A Simulation-Based Approach to Reduce Waiting Times in Emergency Departments

Aydin Teymourifar[1,2][0000-0002-0285-0266]

[1] CEGE - Centro de Estudos em Gestão e Economia, Católica Porto Business School
[2] INESC TEC - Institute for Systems and Computer Engineering, Technology and Science, Porto, Portugal
ateymourifar@ucp.pt

Abstract. The goal of this work is to utilize a simulation model to reduce waiting times before examinations in emergency departments. Different types of arrivals to an emergency department, basic processes, and possible queues are explained. The implementation is conducted in the Rockwell Arena software and some related details are provided. The validity of the simulation model is demonstrated. Then scenarios are developed based on limited boosting of resources to reduce waiting times. It is analyzed how waiting times can be reduced. Also, it is discussed that which resources should be increased for this aim. The Process Analyzer software is used for the analysis of the scenarios, whose details are given. It is also analyzed how the utilization rate of resources changes in scenarios. Data from the literature are used for experimental results. Since the analyzes are based on generalizable approaches, they can be applied in similar emergency departments. The results show that with a reasonable increase in resources, it is possible to significantly reduce waiting times. The implications that may be useful in the management of emergency departments are presented.

Keywords: Emergency Department; Waiting Time; Discrete Event Simulation; Rockwell Arena; Process Analyzer

1 Introduction

Diminishing the waiting time of patients has always been a substantial matter in health management topics. One of the major reasons for this is that high waiting times negatively affect patients' perception of service quality [1–3]. Emergency departments (EDs) are among the most dynamic health units, and the reduction of waiting times becomes more vital there [1]. Simulation is consistently among the methods used for the analysis of dynamic and complex environments such as EDs [4–14].

The outline of the work is shown in Figure 1. A simulation model that is developed by the author in the Rockwell Arena software is applied to decline patients' waiting times in an ED. Main processes in EDs like registration, triage, and examination are included in the model. Usually, there are limited resources to carry out the processes, so waiting queues form in front of them. The aim of this study is to reduce the waiting times before examinations. Although data from a case study in the literature is used for experimental results, the simulation model is generalizable. Thus, it can be applied

in many alike EDs. There are many articles in the literature that deal with an alike topic with a similar method. But unlike the others, this study tries to find a solution to reduce waiting times by considering all the resources used for registration, triage, and examination processes. Different than many studies, the details of the simulation model are presented, making it usable by others for similar situations. Therefore, it is thought that the article contributes to those who read it for administrative purposes, along with the literature.

- Main processes in an ED are described.
- Steps of the simulation of an ED in the Rockwell Arena software are explained.
- Queues that patients wait for, before starting examination are determined.
- Scenarios based on increasing relevant resources to decline waiting times in an ED are designed.
- Scenarios are implemented in the Process Analyzer software.
- Conclusions are presented for the reduction of waiting times that can be applied to similar EDs.

Fig. 1. Outlines of the study.

The other chapters of the study are such that in Section 2 details about the system, and simulation model are described. The experimental results are given and discussed in Section 3. Conclusions are provided in Section 4, as well as the future works.

2 Description of the System and the Simulation Model

As seen in Figure 2, patients come to an ED either by ambulance or through their own means. In an ED, patients are tagged with the colors red, yellow, and green, which are high, intermediate, and low-risk patients, respectively. Some EDs use additional colors, which are not the subject of this article. Figure 2 shows the processes that are focused on, in this study.

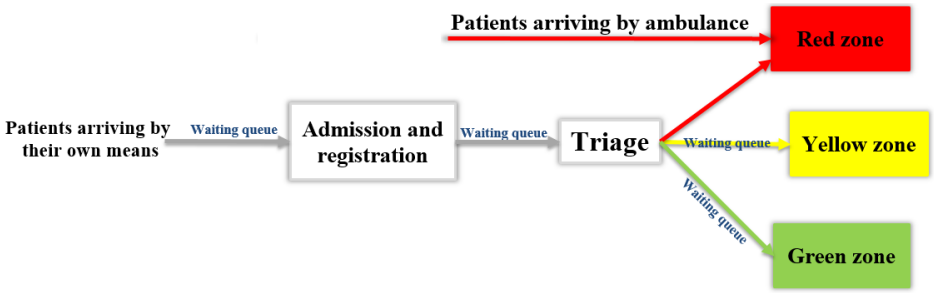

Fig. 2. General flows in an ED [2].

