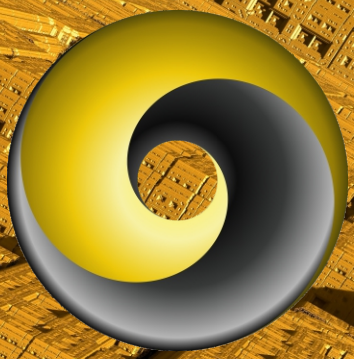

MATHMODEL'22

VI INTERNATIONAL SCIENTIFIC CONFERENCE

07 - 10 DECEMBER, 2022, BOROVETS, BULGARIA

MATHEMATICAL MODELING

PROCEEDINGS

YEAR VI ISSUE 1(6)/2022
ISSN (Print) 2535-0978
ISSN (Online) 2603-3003

Published by
SCIENTIFIC-TECHNICAL UNION of MECHANICAL ENGINEERING - INDUSTRY 4.0
Sofia, BULGARIA

V INTERNATIONAL SCIENTIFIC CONFERENCE

MATHEMATICAL MODELING

Year VI Volume 1/6 DECEMBER 2022

ISSN 2535-0978 (Print)
ISSN 2603-3003 (Online)

PROCEEDINGS

07 – 10 DECEMBER, 2022,
BOROVETS, BULGARIA

PUBLISHER:
SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING "INDUSTRY-4.0"

108, Rakovski Str., 1000 Sofia, Bulgaria
tel. (+359 2) 987 72 90,
tel./fax (+359 2) 986 22 40**,**
office@mathmodel.eu
www.mathmodel.eu

INTERNATIONAL EDITORIAL BOARD

Chairman:		
Assoc. Prof. D. Sc. Milena Racheva Technical University of Gabrovo		BG
Members:		
Abilmazhin Adamov, Prof.	L.N.Gumilyov Eurasian National University	KZ
Alexander Guts, Prof.	Omsk State University	RU
Alexei Zhabko, Prof.	Saint Petersburg State University	RU
Andrey Markov, Prof.	Baltic State Technical University	RU
Andrii Matviichuk, Prof.	Kyiv National Economics University	UA
Andrzej Nowakowski, Prof.	University of Lodz	PL
Anton Makarov, Dr.	Saint Petersburg State University	RU
Armands Gricans, Assoc. Prof.	Daugavpils University	LV
Artūras Dubickas, Prof.	Vilnius University	LT
Avinir Makarov, Prof.	Saint Petersburg State University of Industrial Technologies and Design	RU
Christo Boyadjiev, Prof.	Institute of Chemical Engineering, BAS	BG
Daniela Marinova, Dssoc. Prof.	Technical University of Sofia	BG
Dimitrios Poulakis, Prof.	Aristotle University of Thessaloniki	GR
Evgeniy Smirnov, Assoc. Prof.	Volgograd State Technical University	RU
Galia Angelova, Prof. DSc	Institute of Information and Communication Technologies, BAS	BG
Giovanni Borgioli, Assoc. Prof.	University of Florence	IT
Haskiz Coskun, Prof.	Karadeniz Technical University of Trabzon	TR
Idilia Bachkova, Prof.	University of Chemical Technology and Metallurgy	BG
Irena Stojkovska, Prof.	Ss. Cyril and Methodius University in Skopje	NM
Ivana Štajner-Papuga, Prof.	University of Novi Sad	RS
Kanagat Aldazharov, Assoc. Prof.	Kazakh Economics University	KZ
Karl Kunisch, Prof.	University of Graz	AT
Mahomed Agamirza ogly Dunyamalyev, Prof.	Azerbaijan Technical University	AZ
Marius Giuclea, Prof.	The Bucharest University of Economics Studies	RO
Mihail Okrepilov, Prof.	D.I. Mendeleyev Institute for Metrology (VNIIM)	RU
Mohamed Kara, Dr.	Ferhat Abbas Sétif 1 University	DZ
Mohamed Taher El-mayah, Prof	MTI University	EG
Neli Dimitrova, Prof.	Institute of Mathematics and Informatics, BAS	BG
Nina Bijedic, Prof.	Dzemal Bijedic University of Mostar	BA
Oleg Obradović, Prof.	University of Montenegro	ME
Olga Pritomanova, Assoc. Prof.	Oles Honchar Dnipropetrovsk National University	UA
Özkan Öcalan, Prof.	Akdeniz University of Antalya	TR
Paşc Găvruţă, Prof.	Politehnic University of Timisoara	RO
Pavel Satrapa, Assoc. Prof.	Technical University of Liberec	CZ
Pavel Tvrdík, Prof.	Czech Technical University in Prague	CZ
Pavlina Yordanova, Assoc. Prof.	Shumen University	BG
Petr Trusov, Prof.	Perm State Technical University	RU
Rannveig Björnsdóttir, Prof.	University of Akureyri	IS
Roumen Anguelov, Prof.	University of Pretoria	ZA
Sándor Szabó, Dr. Prof.	University of Pécs	HU
Sashko Martinovski, Assoc. Prof.	St. Kliment Ohridski University of Bitola	NM
Sergey Bosnyakov, Prof.	Moscow Institute of Physics and Technology	RU
Sergey Kshevetskii, Prof.	Immanuel Kant Baltic Federal University	RU
Snejana Hristova, Prof.	University of Plovdiv	BG
Svetlana Lebed, Assoc. Prof.	Brest State Technical University	BY
Tomasz Szarek, Prof.	University of Gdansk	PL
Valeriy Serov, Prof.	University of Oulu	FI
Vasily Maximov, Prof.	Saint Petersburg State University of Industrial Technologies and Design	RU
Ventsi Rumchev, Prof.	Curtin University, Perth	AU
Veronika Stoffová, Prof.	University of Trnava	SK
Veselka Pavlova, Prof.	University of National and World Economy	BG
Viorica Sudacevschi, Assoc. Prof.	Technical University of Moldova	MD
Vladimir Janković, Prof.	University of Belgrade	RS
Vladislav Holodnov, Prof.	Saint Petersburg State Institute of Technology	RU
Vyacheslav Demidov, Prof.	Saint Petersburg State University of Industrial Technologies and Design	RU
Yordan Yordanov, Assoc. Prof.	University of Sofia	BG
Yuriy Kuznetsov, Prof.	Nizhny Novgorod State University	RU
Zdenka Kolar - Begović, Prof.	University of Osijek	HR

