Optimization model for waiting list management and service continuous improvement

Vieira, Elisa[1], Gonçalves, Bruno S.[1], Lima, Rui M.[1] and Dinis-Carvalho[1]

[1] Department of Production and Systems, ALGORITMI Research Centre, School of Engineering, University of Minho, Guimarães, Portugal

ABSTRACT

Purpose - This study aims to assess the number of hours*doctor required per day in each week, in a time horizon of 52 weeks, so that it is possible to gradually and controllably reduce the waiting list and the response time for the triage process that precedes the scheduling of an hospital appointment of orthopaedics speciality. A national decree law requires a response time equal or less than 5 days for the triage process, but currently, in the hospital under study, with a waiting list of 1244 users, the response time is, on average, 66 days for the speciality of orthopaedics.

Design / methodology / approach - With a team of orthopaedists (constituted with the objective of improving access to orthopaedics speciality appointments), the current status of the waiting list was analysed and possibilities for improvement were discussed. Based on the professional's expertise, several parameters were defined as the more relevant to manage the waiting list for the triage process, allowing the development of an optimization model which aims to minimize the number of hours*doctor per day per week required to achieve the defined objectives.

Findings - The model is able to define an optimal number of hours*doctor per day per week meeting all the process constraints. Thus, it is required 1400 hours*doctor to reduce and maintain the waiting list between the boundaries defined as acceptable, as well as reduce the waiting time to 9 days. The model is also capable of orienting the professionals to search alternative optimal solutions that for specific contexts may better fill the hospital needs.

Originality / value - This study presents a tool that can support waiting lists management across any service provided by health organizations. The model ease of use allows for fast parameterization and results achievement in continuous improvement meetings.

Keywords: Operational Research, Hospitals, Continuous Improvement, Optimization Model.

Paper type: Case Study

INTRODUCTION

One of the biggest challenges that hospitals face today relates to the performance of their functions given the large number of users appealing for their services. This is a challenge due to the limited human and financial resources available in hospitals. This problem is reflected by the long waiting lists existing in the different services provided by the hospital units, common in several modern health systems, with regard to public health services (Johannessen and Alexandersen, 2018). If, on the one hand, waiting lists provide for the uninterrupted use of the expensive resources of health services, justifying the installed capacity, on the other hand the dimensions they reach go far beyond the numbers necessary for this purpose (Worthington, 1987).

The orthopaedics appointments are the gateway to the orthopaedic surgery services, which, largely driven by the aging of the population, presents a growing demand trend (Jarman et al., 2020), being in this case one of the specialities with largest number of users on hold. In the specific case of this study, which focuses on the MGRT (Maximum Guaranteed Response Time) of the triage process for scheduling appointments for the orthopaedics speciality, of a public hospital in Portugal, the waiting list for the triage process had (by the date of the study) 1244 users with an average waiting time of 90 days. It is expected that the hospital perform the triage process for appointment request in a MGRT of 5 days (Ministério da Saúde, 2013). Beyond a slow response regarding the patient's point of view, the hospital is incurring financial penalties by the Central Administration of the Portuguese Health System for non-compliance of this times.

Thus, taking the example of supply chain management mentioned by Priyan (2017), in other areas of hospital operations management the people responsible for decision-making are doctors who, despite their excellent clinical capacity, do not have knowledge in the area of operations management. That way, taking into account the contributions and the potential of applying operational research to the efficiency and effectiveness of healthcare services (Carter et al., 2012), this work aims to develop and analyse an optimization model that can be applied as a means of support and guidance to the management of the triage waiting list, in order to respond to the hospital and patients' needs. Recognizing the importance of matching capacity to demand (Eriksson et al., 2011; Siciliani et al., 2014), the model should be able to define an optimal number of hours*doctor per day per week meeting all the process constraints.

To achieve this goal, the case study methodology is adequate. Thus, a case in a public hospital is characterized and analysed to create a solution that can reduce the waiting list. Operational research is not a new approach in the healthcare systems, many researchers and managers in the health services adopt operational research concepts and methodologies used in other business areas (Priyan, 2017).

This study also had the contribution and participation of a team of orthopaedists, constituted in order to improve the service level and consequently its response effectiveness. It is important to recognize the importance of the involvement of health professionals in this process as their contribution was fundamental in the definition of problem parameters and goals.

