

Cost and Delay Time Analytics in OR: A Simulation-based Approach

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Abstract

Background: Operating room (OR) is one of the main hospital parts and management of time and cost are very important in this essential unit. Also, due to the close relationship with other departments, improving its service quality and performance, significantly increases the efficiency of hospital. OR is a complex system in which each lack of coordination effects on all hospital departments. So it is important to identify and categorize the factors that caused loss of OR orchestration and analyze the cost and delay times that imposed by this loss of orchestrations.

Methods: Computer simulation is a useful technique for modelling system and its behavior. OR is a complex system which has lots of agents interacting with each other, so the agent based simulation method is a suitable technique for modelling OR agents, relationships, defining loss of orchestrations and analyzing the results on the system performance.

Findings: By identifying OR non-orchestration factors, the most frequencies are related to the lack of recovery beds, emergency surgery, surgeon delay, lack of patient transferor, prolongation of other surgical procedures, anesthesia and pediatric surgery; and the less frequencies are for clinical changes in the patient status, inadequate testing, and patient's cancellation or lack of readiness. Also, the most delayed and lost time were due to the inadequacy of patient tests, anesthesia and pediatric surgery, prolongation of other surgical procedures, and lack of recovery beds.

Conclusion: Surgery procedure is not just a surgical technique, but has many aspects that should be addressed and resolved. The results indicated that the most effective factor in hospital delay and costs is the shortage of resources and lack of planning, which can be improved by interconnecting communication and on-time information sharing.

Keywords: Simulation, Operating room, Delay time, Cost management

Introduction

The growing increase in health care costs is a major problem in the healthcare system and healthcare managers are trying to find some techniques for improving service delivery and reducing cost.¹ Hospitals are one of the most important sectors in healthcare systems that incur more than 36% of government costs.² Operating room (OR) is one of the most important units for hospital managers³ and it is essential to make appropriate decisions about services, patients, policies, information, processes,

and employees.⁴ OR management needs cooperative approach for care services that also associated with all hospital parts and its performance will effect on other parts performance too. OR work flow optimization, creating a team-based approach to maximize utilizing people, process, and technology is necessary to increase the efficiency and reduce operating costs.⁵

Different dimensions should be considered in OR management:

Time reduction: Time management is an important scenario in managing OR more efficiently. New surgery techniques improve recovery and patient status, but they prolong the operation.⁶ Also duration of surgery has very diversity,⁷ the surgeon's rate of work is also a major factor of time variety in the OR.⁸ The presence or participation

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of the resident increases the surgical time by up to 70% and also increases costs.⁹ Personal differences between anesthesiologists have very little effect on the duration of the surgery,¹⁰ however, specialization in the particular type of surgery can accelerate anesthetic specialists. Teaching a resident will lead to 2-3 minutes of anesthesiologist's delay.¹¹ Also, choosing the correct type of surgery is very important and it is the most effective factor on time spending in OR after surgeon speed.

Work method change: Parallel processes increase OR efficiency by reducing surgical non-operative time.¹² Performing anesthesia and patient exit can be done in a separate room at the same time with cleaning the OR.¹³ There are also methods for parallel processes without additional costs: redesign workflow and reassigning tasks to various specialists,¹⁴ considering the fact that the OR is the most sensitive unit of the hospital, which delays due to the lack of availability of different resources could increase about 5 working days per month.¹⁵ In addition, delays caused by surgeons are much longer than delays for other reasons¹⁶ and we can make some improvement by enhancing the surgeon and other team relationship.

OR Performance Monitoring: For achieving goals, OR performance must be monitored regularly.¹⁷ Useful performance indicators include the type of input/output scale,¹⁸ non-operative time,¹⁹ OR start time,²⁰ and net productivity. The number of operations, overtime, costs, cancellation rates, complexity, duration of surgery, and time and productivity are valuable and should be measured.

Technical tools for management: OR management information system should support process management in right time. An ideal system for tracking patients and resources will help to monitor and report the OR performance.²¹

Focus on process: Properly defined processes improve the common understanding of all patients involved in postoperative treatment. Multi-disciplinary team work, parallel processes, reorganization and tasks reassignment for reduce non-operative and delays times, increase workflow time, and achieve faster start per day will be used.^{22,23}

Facilities: Hospital facilities must design so that support patient flow and allow flexible use for diverse operations.²⁴ The manager must assess the layout of each OR separately and in total. The volume of technology and new equipment, such as the process of endoscopic surgery in ORs, is increasing today. Congestion may adversely affect the ability of the surgical team.²⁵

Personnel: In most countries, the lack of anesthesiologist or nursing staff restricts access to the OR.²⁶ Sometimes

work flow can be achieved by changing the ratio of nurses and surgeons.²⁷ OR activities require a high level of expertise and professional knowledge that needs to be constantly updated.²⁸

Surgical unit personnel: OR manager should consider all team members, the operational environment includes interactions between surgeons, anesthesiologists, nurses, technicians, and patients.