C O N T E N T S

Analysis, modeling, and simulation of emergency department

Natasha Stojkovikj[1*], Limonka Koceva Lazarova[1], Vesna Dimitrievska Ristovska[2], Maja Kukuseva[3], Aleksandra Stojanova Ilievska[1]
Faculty of Computer Science, Goce Delcev University, Stip, North Macedonia[1]
Faculty of Computer Science and Engineering, Ss. Cyril and Methodius University, Skopje, North Macedonia[2]
Faculty of Electrical Engineering, Goce Delcev University, Stip, North Macedonia[3]
natasa.stojkovik@ugd.edu.mk

Abstract: *Overcrowding in the Emergency Department (ED) is one of the most important issues in healthcare systems. Two major causes of this congestion are identified, the first one is unjustified Emergency Department visits and the second one a lack of downstream beds. The lack of downstream beds can deteriorate the quality of care for patients who need hospitalization after an ED visit. In this paper a generic simulation model is developed in order to analyse patient pathways from the ED to hospital discharge.*
Keywords*: EMERGENCY DEPARTMENT, GENERIC SIMULATION MODEL, AGENT BASED MODELING, ANYLOGIC.*

1. Introduction

The Emergency Department (ED) is part of every hospital responsible for providing care for emergency cases and life-treating injuries 24 hours daily, 7 days of the week. ED handles many patients daily and must have a high level of efficiency and quality. Ineffective operation of ED leads to delays of treatment of the patients or even a death of critical patients. The most important issue in ED is overcrowding which has been described as both a patient safety issue and a worldwide public health problem, [1]. The overcrowding (or congestion) in ED occurs when the available capacity in ED cannot meet the demands and results in longer waiting times for the patients to get treatment. This has a negative impact and dissatisfaction of the patients who may leave without getting treatment [2], decrease the quality of care and burnout of nursing staff. Two major causes of the congestion have been identified. Firstly, unjustified ED visit and secondly lack of downstream beds. An unjustified emergency visit concerns a patient who has no health problems or non-emergency health problem. The lack of downstream beds increases the length of stay in ED because patients must wait for a bed in a relevant medical unit. Sometimes patients are admitted to a medical unit that is not adapted to their pathology in order to decrease the ED congestion. This situation is problematic because it reduces the quality of care.

Much research focuses on reducing waiting time of the patients. In [3] each activity in ED during a seven-day period was evaluated and used as input data of the model. The results show significant reducing of the waiting time of the patients. In another research [4, 5] the waiting time of the patients is reduced by assessment from primary triage nurses or physicians of the arriving patient and directed to appropriate staff based on the injuries or health condition.