CHARACTERIZATION OF THE WAITING LIST FOR TRIAGE PROCESS

This study was developed as part of a project for continuous improvement of the external appointments service of the orthopaedics speciality of the hospital. The study regards the access to the first appointment of orthopaedics speciality and aims the reduction of the waiting list and consequently the waiting time.

Patients may access to the hospital (to a speciality appointment) in three different ways: as an outpatient, as an emergency patient, and as a hospitalized patient. This study focuses on the outpatients who came from the primary healthcare services, by the request performed by general clinical doctors (also known as “family doctors” in Portugal). The focus on this type of access to the hospital is justified since it is on this type of access that the hospital is monitored by regulatory health authorities and through which the hospital is subject to financial penalties for non-compliance with the regulated MGRT, shown in Table 1.

Table 1 - MGRT (Ministério da Saúde, 2013)

<table>
<tr><th colspan="3">MGRT (Days)</th></tr>
<tr><td>Triage</td><td colspan="2">5</td></tr>
<tr><td rowspan="3">First Appointment</td><td>Very urgent requests</td><td>30</td></tr>
<tr><td>Urgent requests</td><td>60</td></tr>
<tr><td>Normal requests</td><td>120</td></tr>
</table>

At the date of this study, the number of requests waiting for a first orthopaedic appointment was 4835 with an average waiting time of 210 days. These requests have to be subjected to a triage process and, from the 4835 patients, there was 1244 patients without triage process, with an average waiting time of 66 days and maximum of 543 days. According to the information analysed, only very urgent requests had met the MGRT for the first appointment.

The triage process aims to establish a priority level so that the requests may be ranked according to its urgency. However, in the triage process it is also possible to accept or discard the appointment request. If the request is accepted, then a priority is assigned. If the request is discarded, then it may be completely discarded being then removed from the system (and waiting list). However, the request may be temporarily discarded, being returned to family doctor to review the clinical process of the patient (for example, due to lack of clinical information or due to lack of exams). In the returned requests, the patient remains in the system and the waiting time increases continuously until a response is obtained from the family doctor. The time elapsed between returning the request and receiving the updated request is a time in which the hospital has absolutely no control and compromises its indicators, namely the MGRT for the triage process.

This project has as an essential principle which is the involvement of doctors in the improvement process. So, with the improvement team, consisting of orthopaedic doctors, were presented and discussed the main conclusions of an exhaustive analysis of information collected from the Hospital, referring to the records of the speciality.

According to the orthopaedics doctors, many of the patients who are observed in the appointments were sent to the hospital without a previous study of the disease, namely without being prescribed any exams. It was also identified that several patients do not presented pathologies justifying an appointment in the hospital. All these factors are contributing for the increasing of the waiting list and for the unnecessary use of highly specialised resources as the orthopaedics doctors.

Situations like these would be easily avoidable through the triage process, by discarding or returning the requests. However, the orthopaedic doctors recognize that it is unacceptable to discard a request that is waiting for so long for the triage process (maximum 543 days), and after the triage process will wait for the first appointment. Return a request will only delay the patient process. So, the conclusion is that if the triage time is high it is unacceptable to discard requests. If the triage time is very short, then the hospital may discard non-justified requests.

In this way, relying in the expertise of the team, a waiting time of two weeks for triage was defined as an acceptable period for the discarding of a request. Being so, one of the main objectives outlined by the team was to increase the number of triages to reduce the response time. With the definition of this objective, it was intended to achieve the response time that allows the rejection of requests within the time considered acceptable, becoming also more flexible in identifying the urgent requests.

Thus, since the orthopaedic doctors admit that no triage time is defined in their schedules (the triage process was performed by good will in the emergency room in periods of low service demand), it became essential to assess the number of hours necessary for the objective to be achieved, and also to include those hours in the doctors schedule. In this sense, an optimization model was developed in order to provide a solid support base for decision making, regarding the management of the waiting list for triage process, with the aim of assessing the needed capacity, translated into hours*doctor per day, for the triage process.

OPTIMISATION MODEL TO DEFINE THE REQUIRED DOCTOR CAPACITY

This section shows the modelling of the problem, which aims to achieve the optimal solution for the minimum number of hours*doctor required per day, on a weekly basis, for one year, to control the waiting list of the triage process.