Related Works

Dexter et al²⁹ observed 22 surgeries and analyzed the OR efficiency and found that equipment, environment and work process have the most impact on loss of orchestration in OR. They found some problems in sterilization. Also lack of coordination among inside and outside of OR makes some disruptions in surgery process. In a comprehensive approach for OR scheduling³⁰ 24 heart surgeries and 20 orthopedic surgeries were analyzed; they found that loss of orchestration in OR are mostly related to planning and workload management (37%), awareness of situation (34-42%) and teamwork errors (19%). Zeng et al³¹ compared orchestration in 2 hospitals and they found that many of these problems are related to emergency cases, unpredictable changes in patient status, and some loss of coordination among surgery team that makes some delay, tension and conflict among surgery team. Fairley et al observed 444 surgeries and found 60 cases in which loss of orchestration caused some damages to patient. In most cases there are some bottlenecks in post-anesthesia care unit and lack of capacity makes some delays for other surgeries.³²

Operation research provides a trade-off analysis between the cost efficiency (via minimizing the total costs), responsiveness (through minimizing the delay time and unsatisfied demand) which improve OR efficiency.³³ We can consider OR agents as a network that analysis of them can help us to reduce some coordination problems.³⁴ ORs are precious resources in hospitals, they constitute more than 40% of the hospital revenues and surgical cancellations are very costly to hospitals, so this is critical to consider it as an important problem in analysis of cost and delay time.³⁵

By studying different aspects of OR management, it can be concluded that the OR is a complex environment in which various agents interacting each other with different and sometimes unpredictable behaviors. Delivering services in OR can be seen as a chain of processes that needs orchestration in different chain levels to provide suitable care for patient.³⁶

The loss of orchestration in OR indicates that there is a mismatch between the actual and expected conditions in

OR cooperative ecosystem. Also, loss of orchestration is the main reason for the lack of successful completion of an activity in OR process that there is an important need to do some researches in this area. The result of these loss of orchestrations can lead to inappropriate side effects on the patient, surgery on the wrong part of the patient's body, or inappropriate surgery.

Based on studies, the authors of this paper express a comprehensive definition of resource orchestration in OR as follows:

"OR resource orchestration is a complex task in which many resources must be coordinated to achieve its effectiveness and make the patient, surgeon, information and material flows more efficient. Surgeon availability, time management, patient information, equipment must be coordinated in order to achieve maximum performance with the lowest cost and the highest responsiveness level." Considering the importance of managing health centers, in recent years the use of operation research tools in hospitals and specially the management of ORs has increased significantly.

Simulation is more effective in healthcare systems because of more complexity than definitive models.³⁷ In this research agent-based simulation is used because of high flexibility and providing sensitivity analysis.

In this modeling approach, each patient is considered as an agent that follows a procedure based on his/her status. Also due to the complexity of OR, agent based model provide this possibility to consider the main elements of ecosystem (surgeon, nurse,...) as an agent and real condition can be implemented with good approximation by defining behavior of these agents. This illustrates the realism of the model, which is one of the significant features of agent-based modeling.^{38,39}

Agent based simulation is a useful tool for hospitals, especially ORs. This technique also used for poisoning,⁴⁰ intracellular topics,⁴¹ also, non-medical areas such as transportation management,⁴² social sciences,⁴³ economic,⁴⁴ and healthcare management.⁴⁵

In this research, Hasheminejad OR process was considered and observed and some necessary requirements were identified for analysis and improvement. After interviewing experts, it was decided to concentrate on PCNL (percutaneous nephrolithotomy) surgery to model the process more accurately. The important problem was analysis of cost and delay time related to loss of orchestrations. In this study a comprehensive definition for OR resource orchestration is developed and agent based simulation is used due to its flexibility to define all OR agents and analyze the impact of each agent's loss of orchestrations on delay time and cost of OR.

The purpose of this research is reducing waiting time resulting from loss of orchestrations and costs related to them.

Materials and Methods

This research is a case study with the aim of reducing waiting time and related cost caused by loss of orchestration of OR resources. OR entities include surgical team, anesthesiologist, and patient as the agents that make the whole ecosystem.⁴⁶

One of the positive aspects of agent-based simulation is that this model has high development capability and necessary changes can be made and agent, units, regulations and new conditions can be added if there are any requirements.

The modeling tools in this study in NetLogo 6.0.2. NetLogo is a software for computer simulation and a suitable tool for modelling agent-based systems. The agents of our model in OR are as following: Surgery fellow, anesthesia resident, anesthesiologist, scrub, circulator, recovery nurse, ward nurse, OR clerk, internal patient transferor, external patient transferor, cleaning crew, and patients.