Also, the relevant queues are seen in Figure 2, which are the waiting queues for the admission part, triage, and examination. Admission is only for patients who come with

their own means. Since the condition of the patients arriving by ambulance is serious, they are directly tagged in red and are transferred to the resuscitation unit quickly. Red zone patients are taken under intensive care and observation after the resuscitation process. Other patients are first registered in the admission part, and then they go to the triage department and are tagged as green or yellow. In fact, some of the patients who do not come by ambulance may pass through the triage and be tagged as red. Patients of the yellow area are usually kept under observation after the examination process. This may be true for green-tagged patients as well but for a small proportion of them. They usually just get out of the ED after a basic examination. But most of the yellow zone patients experience some medical analysis and tests after the first examination. In Figure 2, intensive care, observation, medical analysis processes are not shown because, this study, just focuses on reducing the time that patients wait before the examination. Since there is no waiting for red zone patients, here only the waiting times of patients in green and yellow areas are implied. Though to illustrate the general processes in an ED, some details are also given in the following sections.

In the next parts of this section, some details of the simulation of the system in the Arena software are discussed. A method as in Figure 3 is used to adjust the time. In Figure 3 (a), when each entity arrives into the system, the time is assigned as an attribute to it. The used variable H for this purpose is shown in Figure 3 (b).

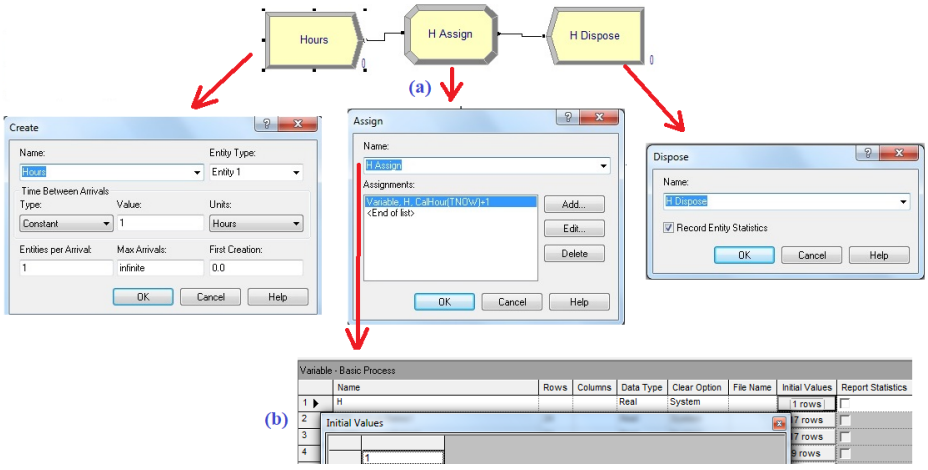

Fig. 3. Time adjustment.

Arrivals of patients into the system begins as in Figure 4 (a), the details of which are given in Figure 4 (b). Arrivals are set by defining a variable as in Figure 4 (c). This variable has 24 lines, each showing the time in seconds between patients' arrivals to the ED within an hour of the day.

Arrival types shown in Figure 2 are separated by a decision module in Figure 4 (d). Patients arriving by ambulance go directly to the red area from the route in Figure 4 (e),

