Perioperative Care and Operating Room Management 15 (2019) 100074

Contents lists available at ScienceDirect

Perioperative Care and Operating Room Management

journal homepage: www.elsevier.com/locate/pcorm

Operating room orchestration by using agent-based simulation

Masoumeh Saeedian[a], Mohammad Mehdi Sepehri[b,e,*], Ammar Jalalimanesh[c], Pejman Shadpour[d]

[a] Faculty of Industrial and Systems Engineering, Tarbiat Modares University, Tehran, Iran
[b] Faculty of Industrial and Systems Engineering, Tarbiat Modares University, Tehran 1411713116, Iran
[c] Iranian Research Institute for Information Science and Technology (IRANDOC), Tehran, Iran
[d] Hospital Management Research Center (HMRC), Hasheminejad Kidney Center (HKC), Iran University of Medical Sciences (IUMS), Tehran, Iran
[e] Hospital Management Research Center (HMRC), Iran University of Medical Sciences (IUMS), Tehran 1969714713, Iran

ARTICLE INFO

Keywords:
Agent-based simulation
Operating room
Orchestration
Performance measurement

ABSTRACT

Background: Increasing demand and costs of healthcare services become a serious problem in healthcare systems. Due to the high demand for surgical interventions, operating room (OR) is the heart of hospital with 60–70% of admissions. Operating room resource orchestration as a resource management and performance measurement techniques has considerable effects on its performance.
Method: Agent-based simulation is an effective approach to model complex systems. As there are many agents interacting in operating room during a surgery, we can consider an OR as a complex system. In this research, we architected and developed an agent based model considering all different units and actors involving in surgery in the OR.
Results: By identifying operating room bottlenecks and consulting with experts, several improving scenarios were developed and finally combined scenario had most effect on total patient waiting time, total patient recovery time and total patient staying at the system by reduction of 9 min, 10 min and 21 min respectively.
Conclusion: The result suggested that we can make significant improvements by in-depth understanding of operating room, orchestration concepts and finally doing simulation.

1. Introduction

The cost of healthcare has increased more rapidly than inflation worldwide.[1,2] As one of the developing countries, Iran healthcare costs are also increasing. According to the World health organization report, Per capita health costs in 2001 was about 3.6% of GDP that has reached to 6.9% in 2003.[3] Currently, 45% of public revenues is spending on healthcare and it has been predicted that it would be twice in 2050. One of the most important parts of health industry that allocated more than 36% of government spending, are hospitals.[4] As OR are consuming 40% of hospital's budget, it is important to take decisions about services, patients, policies, information, process and personnel. Making correct decisions will lead to ensure the productivity of human resources, offering surgical services at the right time, maximizing profit (patient flow) without incurring additional cost or high waiting time. There are many actors (stakeholders) with different backgrounds, goals and aspirations cooperating in surgery. As a result, solving OR challenges requires understanding the complexity in different levels, from different viewpoints. In recent years, many researchers have emphasized the importance of operating room resource and performance management of operating room.[5] Operating room resource orchestration has mentioned as a means of reducing the cost of operating room, improving performance and quality of care.[6] However, the orchestration of operating room is a new topic both in the research and operational field and a few number of researches have done which considered this concept comprehensively. In this paper, operating room orchestration (ORO) problem has modeled. Orchestration concepts are investigated in the PCNL[1] surgery units of Hasheminejad Kidney Center as a case study.

1.1. Operating room orchestration

In general definition, orchestration is defined as the act of working together in harmonious manner. By one definition, orchestration is synchronizing job tasks in a consistent and appropriate manner to achieve a goal, in the best way. Therefore, orchestration is an essential concept in the systems which comprised of different parallel tasks.[7] Study in orchestration has been started from 1950 in different context such as organization department's orchestration.[8] Need to orchestration

* Corresponding author.
E-mail address: mehdi.sepehri@gmail.com (M.M. Sepehri).