The effect on waiting times of the patients and resource of nursing request from the fast-tracking additional unit in the ED using Monte Carlo simulation in MATLAB is represented in [6]. In this model the nursing resource demand and ED occupancy are modeled using Emergency Severity Index patients' level and simulation results show reduction of overall waiting time. The authors in [7] reported that in order for the processes in ED to be improved several various factors in dynamics and unpredictable environment should be considered. To facilitate the decision-making process in ED different techniques and tools have to be utilized such as combination of DES, Data Mining and simulation based multi-objective optimization, [8, 9]. In [10, 11,12] is shown the increased use of Agent Based Model within healthcare settings, particularly within hospitals.

2. Description of ED model

2D model is a geometric model of the object as two-dimensional figure in Cartesian coordinate system or Euclidean space. 2D models are an essential tool for 2D computer graphics often used as a component of 3D geometric models. In the model represented in this paper, 2D model is used to describe the rooms and the resources of ED. Also, digital rendering is used to form the perception of 2D geometric model as a 3D geometric model designed through Modeling and Simulation Software (AnyLogic).

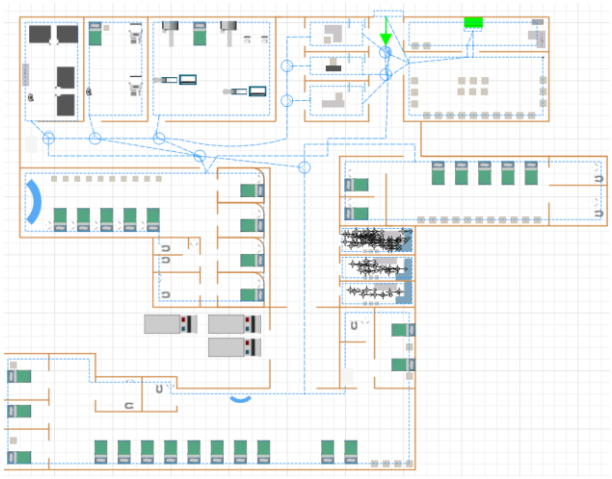

Fig. 1 *ED Model in 2D*

Three dimensinal (3D) model represent the physical object using sets of points in 3D space associated with various geometric entities such as triangles, lines, curved surfaces etc. 3D models can be created automatically or manually. The manual modeling process is similar to sculptural art. A 3D model can be physically created using 3D printing device that form 2D layers of the model printing one layer at a time. The diagram of 3D Emergency Department model used in this research is shown on Fig.2.

Fig. 2 *ED Model in 3D*

The model of ED is developed in modeling and simulation software AnyLogic. In order to achieve a certain level of functionality, the software not only shows the model in 2D and 3D, but also the movement of patients and the filling and emptying of the rooms or beds.

The project is made in AnyLogic simulation and modeling software.

The following resources are used in this model:

-Personnel: Doctors, nurses, and technicians.

- Rooms: Triage rooms, rooms for urgent care.

-Equipment: Ultrasound devices, C-Arm devices, X-ray scanners and tomography devices, Fig.3.

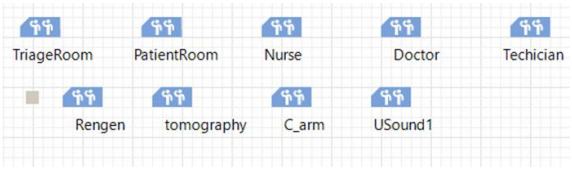

Fig. 3 *Elements of ED model.*

Upon arrival in the system, the patient is registered and goes to the waiting room, then the nurse takes him to the triage room. After triage, the patient continues in the care room (patient room), and then, if necessary, the patient is directed for additional examinations, with an ultrasound machine, X-ray, tomography, or C-arm. If the X-ray needs to be taken, the patient goes to the X-ray room. If the examinations must be done by using ultrasound, then the ultrasound machine is moved to the patient room where the patient is placed.

There are three patient rooms and three triage rooms in the system, which we do not change in the model, i.e., we assume that they are fixed. In the model, the number of nurses, technicians, and doctors, as well as X-ray, tomographic, C-arm devices and ultrasound devices can be changed. For this purpose, the following parameters are set: ArrivalRate, Nurses, Doctors, Technicians, USoundMachine, XRayMachine, Tomograph, CArmMachine.

We can also change the rate of incoming patients in the model. In the model, we can also change: the speed of the patient's movements and the speed of the staff' movements. So, in the model, also are set the parameters SpeedPatient and SpeedStaff.