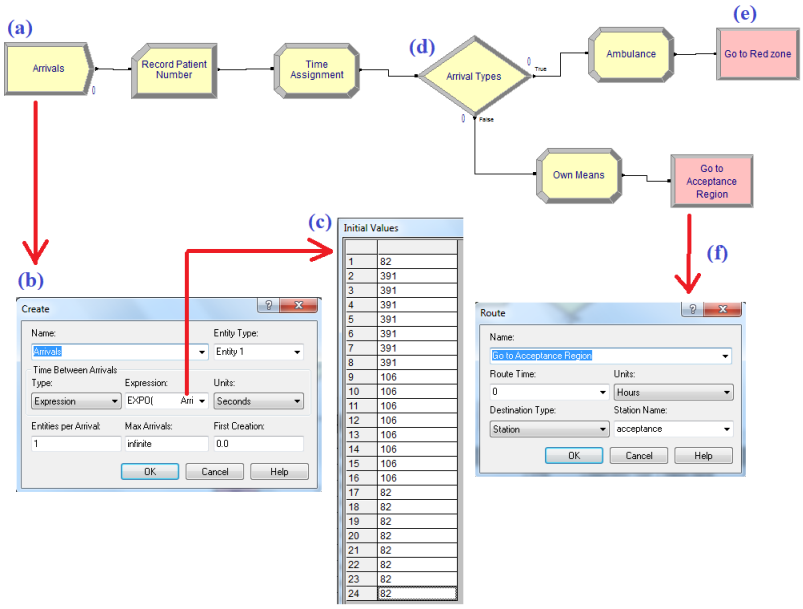

Fig. 4. Arrivals to the ED.

but others move to the admission and register there as in Figure 4 (f). On all figures, the pink elements are made using the station & route modules in the Arena.

As seen in Figure 5 (a) and (b), the station module in Arena is used for the acceptance zone, in which, as in Figure 5 (c) and (d), the registration process is done by the admission staff. Then, patients are sent to the triage area from the route shown in Figure 5 (e).

The triage section also starts with a station module as seen in Figure 6 (a). The process in Figure 6 (b) is done by a triage nurse shown in Figure 5 (d). With the decision module in Figure 6 (c), patients are divided into red, yellow, and green tagged ones. Their percentage is given in the experimental results section. As an example, Figure 6 (d) shows the patients tagged in red. They are then sent to the respective area by the route modules, shown in Figure 6 (e).

Patients who are tagged as green or yellow in the triage section enter the examination area as shown in Figure 7 (a). Using the decision module in Figure 7 (b), they are directed to specific areas. The doctor-nurse teams that examine these patients are the same, but the yellow-tagged patients have priority, which is provided by the Hold module in Figure 7 (c). The condition used in this module is as follows: *SETSUM(Examination Doctors,5) < 4 && SETSUM(Examination Nurses,5) < 4 && SETSUM(Examination Beds,5) < 4 && NQ(Yellow Examination Process.Queue)==0*. This represents the waiting area for the green examination, where patients wait there until at least one examination team is free and there are no patients waiting in the yellow area. In the Arena software, *SETSUM* symbolizes the number of busy resources, while *NQ*

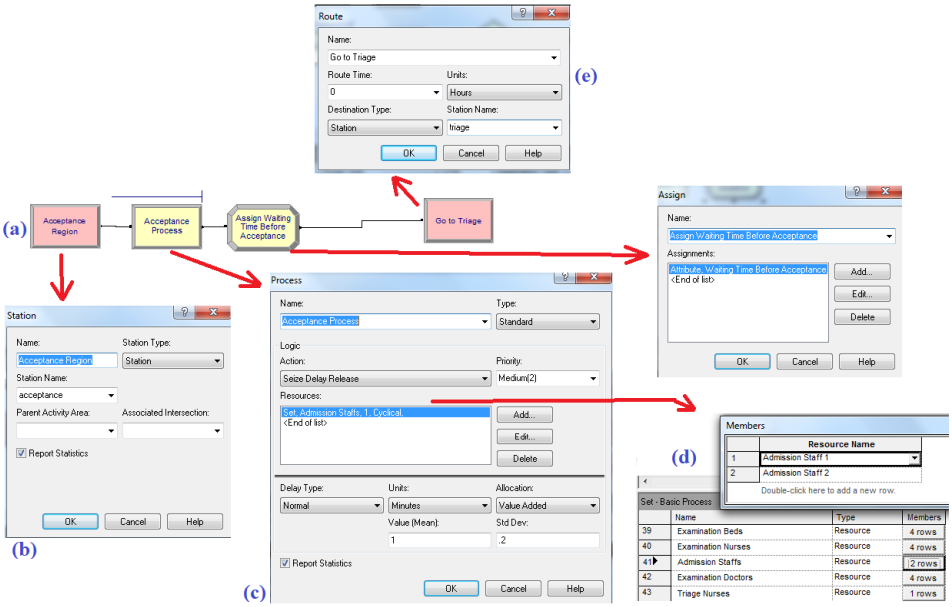

Fig. 5. Acceptance and registration part of the ED.