The classification of Loss of orchestration factors:

Using follow-up of patients in OR for one month and interviewing experts, the loss of orchestration factors, the delay time and cost effects result by this factors were identified and classified. They are described in Table 1.

Also the costs of each agents was collected. The summary of Table 1 is as following:

- Ward management factors: patient non-readiness, shortage of some necessary testimonials, Inadequate testing before surgery and need to do or repeat test.
- Patient related factors: patient now show or delay, change in patient clinical status.
- OR management factors: technical problems in equipment, prolongation of other surgeries, shortage of recover bed, patient transferor shortage, materials sterile problem.
- Doctor and surgeon factors: surgeon delay, cancelation.
- Special reasons: doing emergency surgery, anesthesiology and pediatric surgery.

Model Explanation

In the designed model, each of agents is defined with unique features in a specific location. In this study, from the patient entrance time to the OR until the patient exit, the recovery and transfers to the department is considered. Patients enter the OR according to Poisson distribution.

Table 1. Loss of Orchestrations Factors in OR

Management	Hospital	Planning	Shortage of bed after surgery
		Material	<ul style="list-style-type: none"> • Shortage of medicine • Lack of tools and surgical instruments
	Ward	The lack of notification	The lack of notification between ward and OR for patient readiness
		The lack of patient readiness	<ul style="list-style-type: none"> • Not getting the drug at the right time • Other necessary readiness
		Experiments and testimonials	<ul style="list-style-type: none"> • Lack of necessary testimonials • Inadequate testing before surgery • Need to do or repeat test
		Scheduling	Prolonging other surgical procedures and lack of time
OR	Personnel	<ul style="list-style-type: none"> • Lack of patient transferor • Lack of other personnel 	
	Lack of coordination outside the OR	Disruption in work with personnel leaving the OR because of some problem outside.	
	Equipment	<ul style="list-style-type: none"> • Technical problem • Inaccessibility 	
Technology and tools	Tools and materials	Inaccessibility of tools and materials	
		Tools and materials sterile problem	
Organizational and process factors	Planning	<ul style="list-style-type: none"> • Late start of first surgery 	
		Lack of resources: <ul style="list-style-type: none"> • Lack of recovery bed • Lack of patient transferor • Lack of OR 	
		Education and culture	Inadequate training for a new entrant
	Communication and teamwork	Weak culture about the requirements during the surgery	
		Lack of coordination and proper connection of the surgical team	
		Collaboration and teamwork problems	
	Technical	Poor connection between ward, OR etc	
		Fatigue and distraction	
		Insufficient ability to perform tasks	
		Pull down the necessary steps	
Doctor	Anesthesiologist	Delay or now show	
	Surgeon	Delay or now show	
Human resource	Nurses and anesthetists	Nurses and anesthetists errors	
		Nurses and anesthetists no show	
		Nurses and anesthetists shortage	
	Personnel	Multi task	
		Recovery	Recovery personnel shortage
		Service clerks	Clean Service clerks shortage
		Patient	Patient transferor shortage
Environmental factors	Unrelated conversations etc	Clinical change and lack of tests	

Variety of colors are used to diagnose the status of the service offering agent. The service time is also defined in the model for all agents according to the recorded data. Figure 1 shows the developed model for simulation of the OR with NetLogo software.

In the following, the cost conditions and the delay of each agents are described. Any delay causes the hospital some costs; because the agents in the surgical unit are ready to work and the cost of each agent is calculated per minute in a cumulative manner.

As shown in the Figure 1, the time elapsed in minutes is calculated, and by considering cost variables for agents, the cost of loss of orchestrations are calculated.

Patient Agent

According to the data, each patient has different characteristics. Some of these features include (1) Failure to reach the hospital, in this case, the patient's delay time in model and the cost of all agents of OR at this time is calculated. (2) patient no show. In this condition, the next