The main elements in the system are the following:

Source - generates a certain number of patients (patients per hour).

TimeMeasureStart - for measuring the time of the patient's movement considering from the beginning to the moment when the patient goes to the desired destination.

Registration - the registration service time is uniform on the interval (2.5, 3.3).

Waiting queue for registration - the length of the queue is 20 and priority for serving is FIFO.

Time for registration - the time spent for registration.

The time for registration is distributed according to the triangular distribution on the time interval (0.5, 1, 1.5).

SeizeTriageRoom – consists of the resources Nurses and TriageRooms.

Triage – the service time has triangular distribution at the time interval (5, 8, 15).

releaseTriageRoom - the triage room is left.

SeizeRoomforPatient – consists of the Nurses and RoomForPatient.

releaseNurse - the nurse is released.

SeizecallDoctor – the doctor is called.

selectAction- one of the four options is chosen (USound, Xray, tomography or C-arm machine).

releaseDoctor – the doctor is released.

TimeMeasureEnd – the measurement of the patient' time in the system is finished.

The model, i.e., process Flowchart is given at the following figure:

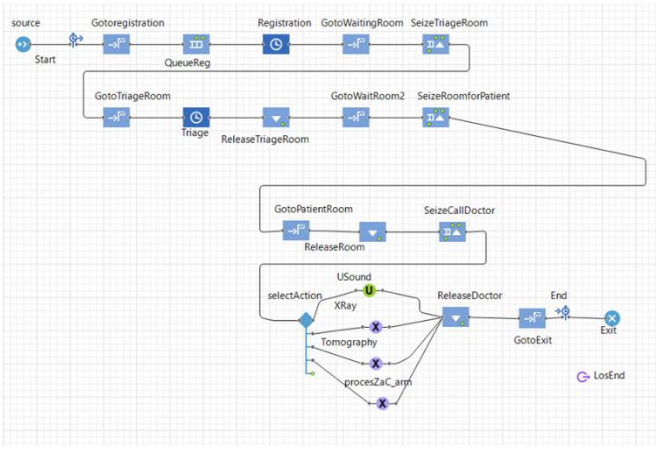

Fig.4 *Schematic representation of the model.*

3. Analysis and simulation of ED model

If 5 patients arrive per hour, the number of resources are the following:

	Number
Nurse	5
Technicians	2
Doctor Assistant	2
Ultra-sound Machine	2
Tomography	1
C-arm machine	1
ECG	2
Rate of arriving	5
X-Ray machine	1

For the given parameters, in AnyLogic modelling and simulation software we obtain the following results (Figure 5 and Figure 6).

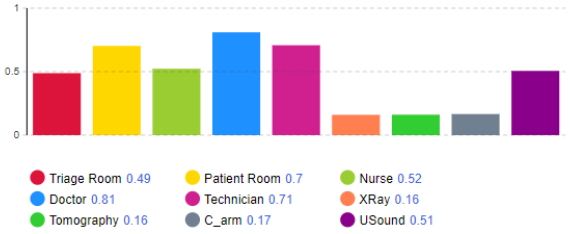

Fig.5 *The utilization of every element particularly for arrival rate= 5, nurses=5, doctors=2 and technicians=2.*

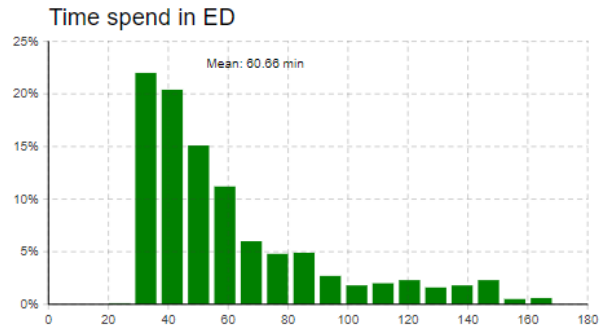

Fig.6 *Time spent in ED system for arrival rate= 5, nurses=5, doctors=2 and technicians=2.*

We can note that if 5 clients arrive per hour, then the utilization of nurses is 52%. The average patients' time spent in the system is 60.66 minutes.