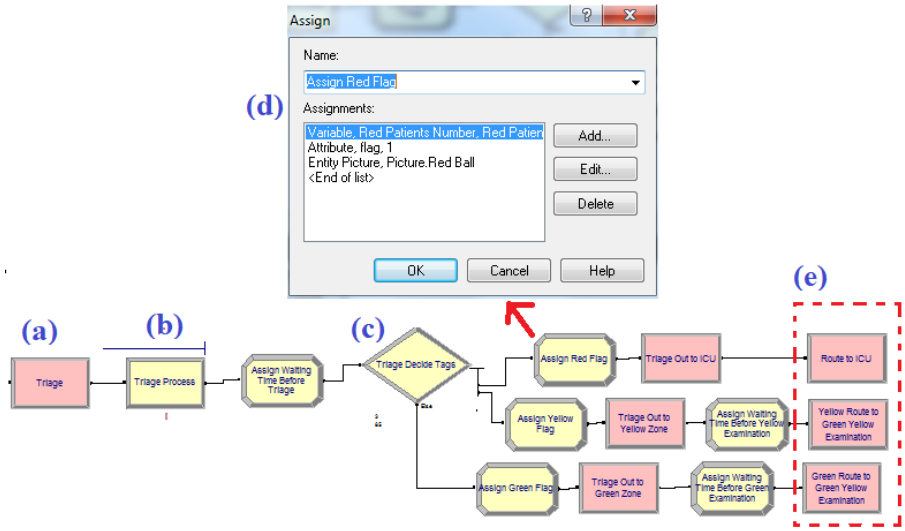

Fig. 6. Triage unit of the ED.

stands for the number of entities waiting in a queue. The values 4 and 5 are respectively the number of resources and the related index. The condition adequately represents the priority of patients of the yellow zone over green ones and the situation in which resources are more focused when a patient comes to the yellow zone.