Although apparently simple, the problem definition is more complex than it looks like at a first glance. There are several constraints related to the triage process that makes the problem hard to solve empirically. The problem is constrained by the existing number of requests in the waiting list, by the requests that arrive to the hospital daily (demand), by the processing time to perform a triage (and the efficiency of the resources), by the number of days that the speciality operates, by the number and distribution of the triage hours by resources and their schedules, and by the waiting list behaviour to achieve the required MGRT.

In order to achieve the intended objective, it is necessary to establish the constraints that the solution to this problem must meet. Thus, regarding the control of patients in the waiting list, two constraints were considered. One of the constraints considers a progressive reduction of the waiting list (maximum number of patients in the list), and the other constraint considers a minimum number of patients in the list. This pair of constraints aims to define the limit values of the waiting list in order to achieve the desired response times and also to distribute, in a more uniform way, the workload between the several weeks of analysis.

Another important constraint to be taken into account is the number of hours*doctor per day that doctors can dedicate to the triage process. As there is a capacity limit (in terms of hours dedicated to the triage process, either by limited number of orthopaedists, or the time they have to dedicate to other tasks) it was established a maximum number of hours*doctor per day. As well, a minimum limit to the number of hours*doctor per day was establish for the triage process. This minimum limit is necessary because since the defined number of hours*doctor per day can only be changed on a week basis (meaning that during a week the number of hours*doctors per day is always the same), this restriction prevents the model from defining weeks without triage process (hours*doctor per day = 0), which is mandatory because a week without triage may mean that urgent cases are not analysed.

Finally, in order to avoid a disparity in week schedules, a pair of restrictions were also established that aim to contribute for smoothing the doctors' schedules, thus imposing a limit on the variation of hours*doctor per day allocated to the triage process between two consecutive weeks.

Being an optimization problem in the area of operational research, it is necessary to define the mathematical notation of the parameters, decision variables, objective function and constraints of the problem. This mathematical notation allows an adequate conceptual modelling of the problem.

Parameters:

LI (initial waiting list): represents the current waiting list when the model is executed.

$\mathbf{LP_i}$ (expected waiting list): represents the expected (forecasted) waiting list for week i.

$\mathbf{FMAX_i}$ (desired maximum waiting list): represents the desired maximum waiting list for week i.

$\mathbf{FMIN_i}$ (minimum waiting list): represents the minimum waiting list for week i.

D (planned days): represents the number of days planned for the service to operate.

P (demand): represents the average number of daily requests that enter the hospital.

TC (cycle time): represents the standard time for the execution of the triage process.

E (efficiency): represents the level of efficiency in the triage process, that is, it quantifies the percentage of time that is actually dedicated to the triage process and, consequently, the percentage of time that is wasted with voluntary or involuntary stops.

T (time factor): Represents the time factor that converts the number of planned days into weeks.

Decision variables:

The model intends to establish the minimum number of hours*doctor per day for every 52 weeks of the study, as follows in expression (1):

$$\mathrm{x_i} = \text{number of hours} * \text{doctor per day in the week i} \qquad (1)$$

$$\mathrm{x_i} \geq 0 \ \wedge \ \mathrm{x_i} = \text{integer}, \forall\, \mathrm{i} \ \in \ \{1, 52\}$$

Objective function

The purpose of the model is to minimize the total number of hours*doctor per day, per week, for the triage process, according to equation (2).

$$\mathrm{Z} = \mathrm{Min} \sum_{\mathrm{i}=1}^{52} \mathrm{x_i} \qquad (2)$$

Constraints

- Expressions (3) and (5) indicate the maximum number of patients on the waiting list for the triage process in the week **i** ($\mathrm{FMAX_i}$):

For $\mathrm{i} = 1$:

$$\left(\frac{\mathrm{E} \times 60 \times \mathrm{D} \times \mathrm{T}}{\mathrm{TC}}\right) \mathrm{x_i} \geq \mathrm{FMAX_i} - \mathrm{LI} - \mathrm{P} \times \mathrm{D} \times \mathrm{T} \tag{3}$$