Do we can optimize the system, if we reduce the number of nurses to 3? Then we have the following results:

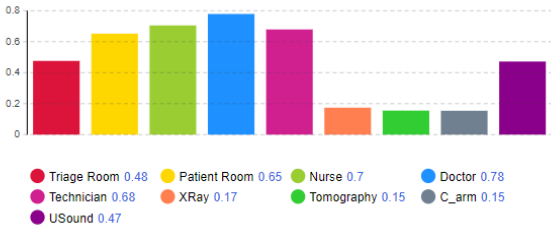

Fig.7 *The utilization of every element particularly for arrival rate= 5, nurses=3, doctors=2 and technicians=2.*

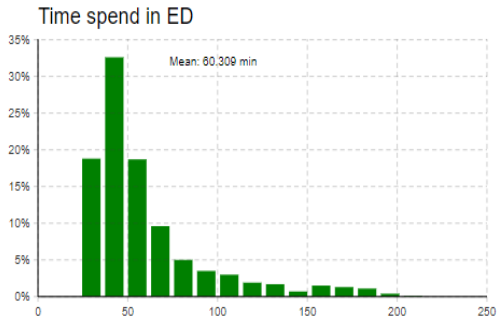

Fig.8 *Time spent in ED system for arrival rate= 5, nurses=5, doctors=2 and technicians=2.*

In this case we have less nurses, but their utilization has increased. The mean time spent in ED is 60.309 min. In order to optimize the system and to increase the utilization of personnel, we will reduce the personnel.

If we change the rate of arrival of clients to 10 clients per hour, and the number of nurses is 5, we will get:

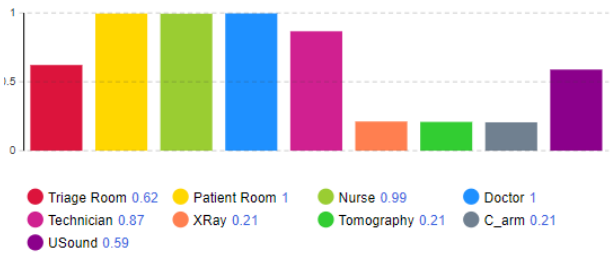

Fig.9 *The utilization of every element particularly for arrival rate= 10, nurses=5, doctors=2 and technicians=2.*

We have an oversupply here because of the small number of doctors and nurses.

For that, we will increase the total number of nurses to 8, and the number of doctors and technicians to 4. We get:

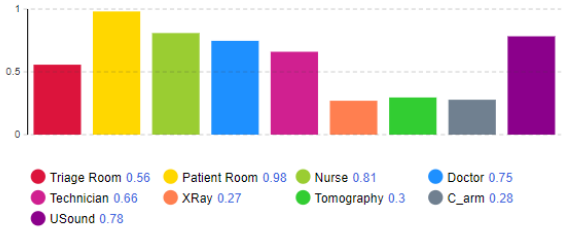

Fig.10 *The utilization of every element particularly for arrival rate= 10, nurses=8, doctors=4 and technicians=4.*

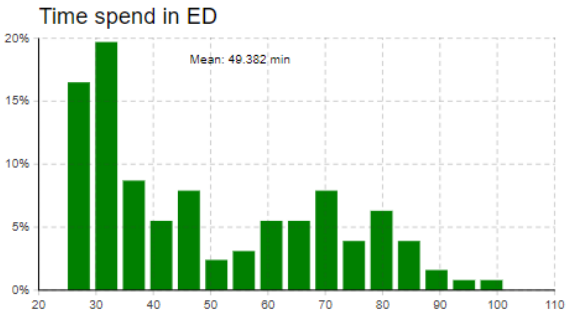

Fig.11 *Time spent in ED system particularly for arrival rate= 10, nurses=8, doctors=4 and technicians=4.*

In this case, the utilization of nurses, doctors and technicians is reduced for that rate of arrival of patients (10 patients per hour).

To increase the rate of arrival to 15 patients per hour, let the number of nurses is 8, and the number of doctors 4 and the number of technicians is 4. We get:

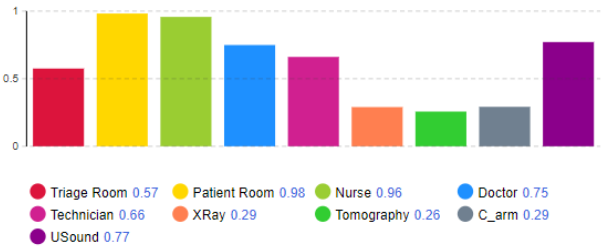

Fig.12 *The utilization of every element particularly for arrival rate= 15, nurses=8, doctors=4 and technicians=4.*

We have huge utilization of the nurses, co we will increase their number to 12, and the number of technicians and doctors to 5. We get:

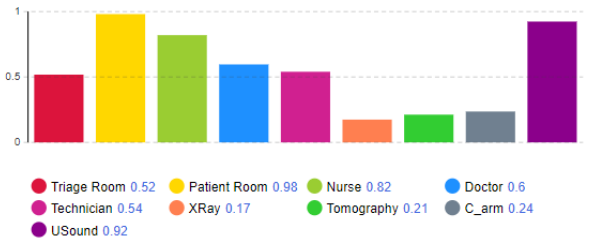

Fig.13 *The utilization of every element particularly for arrival rate= 15, nurses=12, doctors=5 and technicians=5.*

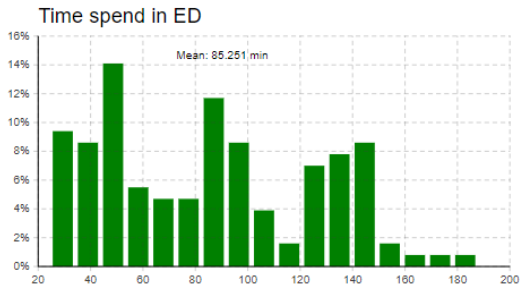

Fig.14 *Time spent in ED system for arrival rate= 15, nurses=12, doctors=5 and technicians =5.*

Nursing utilization has decreased to 82%, and the mean of the patient' time in the total system in Emergency Department will be increased to 85.251 min. This is expected because all the other elements in the ED have a huge percent of utilization.

4. Conclusion

This Emergency Department model is simple model for designing of the connections between its elements. The model uses state machine-based agents which act and communicate within a defined environment. The simulation is done in order to show the validity of the model. This simulation can be used as the core component of a decision support system to aid hospital administrators make better use of resources, achieving a more efficient and improved patient care cycle. This in turn will allow better management of dynamic patient flow, either because of specific circumstances or seasonal fluctuation.

5. References

1. J. M. Pines, R. T. Griffey, *What we have learned from a decade of ED crowding research?* Acad Emerg Med. **22**(8) (2015) :985–7. 10.1111/acem.12716

2. P.A. Shroda, M.C. Reddy, C.J. DeFlitch, *A Systematic Review of Simulation Studies Investigating Emergency Department Overcrowding*, Simulation **86** (2010).

3. S.S. Armel, D.W. Starks, *Emergency Department I: The use of Simulation to Reduce the Length of Stay in an Emergency Department*, In Proceedings of the 35th Conference on Winter Simulation: driving innovations (2003).

4. M. Cooke, J. Dale, J. McLeod, E. Szczepura, A. Walley, S. Wilson, *Reducing Attendances and waits in emergency Departments: A systematic review of present innovations* (2004).

5. K. Fitzgerald, L. Pelletier, M.A. Reznek, *A Queue- Based Monte Carlo Analysis to Support Decision Making for Implementation of an Emergency Department Fast Track*, Journal of healthcare engineering. (2017).

6. A.G.Uriate, E.R. Zuniga, M.U. Moris, A.H Ng, *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** pp.1020122, (2017)

7. A. Nahhas, A. Awaldi, T. Reggelin, *Simulation and the Emergency Department Overcrowding Problem*, Procedia Engineering, **178** pp. 368-376 (2017).

8. A. Gharahigheki, A.S. Kheirkhak, A. Bagheri, E. Rashidi, *Improving Performances of the Emergency Department Using Discrete Event Simulation, DEA and the MADM Methods*, Digital Health, **2** (2016).

9. C. Marley, M. Unwin, G. M. Peterson, J. Stankovich, L. Kinsman, *Emergency department crowding: A systematic review of causes, consequences and solutions*, PLoS One. 2018 Aug 30;13(8):e0203316. doi: 10.1371/journal.pone.0203316.

10. M. R. Friesen, R. D. McLeod, *A Survey of Agent-Based Modelling of Hospital Environments*, IEEE Access, **2**(1) (2014):227-233.

11. M. Taboada, E. Cabrera, M. Luisa Iglesias, F. Epelde, E. Luque, *An Agent-Based Decision Support System for Hospitals Emergency Departments*, Procedia Computer Science, **4** (2011), 1870-1879, https://doi.org/10.1016/j.procs.2011.04.203.

12. H. Stainsby, M. Taboada and E. Luque, *Towards an Agent-Based Simulation of Hospital Emergency Departments*, 2009 IEEE International Conference on Services Computing, 2009, pp. 536-539, doi: 10.1109/SCC.2009.53.