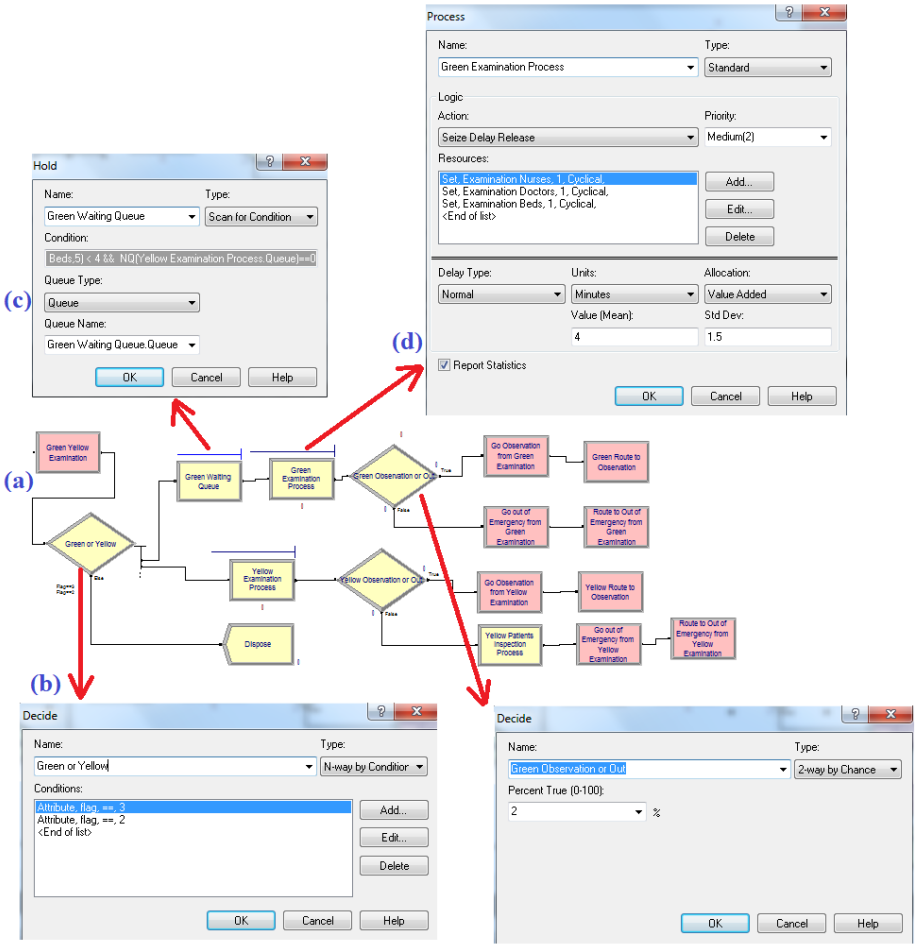

Fig. 7. Examination processes in the green and yellow zones.

Figures 8 (a), (b) and (c) show the red, observation, and exit zones, respectively, although, as mentioned before, these parts do not affect the outputs of this study. The resources in the red and observation zones are different from the green and yellow examination zones. Even when necessary, a team is called from the other parts of the ED and/or nearby health units for the red zone, because patients in this area can never

be kept waiting and should be subjected to an immediate resuscitation process. This is shown as the resuscitation and intensive care unit (ICU) process in Figure 8 (a). Red zone patients are directed to observation zone after the resuscitation process. Patients go out of the ED, through the components shown in Figure 8 (c).

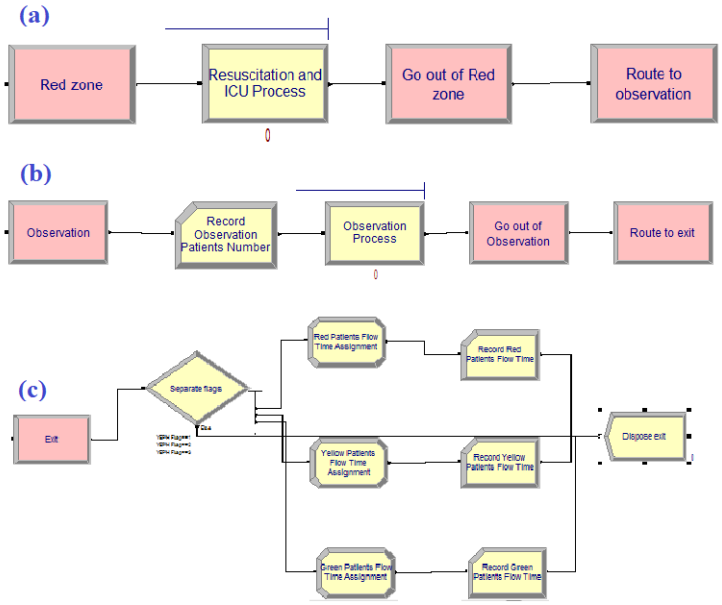

Fig. 8. (a) Red, (b) observation and (c) exit zones.

Expressions are defined for the outputs of the simulation, as seen in Figure 9 (a), (b), (c) and (d), and they are employed as seen in Figure 9 (e). They are characterized as user-defined outputs.

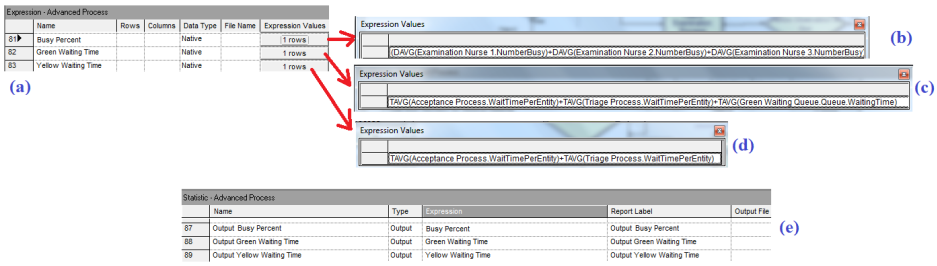

Fig. 9. Defining outputs and the simulation model.