[1] Percutaneous NephroLithotomy

https://doi.org/10.1016/j.pcorm.2019.100074
Received 30 August 2018; Received in revised form 28 December 2018; Accepted 13 March 2019
Available online 26 March 2019

become clearer when you want to manage a system with limited amount of resources such as time, human resources and money. Despite the lack of a unified theory about orchestration, many different areas have used general theories about orchestration.[9] This indicates that, orchestration basic elements and concepts are useful for many different applications.

Reading the above, we define ORO as "complex task in which many resources (patient, operating room staffs, information, materials and equipment) should be orchestrated to make patient, surgeons, information and materials flow more smooth.

1.2. Problem definition

Operating room is a complex environment with different behaviors, components with interaction, which are naturally unpredictable. Service delivery process in the operating room can be seen as a chain of processes that requires orchestration at different levels in the care network to provide treatment for patients.[10] So, the processes of operating room can be considered as interaction of people, equipment, procedures and materials. This type of interconnection between health processes, requires orchestration between patients, care givers and various departments at different levels.

According to Fig. 1, different factors affect the orchestration of Operating Rooms. Some elements like human resources, information, consuming materials and procedures are our system inputs. Operating room physical spaces, safety regulations and medical equipment could be considered as system constraints. Other elements including patient arrival, equipment failure and patient diversity make the system uncertain. Finally we can assess our OR orchestration performance, by the aid of indicators such as patient waiting time, resource utilization level and length of stay.

Accordingly, the aim of this study is to provide a model for ORO and improve the quality of services provided to patients, by modeling the OR and defining indicators and providing scenarios to help hospital decision-makers to manage their resources effectively, to reduce wastes and to evaluate the performance of the operating room.

2. Theoretical framework

One of the best approaches in complex systems analysis is agent-based modeling.[11,12] Agent-based modeling is a computer technique for complex systems dynamic investigation.[13,14] Agent based modeling also allowed the researchers to capture the dynamics of individual patients, both their internal dynamics of receiving and responding to treatment and their interactions with the larger ecosystem.[15]

According to[16] orchestration problems could be analyzed with agent-based approach that investigate relation of agents and communication between them. These agents can represent anything in real-world, for example the patient in the hospital's internal network. ORO analysis is mapping the relationship between different actors and resources that enables the possibility of visual and mathematical analysis. According to Fig. 2, in the proposed model each agent plays role of service provider which delivers a specific service to the patient. Orchestration leads to better quality of services and effective collaboration between service providers.

3. Method

In this part, we are trying to model ORO with agent-based simulation. In the model, we consider all type of actors such as patient, surgeon, nurse, etc. with different characteristic as model agents. The flexibility of the agent based modeling lets us to confront the complexity of operating room.[17]

We have used Netlogo simulation package 6.0.2, as platform of agent based simulation.[18] Table 1 shows the model agents:

3.1. Operating room processes

Operating room processes are divided into three categories: pre-operative, operative, and post-operative.[19] Fig. 3, illustrates the three phases of the operating room process. We extracting the procedures of each phase, according to the HashemiNejad Kidney Center operating room.

As there are many actors collaborating to complete these procedures, orchestration is very important.

3.2. Rules and conditions of the model agents

Agents are followed this rules and conditions:

- Any patient can only be at one location at a moment to get a service.
- Each serving agent can only serve one patient at a time and become