For $\mathrm{i} > 1$:

$$\left(\frac{\mathrm{E} \times 60 \times \mathrm{D} \times \mathrm{T}}{\mathrm{TC}}\right) \mathrm{x_i} \geq \mathrm{FMAX_i} - \mathrm{LP_{i-1}} - \mathrm{P} \times \mathrm{D} \times \mathrm{T} \tag{4}$$

- Minimum number of patients in the triage waiting list in the week **i** (**$\mathbf{FMIN_i}$**,) are presented according to expressions (5) and (6) :

For $\mathrm{i} = 1$:

$$\left(\frac{\mathrm{E} \times 60 \times \mathrm{D} \times \mathrm{T}}{\mathrm{TC}}\right) \mathrm{x_i} \leq \mathrm{FMIN_i} - \mathrm{LI} - \mathrm{P} \times \mathrm{D} \times \mathrm{T} \tag{5}$$

For $\mathrm{i} > 1$:

$$\left(\frac{\mathrm{E} \times 60 \times \mathrm{D} \times \mathrm{T}}{\mathrm{TC}}\right) \mathrm{x_i} \leq \mathrm{FMIN_i} - \mathrm{LP_{i-1}} - \mathrm{P} \times \mathrm{D} \times \mathrm{T} \tag{6}$$

- Expression (7) shows the maximum number of hours*doctor per day in the week **i** (**$\mathbf{HMAX_i}$**):

$$\mathrm{x_i} \leq \mathrm{HMAX_i} \tag{7}$$

- The minimum number of hours*doctor per day for week **i** (**$\mathbf{HMIN_i}$**) is indicated by the expression (8)

$$\mathrm{x_i} \geq \mathrm{HMIN_i} \tag{8}$$

- The maximum variation in the number of hours * doctor per day between two consecutive weeks (**$\mathbf{V_i}$**) is limited according to expressions (9) and (10):

$$\mathrm{x_i} - \mathrm{x_{i+1}} \leq \mathrm{V_i} \tag{9}$$

$$\mathrm{x_{i+1}} - \mathrm{x_i} \leq \mathrm{V_i} \tag{10}$$

The described model was applied to the specific case of the waiting list for triage process of the orthopaedics speciality, and the results obtained are presented and discussed in the following section.

RESULTS

All the information needed to parameterise and solve the problem was compiled into a spreadsheet in the Microsoft Office Excel software. The optimiser engine used was the OpenSolver tool.

The parameterization of the model was done according to the values presented in Table 2:

Table 219 – Parameters of the problem.

Parameters	
LI	1244 (patients)
$\mathbf{FMAX_i}$	Represented in Figure 1
$\mathbf{FMIN_i}$	300 (patients)
D	244 (days)
P	42 (patients)
TC	6 (minutes)
E	80%
T	0,02
HMAXi (hours)	8
HMINi (hours)	4
Vi (hours)	2

The data presented in Table 2192, with regard to LI, refers to the current state of the triage process waiting list when the model was executed. The TC was determined according to the expertise of the team of specialists. The D corresponds to days scheduled for the year in study. The value of P corresponds to the daily average demand of the previous year. As for the value of the efficiency, that was determined taking into account the voluntary and involuntary stops, since the doctors perform different functions in different services at the hospital. The parameter T corresponds to a conversion constant to convert the number of days into weeks. With regard to $FMAX_i$, because it represents a desired value for the waiting list, it is presented together with the model solution. The $FMIN_i$ represents the minimum number of patients in the waiting list.

The values of the parameters were defined according to the information obtained from the hospital and from the inherent characteristics of the triage process. All parameters characterize as accurate as possible the real state of the hospital and orthopaedics speciality.

According to the information parameterised, the model presented an Optimal Solution (OS) that meet all the constraints of the problem. Figure 1 shows the solution of the problem, as well as the values of the constraints FMAXi and FMINi imposed.