3 Experimental Results

For experimental results, data from a case study from the literature is operated, where there are multiple EDs but only the data for one of them is used. The time between arrivals at the chosen hospital is as in Table 1, i.e. the variable shown in Figure 4 (c) is filled with the mentioned values in Table 1 [2].

Table 1: Average time between arrivals of patients to the ED (in seconds).

Time intervals	Value
02:00–08:59	391
09:00–16:59	106
17:00–01:59	82

About 8% of patients arrive at the ED by ambulance, which is represented in Figure 4 (d). As seen in Figure 5 (d), the number of resources in admission, triage, and examination zones are two, one, and four, respectively. The examination team consists of a doctor, a nurse, and the facilities necessary for the examination. In Figure 5 (d), these are defined separately, but it is also possible to collect them all under one examination resource. Furthermore, in Figure 4 (d), the needed facility is named as examination bed, which actually means all the requirements for the examination.

As seen in Figure 5 (c), the distribution of the registration process is Normal(1,0.2). Like admission, the triage process shown in Figure 6 (b) also is according to Normal(1,0.2) distribution. In the Triage section, 3%, 12%, and 85% of the patients are tagged as red, green, and yellow, respectively, which is shown in Figure 6 (c). Commonly, patients who are tagged as green in EDs are more than yellow ones, but in the case study, it is the opposite. The reason for this and related details can be found in reference [2].

As shown in Figure 7 (d), the duration of the examinations in the green area is according to Normal(4,1.5) distribution. In the yellow zone, the period of the examinations follows Normal(5,1.5) distribution [2].

The data is employed within the simulation model illustrated in Section 2. The simulation period is 30 days, i.e. one month, the warm-up period is the first 3 days, and the number of repetitions is 3 times. For the validity of the gained results, a comparison is made with the relevant study in the literature. For this aim, the monthly total number of green, yellow, and red patients, utilization rate of resources, waiting times of green and yellow tagged patients are used. They are reported in the literature as 18723, 2297, 15872, 554, 68.17, 9.88, and 0.54, respectively [2], which are found 18852, 2202, 16130, 520, 69.24, 9.61, and 0.54. Therefore, it can be said that the simulation is valid. The waiting times are in minutes.

26 scenarios are designed based on increases of up to two units in the resources, which are admission staff, triage nurses, and examination teams. So, in total, there are 27 cases with the current situation. A maximum increase of two units in resources can be interpreted as a constraint. But it should be considered that in real life, these increases are not easy. The results of the scenarios are acquired from Process Analyzer. For this aim, the file of the Arena model whose validity has been approved is used inside of the Process Analyzer software. As seen in Figure 10, resources are selected in the Controls part, while simulation outputs are selected on the side of Responses.

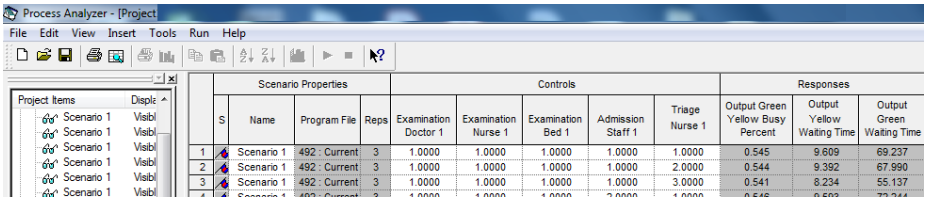

Fig. 10. Using the Process Analyzer software to analyze scenarios.

The obtained results are presented in Table 2. In the first column of the table, scenarios are denoted by *S*. The numbers of resources are written in the second, third, and fourth columns. In this table, the waiting times are in minutes. As seen, waiting times in both green and yellow zones fall significantly, especially as the number of examination teams is supplemented. Increases in the resources of admission and triage staff also reduce waiting times.

As seen in Figure 11, there is no significant dissimilarity between scenarios in terms of the utilization rate of resources. There are scenarios like S-23, S-25, and S-26, which look that have better results regarding the waiting times. However, it can be said that the results don't alter broadly after S-18. Therefore, for the employed data, it can be declared that raising by two units the number of resources that conduct examinations causes a substantial improvement. Thus, for example, applying S-18, savings can be made in resources compared to S-26. Obviously, these results may be different for other case studies.