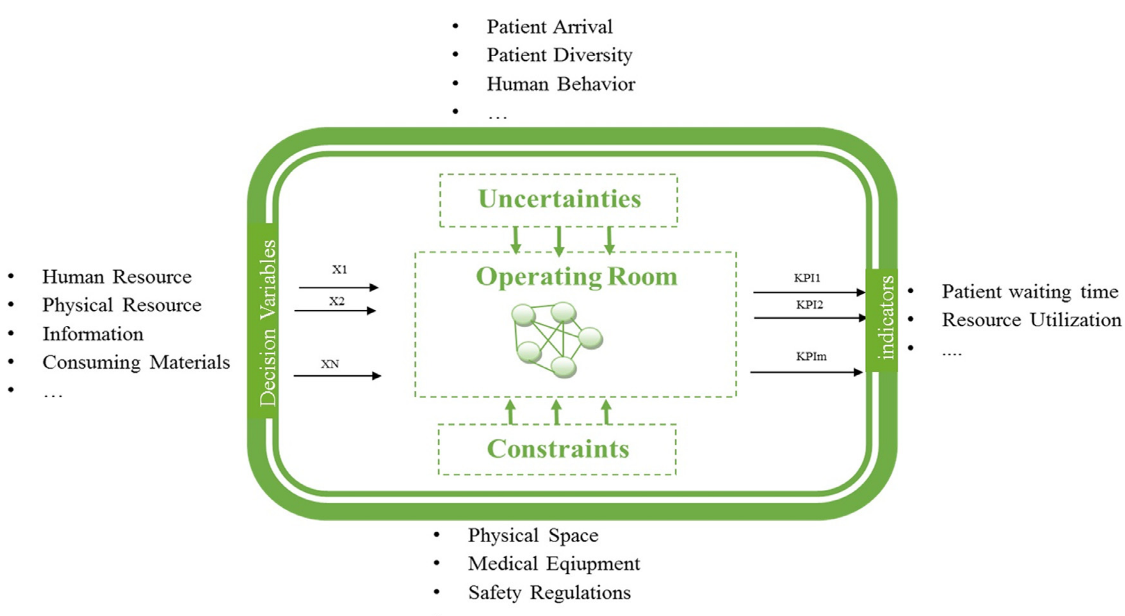


Fig. 1. operating room complexities.

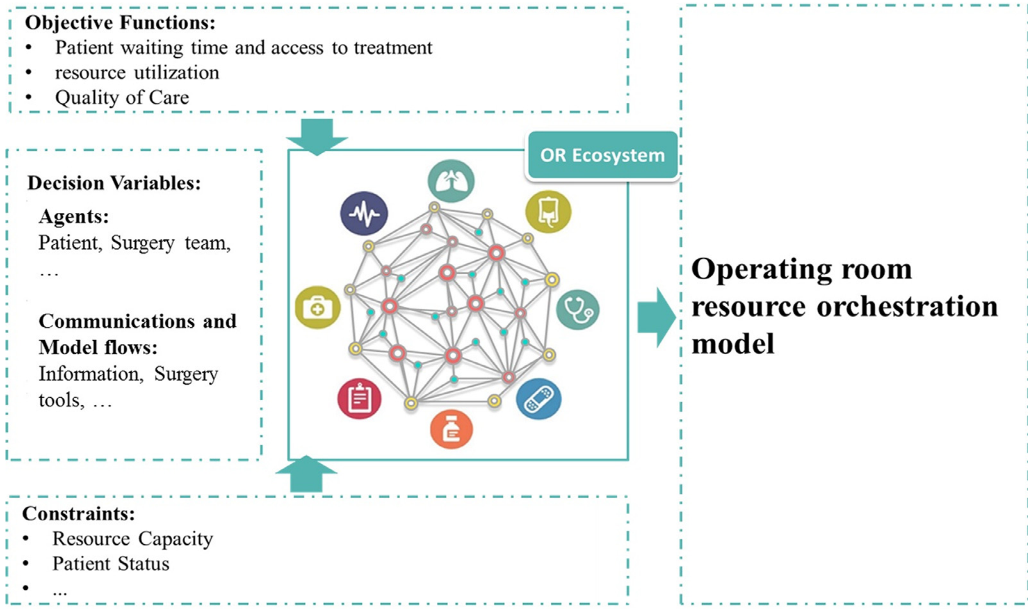


Fig. 2. ORO structure (Proposed framework).

Table 1
Model agents.

No.	Resources	Number of agents
1	Surgery fellow	2
2	Anesthesia resident	2
3	Anesthesiologist	2
4	Scrub	2
5	Circulator	2
6	Recovery nurse	1
7	Ward nurse	1
8	Operating room clerk	1
9	Internal patient transferor	1
10	External patient transferor	1
11	Cleaning crew	2
12	Patients	According to patient arrival rate to the operating room

busy until finishing the service.