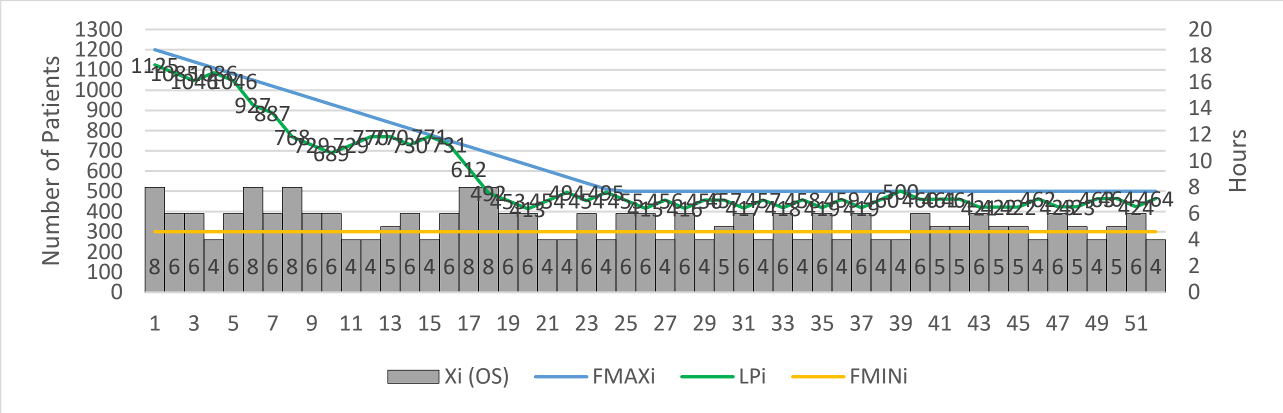

Figure 1 - Optimal solution of the problem (x_i – right *y* axis).

The results represent the optimal solution for the problem with respect to each of the 52 decision variables established in order to minimize Z. As can be seen, the maximum number of triage processes per day ($FMAX_i$) was defined as decreasing by an amount of 30, from one week to the other, until week 24. This behaviour will create a steady reduction of the triage processes requests in the waiting list as shown by the LP_i curve. It was also defined that the number of patients could be between 500 and 300. Such event occurs after week 25.

Thus, according to the objective function, the minimum number of hours*doctor required to meet all constraints is 1400 hours*doctor. From week 1 to 24, the maximum is 8 hours*doctor and the minimum is 4 hours*doctor, which may be diluted by the team members. After week 25, the minimum is still 4 hours*doctor, but the maximum does not exceed 6 hours*doctor.

It is important to notice that the expected (forecasted) behaviour for the waiting list complies with $FMAX_i$ and $FMIN_i$ constraints by varying between the constraint's lines (in the graph). The variation is more accentuated in the first 25 weeks and tends to stabilise after that. This may be explained as the variation of the limits of the waiting list become more constrained after week 25 which allows less variation to the forecasted waiting list.

Since the very beginning, the development of the optimisation model was designed to constitute an agile tool for use in the continuous improvement meetings of the project team. The ease of use allows the team to use it during the plan phase of each continuous improvement cycle. One of the capabilities of the tool is to allow the team to search an alternative optimal solution in a guided manner. These capabilities also allow the team to understand the effects of changing the number of hours*doctor per day, per week, in the length and MGRT of the waiting lists. These capabilities are especially important so the team can reallocate the number of hours*doctor to best fit the doctors' schedules. Therefore, to ensure the compliance with all the constraints, a colour scheme was applied to the model in a way that any violation of any constraint is identified. As said before, this allows for searching alternative optimal solutions and also search for solutions that (although may not be optimal in terms of minimum hours*doctor per day) may better adjust the number of hours*doctor according to the service context. This approach transforms the model into a useful and didactic tool for the continuous improvement team, that will allow testing alternative scenarios to verify which is the best alternative solution.

So, by applying the described method, an Alternative Optimal Solution (AOS), shown in Figure 2, was found. The values of the decision variables were entered manually, in order to establish a higher number of hours in the first weeks, to guarantee faster effects in the reduction of the waiting list and reach the stability of the waiting list sooner. This approach also allows for a better balance in terms of doctors' schedules considering the needed hours for the triage process. It is important to state that similar results could be automatically obtained by changing the parameters of $FMAX_i$, requiring a faster decrease in the waiting list.