4 Conclusion and Future Works

Since waiting times in healthcare units, especially in EDs, affect patients' perception of quality, reducing them has always been among the goals of managers. This paper describes the general processes and possible queues in an ED. On this basis, a simulation model is utilized within the Rockwell Arena software. Unlike many studies in the literature, details of the simulation process in Arena are given. The queues that a patient waits in for an examination and the resources used there are determined. Unlike many others, this study only focuses on decreasing waiting times for examinations. Though, some other relevant parts are also expressed.

Table 2: Outputs for the current state and scenarios

	Admission staff	Triage Nurses	Examination teams	Utilization rate of resources	Average waiting time in the yellow zone	Average waiting time in the green zone
Current state	2	1	4	0.545	9.61	69.24
S-1	2	2	4	0.544	9.39	67.99
S-2	2	3	4	0.541	8.23	55.14
S-3	3	1	4	0.546	9.59	72.24
S-4	3	2	4	0.538	8.69	54.47
S-5	3	3	4	0.539	8.23	54.86
S-6	4	1	4	0.54	8.98	64.02
S-7	4	2	4	0.543	8.42	52.43
S-8	4	3	4	0.542	8.40	59.52
S-9	2	1	5	0.539	2.25	7.79
S-10	2	2	5	0.546	2.11	9.62
S-11	2	3	5	0.545	1.94	8.31
S-12	3	1	5	0.543	2.36	8.55
S-13	3	2	5	0.545	1.92	8.98
S-14	3	3	5	0.546	1.75	7.52
S-15	4	1	5	0.546	2.21	7.95
S-16	4	2	5	0.543	1.79	7.33
S-17	4	3	5	0.541	1.79	7.55
S-18	2	1	6	0.547	1.43	3.85
S-19	2	2	6	0.547	0.94	3.58
S-20	2	3	6	0.545	0.92	3.52
S-21	3	1	6	0.545	1.47	4.06
S-22	3	2	6	0.551	0.97	3.67
S-23	3	3	6	0.544	0.89	3.66
S-24	4	1	6	0.545	1.40	3.93
S-25	4	2	6	0.54	0.92	3.37
S-26	4	3	6	0.546	0.93	3.57

Fig. 11. Variations of (a) utilization rate of resources, average waiting times in (b) yellow and (c) green zones according to the scenarios.

In an ED, patients are tagged as red, yellow, or green. Patients who are labeled as red, cannot be kept waiting, as they urgently need resuscitation. Therefore, waiting times for them are not considered. In this study, waiting times are for green- and yellow-tagged patients. The sections that these patients wait are the queues before registration, triage, and examination. In these areas, the resources that affect waiting times are the registration staff, triage nurses, and teams of doctors and nurses performing examinations. In addition, the facilities required for the examination are also among the influencing resources. Therefore, to decline waiting times, the appropriate level of these resources must be found. But as in many optimization problems, there are constraints as well. In particular, it may not be easy to increase the number of doctor-nurse teams and the required facilities. Besides, it should be noted that in this study, waiting times are only the time before starting the examination for the green and yellow-tagged patients. They may be directed to other parts of the ED or even be kept under observation after the initial examination, whose analysis is not the subject of this paper. Another study will be conducted on these processes, in the future.

Scenarios about increasing resources impacting the waiting times of patients are designed and implemented in the Process Analyzer software. An upper limit has been defined for the proliferation of the resources because it can be difficult to increase staff. Likewise, physical facilities need to rise as well when the examination teams are increased, which may not be easy. For the used case study, the most significant improvement in waiting times occurs when the doctor-nurse team performing the examination is increased. However, boosting triage and admission staff alike resulted in a reduction in waiting times. These results are valid for both green and yellow zones patients. Since the urgency of yellow zone patients is higher than green tagged patients, it is even more important for them to lessen waiting times.

The described simulation model represents a general case and can be used for similar EDs. Although dissimilar results may be obtained for different case studies, the method can be generalized.

The rate of patients' arrival to an ED varies according to different time intervals. Therefore, waiting times alter throughout the day. In this case, it may make sense to change resources over time. In future studies, it is planned to conduct a study based on this idea. In addition, for the case study used in this work, the reason why there is no improvement in the utilization rate of the resources may be due to the fact that the crowdedness is in certain time intervals, which will be investigated in future works.