- Patient will go in a queue until the serving agents are busy.
- The first comer will get a service firstly.
- The urgent patients are prioritized to other patients, and after arriving to the operating room, he/she will be transferred to the first position in the queue.
- According to the HashemiNejad Kidney Center, we consider two operating room with the same equipment for PCNL surgery.

3.3. Model description

In the model, each agent is defined with unique features in a specific place and agents communicate each other. We modeled the patient flow by entering patient to the operating unit. Patients enter to the operating unit according to Poisson distribution function. Hasheminejad operating unit has seven rooms that our case study "PCNL surgery" is done at two of them. We used different colors for distinguishing the status of servicing agents. Service time also is defined in the model for all agents according to data records.

Fig. 4 shows the developed model for operating room simulation using Netlog software.

4. Results

After completing the model, it was executed 31 times and each time for 1 day. The model was run 31 times. According to central limit theorem, the number of samples should be above 30 to use normal distribution, appropriately.

The tests were independent from each other by using different simulation random Sid. The hypothesis was tested at the error level of $\alpha = 0.05$. The statistical factors are calculated as follow:

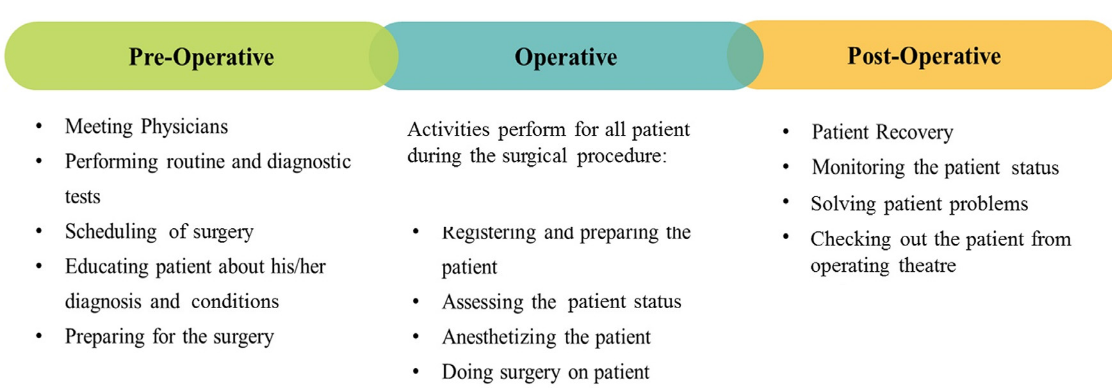
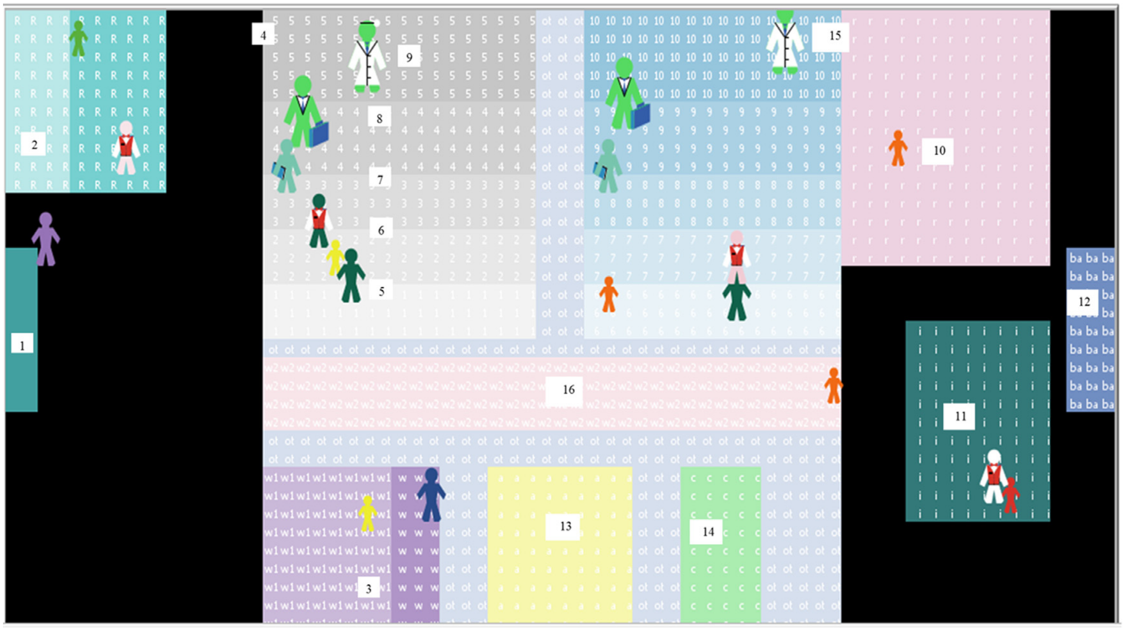


