the scheduling system user, that includes patients and exams information, but also information relative to the calculation of time slots and cost functions. These variables are listed in Table 1.

TABLE I: Algorithm input data

Patients	Exams	Exam's availability	Time slot granularity	Penalty costs
Patient name	Exam name	Day	Number of days	Not scheduling
Patient number	Exam number	Start hour	Hours per day	Scheduling in different days
Requests		End hour	Number of slots per hour	Not scheduling consecutively

The schedule is represented in the form of a matrix structure, with rows representing the days and the columns being the product of the hours per day and number of slots per hour. Every element of the matrix represents the time slot. From the schedule matrix, it's created a patient schedule and an exam schedule, for every patient/exam. The scheduling algorithm is expected to obtain as a result, the schedules for each exam and patient.

In order to obtain the schedules, the algorithm passes through each time slot to find an available slot, following a set of variables and constraints:

- The number of exams requested per patient
- The number of slots available for each exam
- The ratio of number of slots available and the number of requests per exam
- The order of the exams to be schedule based on the above ratio
- The order of patient to be schedule based on its requests

The result of each schedule iteration has a cost function associated, to penalize the schedule when it doesn´t meet the goals defined. The scheduling costs includes:

- Penalty for not scheduling the exam
- Penalty for scheduling in different days
- Penalty for not scheduling consecutively

The algorithm continues to iterate schedules until it reaches a point where the difference of the cost functions is close to zero or after a defined number of iterations is reached. A flowchart of the scheduling algorithm is presented in the Figure 1.

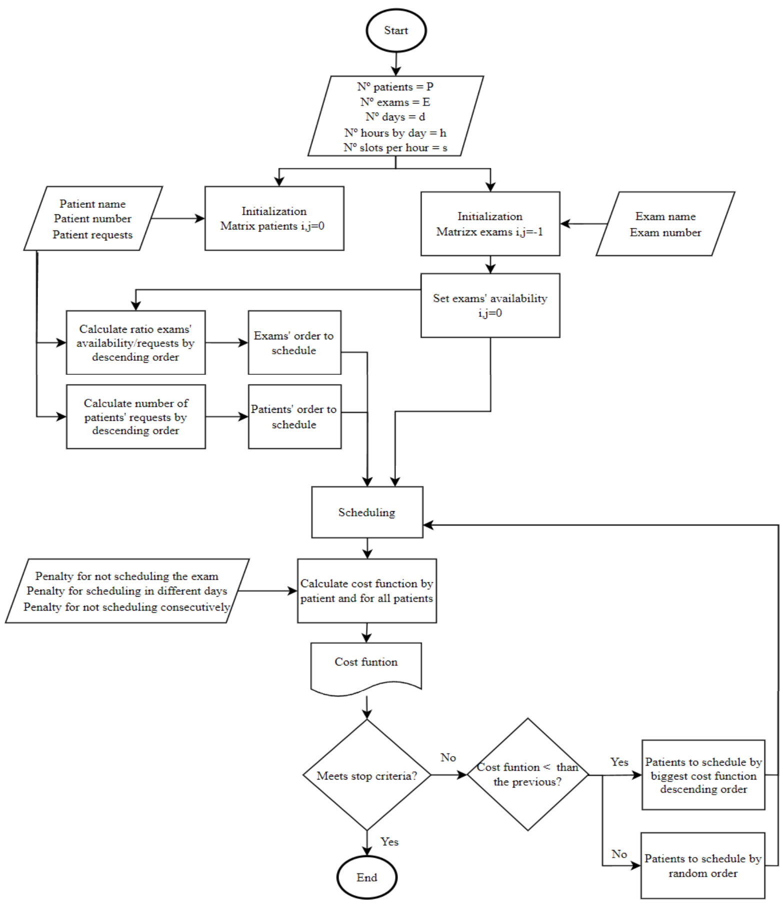

Fig. 1: Flowchart of the scheduling algorithm

5. Case study

This section presents a case study that was developed to optimize a real-world scheduling problem for cancer diagnosis and staging in an oncology centre. Computational assessments were performed to evaluate the proposed optimized scheduling algorithm and compare with the current manual method of scheduling in the oncologic centre, the first come first served method.

5.1. Methodology

The case study was carried out in an oncology centre department that is composed by a multi-disciplinary team that focus on providing a patient-centred care to patients with cancer or in the process of being diagnosed. Due to the urgency characteristic of this disease, the diagnosis and staging are an important stage, the multi-disciplinary team privileges a rapid and convenient process for the patients. The pathway begins with the patients to have a first appointment in which they are evaluated and diagnostic tests are required. Once a week, the multi-disciplinary team meets to assess all the patients and deliberate the scheduling of the diagnostic tests for all patients, priority cases and discuss the possible need for additional medical exams. Only after this meeting, the medical exams are schedule and the patients informed.