Registration, triage, and examination are between influential processes in an ED, and the level of resources used for them affects waiting times. In this work, unlike many studies in the literature, a model is developed to reduce waiting times by focusing on these processes and related resources. Different than many papers, details about the model are provided. on the other hand, it should be emphasized that one of the main limitations of this work is that only some aspects of specific activities are included in the presented scenarios. In future studies, the model will be generalized by considering more processes. Moreover, it is planned to design a more comprehensive simulation model, including more than one ED. In this case, considering the distance of the patients to EDs, an example of the applications of the sectorization problems [15] in

health management will be presented.

Acknowledgements

Financial support from Fundação para a Ciência e Tecnologia (through project UIDB/00731/2020) is gratefully acknowledged.

The author would like to thank the editors and the anonymous referees for their valuable comments which helped to significantly improve the manuscript.

References

1. Teymourifar, A., Kaya, O., Ozturk, G.: Contracting models for pricing and capacity decisions in healthcare systems. Omega **100**, 102,232 (2021)
2. Kaya, O., Teymourifar, A., Ozturk, G.: Analysis of different public policies through simulation to increase total social utility in a healthcare system. Socio-Economic Planning Sciences **70**, 100,742 (2020)
3. Kaya, O., Teymourifar, A., Ozturk, G.: Public and private healthcare coordination: An analysis of contract mechanisms based on subsidy payments. Computers & Industrial Engineering **146**, 106,526 (2020)
4. Lin, C.H., Kao, C.Y., Huang, C.Y.: Managing emergency department overcrowding via ambulance diversion: A discrete event simulation model. Journal of the Formosan Medical Association **114**(1), 64–71 (2015)
5. Cabrera, E., Taboada, M., Iglesias, M.L., Epelde, F., Luque, E.: Simulation optimization for healthcare emergency departments. Procedia Computer Science **9**, 1464–1473 (2012)
6. Ruohonen, T., Neittaanmaki, P., Teittinen, J.: Simulation model for improving the operation of the emergency department of special health care. In: Proceedings of the 2006 Winter Simulation Conference, pp. 453–458. IEEE (2006)
7. Komashie, A., Mousavi, A.: Modeling emergency departments using discrete event simulation techniques. In: Proceedings of the Winter Simulation Conference, 2005., pp. 5–pp. IEEE (2005)
8. Cabrera, E., Taboada, M., Iglesias, M.L., Epelde, F., Luque, E.: Optimization of healthcare emergency departments by agent-based simulation. Procedia computer science **4**, 1880–1889 (2011)
9. Duguay, C., Chetouane, F.: Modeling and improving emergency department systems using discrete event simulation. Simulation **83**(4), 311–320 (2007)
10. Ahmed, M.A., Alkhamis, T.M.: Simulation optimization for an emergency department healthcare unit in kuwait. European journal of operational research **198**(3), 936–942 (2009)
11. Baesler, F.F., Jahnsen, H., DaCosta, M.: The use of simulation and design of experiments for estimating maximum capacity in an emergency room. In: Winter Simulation Conference, vol. 2, pp. 1903–1906 (2003)
12. Uriarte, A.G., Zúñiga, E.R., Moris, M.U., Ng, A.H.: How can decision makers be supported in the improvement of an emergency department? a simulation, optimization and data mining approach. Operations Research for Health Care **15**, 102–122 (2017)
13. De Angelis, V., Felici, G., Impelluso, P.: Integrating simulation and optimisation in health care centre management. European Journal of Operational Research **150**(1), 101–114 (2003)
14. Liu, Z., Rexachs, D., Epelde, F., Luque, E.: A simulation and optimization based method for calibrating agent-based emergency department models under data scarcity. Computers & Industrial Engineering **103**, 300–309 (2017)
15. Teymourifar, A., Rodrigues, A.M., Ferreira, J.S.: A comparison between simultaneous and hierarchical approaches to solve a multi-objective location-routing problem. In: Graphs and Combinatorial Optimization: from Theory to Applications, pp. 251–263. Springer (2021)