Fig. 3. Operating room process (Hasheminejad Kidney Center).



1) Operating unit entrance
2) Ward
3) Waiting area in operating unit for preparation
4) Operating room 1
5) Circular
6) Scrub
7) Anesthesia technician
8) Anesthesia resident
9) Surgery Fellow
10) Recovery
11) Nursing station
12) Operating unit exit
13) Warehouse
14) CSR
15) Operating room 2
16) Waiting area for operating room entrance

Fig. 4. Netlogo model design for operating room.

$$\mathbf{T} = \frac{\overline{\mathbf{x}}_2 - \overline{\mathbf{x}}_1}{\mathbf{S_p}\sqrt{\frac{1}{\mathbf{n}_1} + \frac{1}{\mathbf{n}_2}}} \tag{1}$$

$$\mathbf{S_p^2} = \frac{(\mathbf{n}_1 - 1)\mathbf{S}_1^2 + (\mathbf{n}_2 - 1)\mathbf{S}_2^2}{\mathbf{n}_1 + \mathbf{n}_2 - 2} \tag{2}$$

The decision condition is as follows: (If the following conditions are satisfied, H0 hypothesis is rejected; otherwise, the zero assumption is acceptable and H1 is rejected).

$$\left.\begin{matrix} H0\colon \mu 1 = \mu 2 \\ H1\colon \mu 1 \neq \mu 2 \end{matrix}\right\} \rightarrow |T| > T\left(\frac{\alpha}{2},\ \mathrm{n}_1 + \mathrm{n}_2 - 2\right) \tag{3}$$

4.1. Validation of simulation results

The purpose of model validation is to approximate the power of model to behave reality. However, the model cannot completely reflect reality, and the best models are good approximations of the reality.

We considered some criteria to measure the ORO. The results were compared with the actual hospital data for validation.

The measures are:

1 The waiting time for admission
2 The waiting time in the operating room
3 Operating room cleaning and turn-around
4 Total patient waiting time
5 Duration of patient staying in recovery unit
6 Total surgery time
7 Total patient stay time in the system

Fig. 5 shows the results of the simulation for the mentioned measures. Each point depicts a simulation results for one day.

According to Table 2, considering that for all measures $|T| < T(\frac{\alpha}{2}, \mathrm{n}_1 + \mathrm{n}_2 - 2)$, the H0 hypothesis is accepted with 95% confidence interval. In fact, with 95% of confidence interval, we conclude that the difference between the two meanings is not statistically significant.

4.2. Operating room bottlenecks

The validation shows that the simulation results are reliable. Therefore, due to the results of numerous runs of the model, the bottlenecks were identified. In the model, tasks with the most waiting queues or unallocated resources are considered as a bottleneck. According to the results, bottlenecks are: waiting for operating room cleaning and turn-around, waiting for the patient transfer, services and the presence of an empty bed in the recovery unit.