Focused on the patients' needs, the main goal of the oncologic centre department is to minimize the waiting time of the execution of all diagnostic tests for each patient and, ideally, to not exceed the defined time window. Therefore, the aim of the model is defined as the minimization of the sum of the cost functions of each and all patients (1), that includes penalties for not scheduling the exam, $\mathrm{C}_{no\ schedule}$ (2), for scheduling in different days, $\mathrm{C}_{different\ days}$ (3), and for not scheduling consecutively, $\mathrm{C}_{same\ day}$ (4).

The problem is mathematically described by the optimization function:

$$min\ \Sigma(\mathrm{C}_{no\ schedule} + \mathrm{C}_{different\ days} + \mathrm{C}_{same\ day}\ ) \tag{1}$$

Where the parcels of the objective function are calculated by:

$$\mathrm{C}_{no\ schedule} = (r_r - r_s) \times \mathrm{w}_{ns} \tag{2}$$

$$\mathrm{C}_{different\ days} = (d_f - d_i) \times \mathrm{w}_{sdd} \tag{3}$$

$$\mathrm{C}_{same\ day} = (h_f - h_i) \times \mathrm{w}_{ssd} \tag{4}$$

Subject to:

$$r_p > 0$$
$$\mathrm{C}_{no\ schedule}, \mathrm{C}_{different\ days}, \mathrm{C}_{same\ day} => 0$$

In the Table 2 there is defined the sets and parameters of the cost function.

TABLE II: Sets and parameters of the cost function

Parameter	Value
R	Set of patients' requests
r_r	Number of requests by patient
r_s	Number of patients' requests schedule
D	Set of days
d_i	Day of the first exam schedule
d_f	Day of the last exam schedule
H	Set of hours
h_i	Hour of the first exam schedule
h_f	Hour of the last exam schedule
w_{ns}	Weight no schedule
w_{sdd}	Weight schedule in different days
W_{ssd}	Weight schedule in same day not sequentially

The algorithm developed was tested in three different approaches that essentially differs in the number of iterations and its order of patients and exams to be schedule:

1. The first come first served approach (baseline scenario)
2. The iterations approach
3. The permutations approach

The first approach is the baseline scenario and consists of a unique scheduling in which the patients' order to schedule is defined by the arrival order and the exams by the ascendent order of their number identification. The second approach is based on a limited number of iterations in which there is a first schedule followed by multiple reschedules. The patients' order in this approach is the decreasing order of number of requests by patient and the exams' order is the decreasing order of the ratio of requests/availability for each exam. Regarding the reschedule, the patients' order is the descending order of the patients with the biggest cost function from the last iteration. The latter approach executes all the possible combinations of the patients' order to schedule. The exams' order is also the decreasing order of the ratio of requests/availability for each exam. The Table 3 summarizes this information.

TABLE III: Details of the different approaches

Experiment	Number of iterations	Patients' order	Exams' order	Reschedule patients' order
FCFS approach	1	Order of arrival	Order by exam number	-
Iteration approach	10	Decreasing order of number of requests	Decreasing order of the ratio of requests/availability for each exam	Descending order of the patients with the biggest cost function
Permutation approach	Ex: 5040 (7 patients)	All combinations of order	Decreasing order of the ratio of requests/availability for each exam	The next combination of order

Two experiments where design to evaluate the performance of the proposed algorithm in different scenarios. In the experiment 1, the FCFS approach (baseline scenario) is compared to the iteration approach (optimized scenario) in terms of time and cost function. In the experiment 2, a third approach, the permutation approach, is included to compare the results of the experiment 1 with an approach that generates the best possible solution regarding the input parameters. The three different approaches are compared in two situations:

1. The exams' availability is defined to all the requests to be schedule
2. The exams' availability is reduced in about 25% to not all requests to be schedule

In the Table 4 are listed the input parameters of the experiments.

TABLE IV: Input parameters

Parameter	Value
Number of patients	7
Number of exams	7
Number of patients' requests	21
Number of days (time horizon)	14
Hours per day	24
Number of slots per hour	2

5.2. Computational results

The results obtain from the experiment 1 is shown in the Table 5 and from the experiment 2, in the Table 6. In the first experiment, the partial cost functions are relative to each patient, and the cost function represents the sum of all patients' cost functions. The cost function results shows that the optimize scenario has tendentially a better result, even though it is not significant. However, with the partial cost functions of each patient, it is perceptible that even though the results between the two scenarios are similar, the optimized scheduling algorithm can have impact in, at least, a patient.