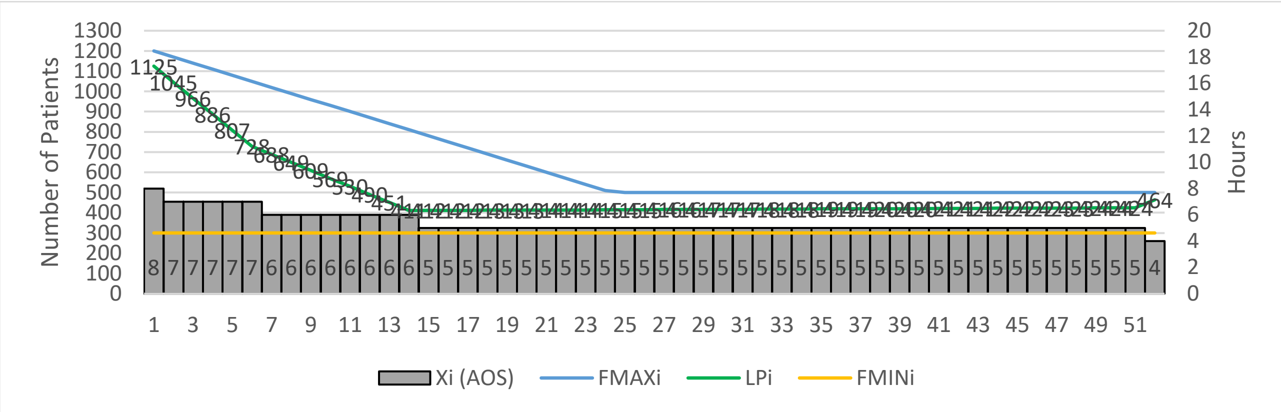

Figure 2 - Alternative Optimal Solution of the problem.

Analysing the results, the most significant changes are visible in LPi that stabilizes after 14 weeks, 4 weeks less than in the previous solution, which would be expected as this solution uses more hours*doctor in the same time horizon (OS = 405; AOS = 444). This forcing in the first weeks is only possible if the doctors' schedules can accommodate such number of hours. Being an optimal solution, the value of the objective function remained the same, 1400 hours*doctor for a period of 52 weeks.

As it is possible to verify, 5 hours*doctor per day nearly meets the current demand. This means that depending on the desired aggressiveness to decrease the waiting lists the number of hours*doctor per day may vary, then stabilizing around 5 hours*doctor per day.

The possibility of subcontracting or proposing overtime hours to doctors in the service has been considered by the hospital administration, although this only make sense if the needed hours cannot be accommodated in the doctors' schedules.

A comparison between the Optimal Solution and the Alternative Optimal Solution was developed in order to understand the effects of the solutions presented regarding the MGRT. Figure 3 shows the MGRT for triage at the end of each week, for each of the solutions.

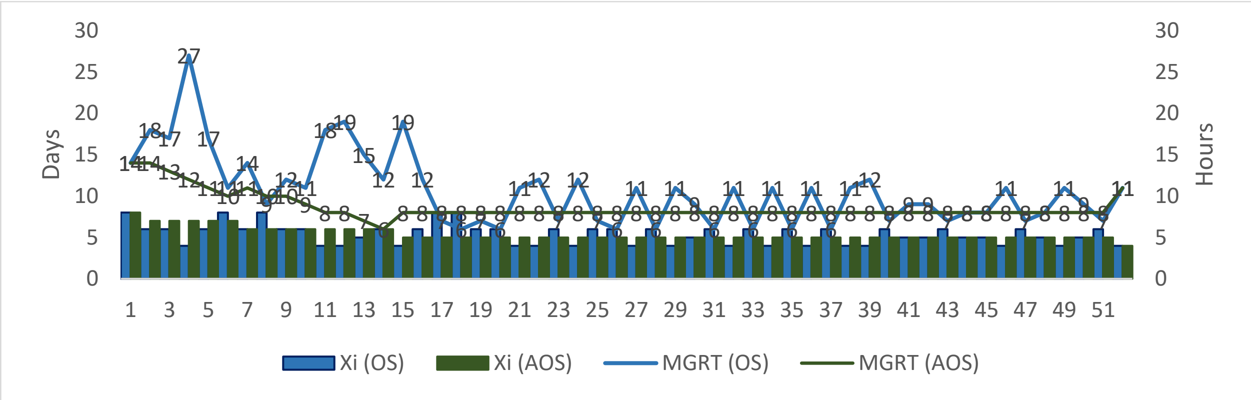

Figure 3 - MGRT for triage process.