4.3. Operating room improvement scenarios

Noting to the bottlenecks, we defined some scenarios considering expert opinions to improve operating room. Different scenarios have been studied such as: adding a recovery nurse, adding one bed in the recovery unit, adding a patient transferor and a cleaning staff, clerks fatigue effect on operating room performance and patient waiting time, prioritizing urgent patients, flexible servicing time effect, and combination of more effective scenarios (will discussed in next section) have been studied on this model. Table 3 presents significant effects of improvement scenarios on measures. As it can be seen, the combining scenario, including adding recovery bed, adding a patient transferor and flexible staffing behavior had the most positive effect on all measures.

5. Discussion and conclusion

Investigating different scenarios using agent based modeling showed that by slightly modifying the service delivery processes and allowing a bit of flexibility in service time for some processes, it would

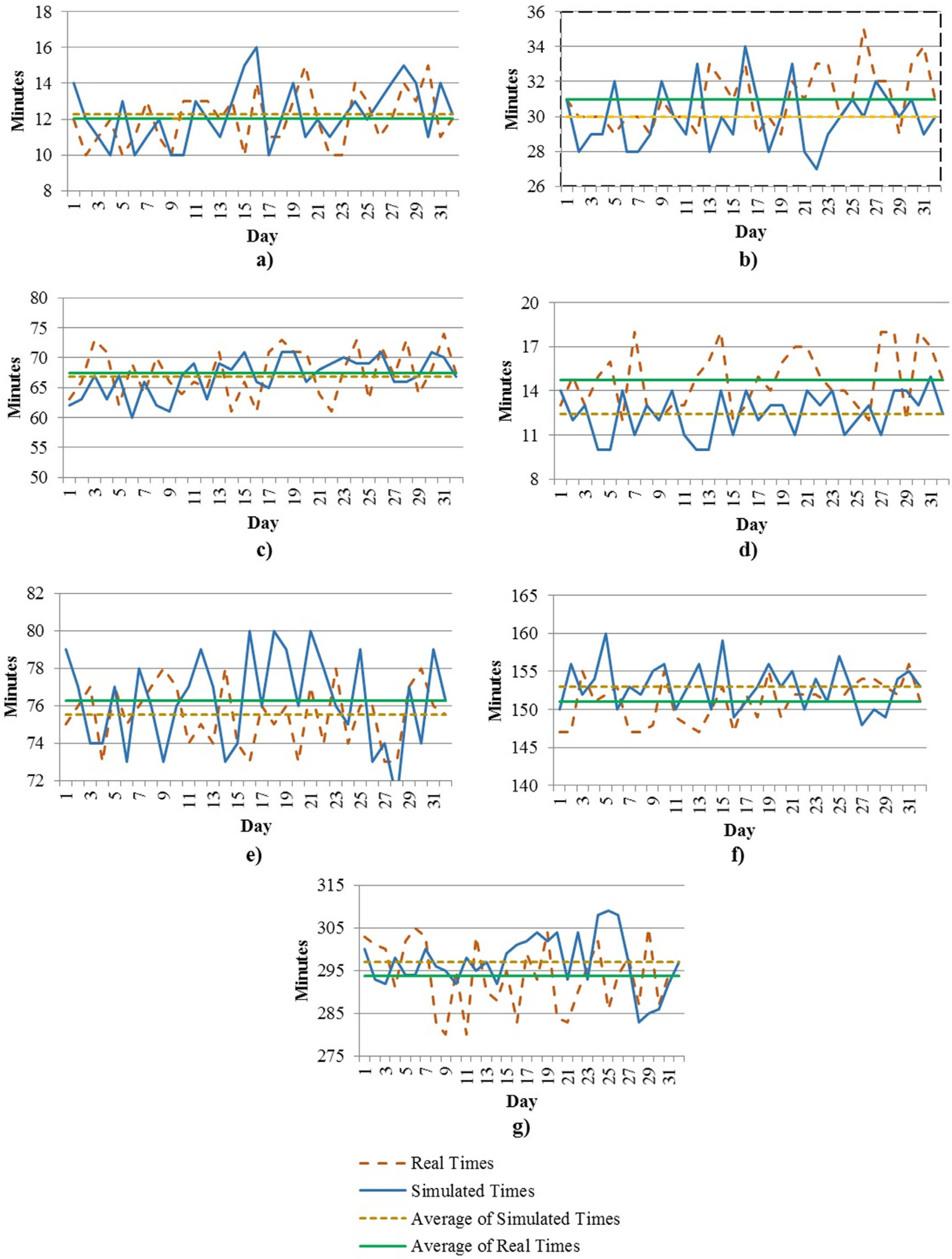


Fig. 5. Comparison of actual and simulated results for: (a) Admission waiting time, (b) Operating room waiting time, (c) Total patient waiting time, (d) Operating room cleaning and turn-around time, (e) Total patient recovery time, (f) Total surgery time, (g) Total patient staying time at system.

be possible to reduce patient waiting time, significantly. Suggested solutions for reducing waiting time for patients showed that with a slight change in existing service delivery processes and flexibility in service time in some processes can reduce the waiting time of patients significantly. It also would be concluded from this research that:

- Adding human resources has a significant impact for managing bottlenecks.
- As we mentioned, the combined scenario has the highest improvement effect on all criteria. The flexible behavioral scenario of personnel is considered as the most effective scenario; this can be modeled with agent based simulation methodology.
- Personnel fatigue can have a negative impact on all criteria.
- The entry of the urgent patient has the most negative effect and increases the waiting time and the patient's staying time in the system.

Table 2
Comparison of simulated and real data means.

No.	Measure	Test statistic	Simulated data mean	Real data mean