TABLE V: Results of experiment 1

Scenario	Time	Partial cost functions	Cost function
Baseline scenario	$d_i = 3$ $h_i = 17.30$ $d_f = 13$ $h_f = 16.30$	[400, 200, 500, 400, 420, 360, 600]	2880
Optimized scenario	$d_i = 3$ $h_i = 17.30$ $d_f = 13$ $h_f = 16.30$	[400, 200, 500, 400, 590, 160, 500]	2750

As for the experiment 2, in the scenario 1, all the requests were schedule, and therefore, the cost functions are low, but there were penalties for not scheduling in the same day or sequentially. In the scenario 2, because there were no available slots to schedule all the requests, the cost functions are much bigger. Although, in both scenarios the same pattern occurs, in which, the iteration approach has better results than the FCFS approach, although without much difference. Comparing these results to the permutation approach, its noticeable that this approach has much lower cost functions, and such, has found the most optimized patients' requests order to schedule.

TABLE VI: Results of experiment 2 (cost function)

Scenario	FCFS approach	Iteration approach	Permutation approach
Scenario 1	2880	2750	1630
Scenario 2	52910	52320	51590

Although the optimized approach has tendentially better results than the baseline approach, the difference isn't significantly. Nonetheless, it's important to have in consideration that as the multi-disciplinary team is gradually implementing a patient-centred care, the patient's comfort and convenience is a concern and a priority, and reducing the waiting time of, not all, but some of the patients its an important goal accomplished. As for the permutation approach, it demonstrated that generating all the possible combinations, the best solution regarding the input parameters is known. Therefore, a disadvantage of this approach is being time consuming, especially when the number of the parameters are scaled up, for example, the number of patients.

6. Conclusion

This paper focused on the optimization of a scheduling problem of an oncologic centre with the challenge of better allocate the patients appointments to improve particularly their experience in a patient-centred care paradigm.

The results of the experiments carried out to assess the performance of the optimized scheduling has shown that the proposed algorithm has achieved better results for the defined cost function comparing to the current manual method of scheduling in the oncologic centre, the first come first served method.

An improved and optimized scheduling system can provide better care conditions, not only directly reducing the time of completion of all the medical tests in due time, to define and begin treatments as soon as possible, but also facilitate the whole process to the patients by reducing the periods between doing medical tests and the inconvenience of displacement to the centre. Also, understanding the characteristics of the scheduling system and optimizing it, in addition to being beneficial to the patients, is also cost worthy for the system and for the institutions, in terms of resource management.

The present work proves that it is possible to make a shift on the strategy in clinical activities. Changing the focus from the clinical entity and doctors' team to the patient is cost worthy for the system and improves the quality of treatments and life for the patients.

An extension of this study could focus on the allocation of patients that couldn't be scheduled in the time horizon defined, with priority in the following week. An interesting path could pass through articulating efforts with the medical exams departments to reserve, based on the historical data of the patients, medical exams slots.

References

[1] M. H. Monteiro, "A adopção da eHealth nos hospitais públicos em Portugal 1996-2007," Instituto Superior de Ciências Sociais e Políticas, 2010.

[2] T. Cayirli and E. Veral, "Outpatient Scheduling in Health Care: a Review of Literature," *Prod. Oper. Manag.*, vol. 12, no. 4, pp. 519–549, 2003.
https://doi.org/10.1111/j.1937-5956.2003.tb00218.x

[3] P. Hooshangi-Tabrizi, I. Contreras, N. Bhuiyan, and G. Batist, "Improving patient-care services at an oncology clinic using a flexible and adaptive scheduling procedure," *Expert Syst. Appl.*, vol. 150, 2020.
https://doi.org/10.1016/j.eswa.2020.113267

[4] A. G. Leeftink, I. A. Bikker, I. M. H. Vliegen, and R. J. Boucherie, "Multi-disciplinary planning in health care: a review," *Heal. Syst.*, vol. 9, no. 2, pp. 95–118, 2020.
https://doi.org/10.1080/20476965.2018.1436909

[5] D. Gupta and B. Denton, "Appointment scheduling in health care: Challenges and opportunities," *IIE Trans. (Institute Ind. Eng.*, vol. 40, no. 9, pp. 800–819, 2008.
https://doi.org/10.1080/07408170802165880

[6] J. Marynissen and E. Demeulemeester, "Literature review on multi-appointment scheduling problems in hospitals," *Eur. J. Oper. Res.*, vol. 272, no. 2, pp. 407–419, 2019.
https://doi.org/10.1016/j.ejor.2018.03.001

[7] S. Li, G. Koole, and X. Xie, "An adaptive priority policy for radiotherapy scheduling," *Flex. Serv. Manuf. J.*, vol. 32, no. 1, pp. 154–180, 2020.
https://doi.org/10.1007/s10696-019-09373-4

[8] R. W. Day, M. D. Dean, R. Garfinkel, and S. Thompson, "Improving patient flow in a hospital through dynamic allocation of cardiac diagnostic testing time slots," *Decis. Support Syst.*, vol. 49, no. 4, pp. 463–473, 2010.
https://doi.org/10.1016/j.dss.2010.05.007

[9] D. P. Pop and A. Altar, "Designing an MVC model for rapid web application development," *Procedia Eng.*, vol. 69, pp. 1172–1179, 2014.
https://doi.org/10.1016/j.proeng.2014.03.106