Regarding the presented results, it is important to note that the values represent the system state at the end of each week, which means that the MGRT represents the expected value if the capacity of current week was maintained in the following week.

As an example, in the first week of the study both OS and AOS defined 8 hours*doctor per day. With this number of hours, the MGRT at the end of the week is 14 days for both solutions. In the second week the OS defined 6 hours*doctor per day and the AOS defined 7 hours*doctor per day. This difference also promoted a difference in the MGRT: the AOS maintained a MGRT of 14 days and the OS presented a MGRT of 18 days (increase of 4 days).

Throughout all the 52 weeks period, it is possible to observe that there is a higher variation of the MGRT in the OS than in the AOS. This was an expected behaviour as the main goal when defining the AOS was to minimize the variation of hours*doctor per day between weeks.

In both solutions, after the waiting list reach the stable stage, the MGRT values were steadily maintained below the two weeks period indicated as acceptable by the team. In global terms the average MGRT for the OS is 11 days and for the AOS 9 days, which also corroborates the specified two weeks period.

CONCLUSIONS

The model presented an optimal solution to the problem, revealing the minimum number of hours*doctor per day required, meeting all the constraints of the problem. Considering all the constraints and their parameterization, the minimum number of hours*doctor for the time horizon of 52 weeks is 1440. The MGRT obtained is dependent on the hours*doctor per day, per week. In global terms the average MGRT for the OS is 11 days and for the AOS is 9 days, which meet the requirements of being less than two weeks.

More than defining the number of hours needed, this project built a sense of awareness on the dimension of the problem which also reinforced the need of a team for continuous improvement. The work carried out with the continuous improvement team will allow a better perception of the information analysed, as well as a better adaptation to the reality of the speciality under study.

The developed optimization model presents itself as a tool to support decision making regarding the management of the waiting list for the triage process, however it can be extrapolated to deal with other services waiting lists. The model was also designed to be a useful and didactic tool for the continuous improvement team, that will allow testing alternative scenarios to verify which is the best alternative solution. In a continuous improvement cycle the model may be easily updated to start a new cycle in the plan phase.

Allied to the model and the definition of the needed hours to decrease the waiting list for the triage process, the team of orthopaedic doctors has been strongly committed to attain an overall improvement of the service. Such commitment is, in fact, the most important input for continuous problem solving.

ACKNOWLEDGMENTS

The authors would like to thank to the hospital administration and health professional that collaborated with the research team during this work.

This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the Projects UIDB/00319/2020 and POCI-01-0145-FEDER-030299.

REFERENCES

Carter, M., Hans, E. and Kolisch, R. (2012) ‘Health care operations management’, *OR Spectrum*, 34, pp. 315–317. doi: 10.1007/s00291-012-0288-1.

Eriksson, H. *et al.* (2011) 'Reducing queues: Demand and capacity variations', *International Journal of Health Care Quality Assurance*, 24(8), pp. 592–600. doi: 10.1108/09526861111174161.

Jarman, M. P. *et al.* (2020) 'The National Burden of Orthopedic Injury: Cross-Sectional Estimates for Trauma System Planning and Optimization', *Journal of Surgical Research*, 249, pp. 197–204. doi: 10.1016/j.jss.2019.12.023.

Johannessen, K. A. and Alexandersen, N. (2018) 'Improving accessibility for outpatients in specialist clinics: reducing long waiting times and waiting lists with a simple analytic approach', *BMC Health Services Research*, 18(1), p. 827. doi: 10.1186/s12913-018-3635-3.

Ministério da Saúde (2013) 'Portaria 95/2013', *Diário da República n.º 44/2013, Série I de 2013-03-04*, pp. 1185–1191.

Priyan, S. (2017) 'Operations research in healthcare: a review', *Juniper Online Journal of Public Health*, 1(3), pp. 1–12.

Siciliani, L., Moran, V. and Borowitz, M. (2014) 'Measuring and comparing health care waiting times in OECD countries', *Health Policy*. Elsevier, 118(3), pp. 292–303. doi: 10.1016/J.HEALTHPOL.2014.08.011.

Worthington, D. J. (1987) 'Queueing Models for Hospital Waiting Lists', *The Journal of the Operational Research Society*. Palgrave Macmillan Journals, 38(5), pp. 413–422. doi: 10.2307/2582730.