1	Admission waiting time	$\lvert T\rvert = 0.121184089 < T(\frac{\alpha}{2}, n_1 + n_2 - 2)$	12.29032258	12.03225806
2	Operating room waiting time	$\lvert T\rvert = 0.444750685 < T(\frac{\alpha}{2}, n_1 + n_2 - 2)$	29.96774194	31
3	Total patient waiting time	$\lvert T\rvert = 0.100203461 < T(\frac{\alpha}{2}, n_1 + n_2 - 2)$	66.87096774	67.4516129
4	Operating room cleaning and turn-around time	$\lvert T\rvert = 0.775996789 < T(\frac{\alpha}{2}, n_1 + n_2 - 2)$	12.4516129	14.74193548
5	Total patient recovery time	$\lvert T\rvert = 0.313684894 < T(\frac{\alpha}{2}, n_1 + n_2 - 2)$	76.25806452	75.51612903
6	Total surgery time	$\lvert T\rvert = 0.511801855 < T(\frac{\alpha}{2}, n_1 + n_2 - 2)$	153.0322581	151
7	Total patient staying time at system	$\lvert T\rvert = 0.292780725 < T(\frac{\alpha}{2}, n_1 + n_2 - 2)$	296.9677419	293.6774194

Table 3
Improvement scenarios effect on operating room measures (only more significant values).

Scenarios	Measures Admission waiting time	Operating room waiting time	Total patient waiting time	Operating room cleaning and turn-around time	Total patient recovery time	Total surgery time	Total patient staying time at system
Adding a recovery nurse	-	-	−3 min	-	−6 min	-	−7 min
Adding one bed in the recovery unit	-	-	−3 min	-	−8 min	-	−11 min
Adding a patient transferor	-	-	−7 min	-	-	-	−9 min
Adding a cleaning staff	-	-	−6 min	−5 min	-	-	−6 min
Clerks fatigue effect	-	-	+6 min	-	-	+7 min	+18 min
Prioritizing urgent patients	-	+149 min	+218 min	-	-	-	+220 min
Flexible servicing time effect	−2 min	−4 min	−4 min	-	-	-	−21 min
Combination of more effective scenarios (2,3,7)	−3 min	−5 min	−9 min	−3 min	−10 min	−5 min	−21 min

6. Research limitations

This research also had some limitation both in data gathering in hospital and simulation method aspects. Some of our research limitations are as follows:

- Attending in the operating room and gathering real data by following patient up was a sophisticated process.
- Simulation generates a way of assessing solutions but does not produce solutions themselves.
- The difficulty in finding the optimal values growths by increasing in the number of parameters.
- In case of having a large number of agents, execution speed drops considerably, although this is not important in our case due to the limited number of agents. Usually agent based simulation tool is not designed for extensive simulations.

Conflict of interest

All authors declare that they have no conflict of interest.

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Fone D, Hollinghurst S, Temple M, Round A, Lester N, Weightman A, Palmer S. Systematic review of the use and value of computer simulation modelling in population health and health care delivery. *J Public Health.* 2003;25(4):325–335.
2. Deloitte. *2016 Global Health Care Outlook: Battling Costs While Improving Care.* 2016; 2016.
3. Ghaffari S, Jackson TJ, Doran CM, Wilson A, Aisbett C. Describing Iranian hospital activity using Australian Refined DRGs: a case study of the Iranian Social Security Organisation. *Health Policy.* 2008;87:63–71.
4. Lee JW. *Iran National Accounts.* Canada: World Health Organization; 2005.
5. Toba S, Tomasini M, Yang YH. Supply chain management in hospital: a case study. *Calif J Oper Manag.* 2008;6.1:49–55.
6. Tello-Leal E, Chiotti O, Villarreal PD. Process-oriented integration and coordination of healthcare services across organizational boundaries. *J Med Syst.* 2012;36(6):3713–3724.
7. Cha HS, Pingry DE, Thatcher ME. Managing the knowledge supply chain: an organizational learning model of information technology offshore outsourcing. *MIS Quart.* 2008;1:281–306.
8. Skipper JB, Craighead CW, Byrd TA, Kelly Rainer R. Towards a theoretical foundation of supply network interdependence and technology enabled coordination strategies. *Int J Phys Distrib Logist Manage.* 2008;38.1:39–56.
9. Poulymenopoulou M, Malamateniou F, Vassilacopoulos G. Specifying workflow process requirements for an emergency medical service. *J Med Syst.* 2003;27(4):325–335.
10. Malone TW, Crowston K. What is coordination theory and how can it help design cooperative work systems? *Proceedings of the 1990 ACM Conference on Computer-supported Cooperative Work.* 1990; 1990:357–370.
11. Macal CM, North MJ. Agent-based modelling and simulation. *Winter Simulation Conference.* 2009; 2009:86–98.
12. Jalalimanesh A, Haghighi HS, Ahmadi A, Soltani M. Simulation-based optimization of radiotherapy: agent-based modeling and reinforcement learning. *Math Comput Simul.* 2017;133:235–248.
13. Bandini S, Manzoni S, Vizzari G. Agent based modeling and simulation: an informatics perspective. *J Artif Soc Soc Simul.* 2009;12(4):4–10.
14. Isern D, Moreno A. A systematic literature review of agents applied in healthcare. *J Med Syst.* 2016;40(2):43.
15. Kalton A, Falconer E, Docherty J, Alevras D, Brann D, Johnson K. Multi-agent-based simulation of a complex ecosystem of mental health care. *J Med Syst.* 2016;40(2):39.
16. Hossain L, Kuti M. Disaster response preparedness coordination through social networks. *Disasters.* 2010;34(3):755–786.
17. Barnes S, Golden B, Price S. *Applications of agent-based modeling and simulation to healthcare operations management. Handbook of Healthcare Operations Management.* New York: Springer; 2013:45–74.
18. Chiacchio F, Pennisi M, Russo G, Motta S, Pappalardo F. Agent-based modeling of the immune system: NetLogo, a promising framework. *BioMed Res Int.* 2014;2014.
19. Marjamaa R, Vakkuri A, Kirvelä O. Operating room management: why, how and by whom? *Acta Anaesthesiol Scand.* 2008;52.5:596–600.