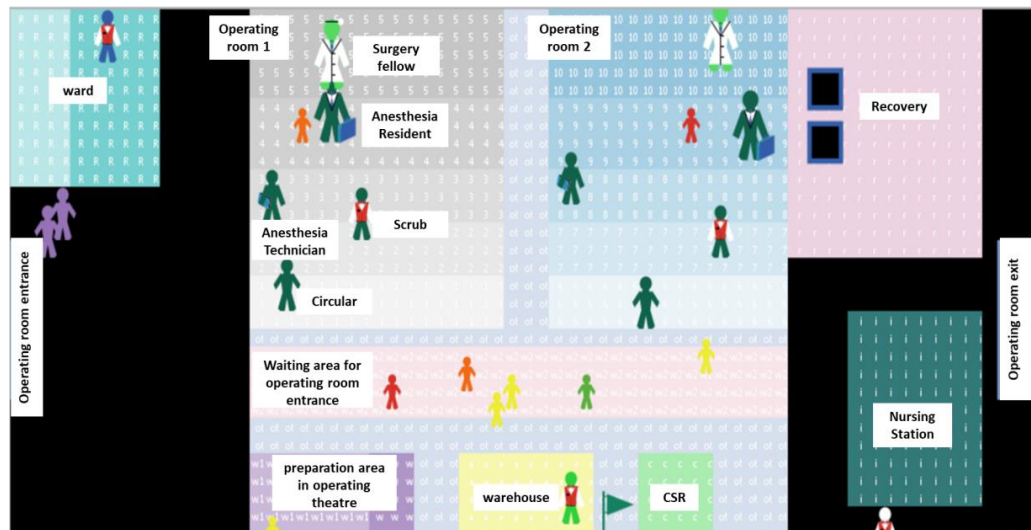


Figure 1. Model Designed by NetLogo to Do Cost and Delay Time Analytics in OR.

patient is transferred for surgery to the OR; in this case, the patient's delay time and the cost of all the agents of the OR at this time is calculated. Changing the patient's clinical status, which may lead to operation delay or cancellation of the operation. These cases cause delay time and cost due to OR agents waste. These items are also calculated and defined in the model.

Physician/Surgeon Agent

In some cases, the surgeon arrives by delay or the first operation usually starts late at morning. In this case this delay cause lateness in other operations and makes cumulative costs (all agents present in the OR).

Ward Management

Patient's non-readiness, shaving, fasting, lack of necessary testimonials, inadequate tests, make the patient some requirements to do some examinations.

Operating Room Management

1. The technical fault in the OR equipment causes a delay for repairing or replacing them which has cost and time lag for the system.
2. The prolongation of other surgical procedures: in some cases due to the patient's specific conditions and some other uncertainties, such as bleeding during surgery, the surgery time takes longer than normal and it causes delay time and surplus costs for hospital.
3. Lack of recovery beds: Due to the fact that the time of recovery is longer for some patients with certain conditions, sometimes it happens that the patient's surgery is over, but recovery bed is not free, and it is not possible to transfer the patient from OR. It will

cause a delay for next operation and also imposing surplus costs.

4. Replacement of tools and equipment and sterile problems: in some cases, fixing these problems make some delay and additional costs for system.

Special Reasons

Some emergency situations might occur during the surgery and they cause some delay time and additional costs for the OR. These special cases are defined in the model.

Results

In this stage, after modeling OR with agent based simulation and applying loss of orchestrations and cost variables, verification of the model was checked. Then, the model was ran 31 times for duration of 1 day per each run. After that, the outputs of model and actual collected data from hospital were compared to validate the model. Therefore, the output of model was checked by hypothesis test and comparing with actual data and based on them the model was validated and cost results were confirmed.

Validation of the Model

Validation of the model means that in which extent the model expresses the reality. However, the model cannot fully reflect the reality and in the best situation models give good approximation of the reality. Therefore, to validate the model it should be investigated that how close the actual and the simulated results are. After model completion, model was ran 31 times, 1 month duration per each run. According to central limit theory, for number of sample greater than 30, distribution of samples will be normal. So, the number of runs was chosen as 31. These results were compared by actual data from hospital. To validate the model, the hypothesis test was performed and

the validity of the model was confirmed. The tests were independent from each other by using different simulation random Sid. The hypothesis was tested at the error level of. The statistical factors are calculated as follow:

$$T = \frac{\bar{x}_2 - \bar{x}_1}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad (1)$$

$$S_p^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} \quad (2)$$

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).

$$H_0: \mu_1 = \mu_2$$

$$\} \rightarrow |T| > T(\frac{\alpha}{2}, n_1 + n_2 - 2) \quad (3)$$

$$H_1: \mu_1 \neq \mu_2$$

The results for one agent are shown in Figure 2. 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 OR

orchestration. The results were compared with the actual hospital data for validation.

Figure 2 shows the simulated results for some agents. Each point is the result of 1 day simulation. Based on the results obtained from the model, the average delay time of various factors was not significantly different from actual data; therefore the validity of the model is confirmed. Therefore, the results are reliable and the effect of each delay and loss of orchestration factors on the cost can be investigated.

Results Interpretation of Cost and Delay

In this section the results of surgeries simulated which performed at OR are presented. Noting to the time lost and cumulative cost of the engaged agents in model, the imposed cost on hospital corresponding to each delay due to loss of orchestration was obtained.

According to results, the highest frequencies are related to lack of recovery bed, emergency operation, surgeon's delay, shortage of patient transferor, prolongation of other surgical procedures, anesthesia and pediatric surgery; and lowest frequencies are related to change in patient's clinical status, inadequacy of tests, cancellation from patient side and patient who is not ready (Figure 3).

As it can be seen in Figure 4, the highest delay time is due

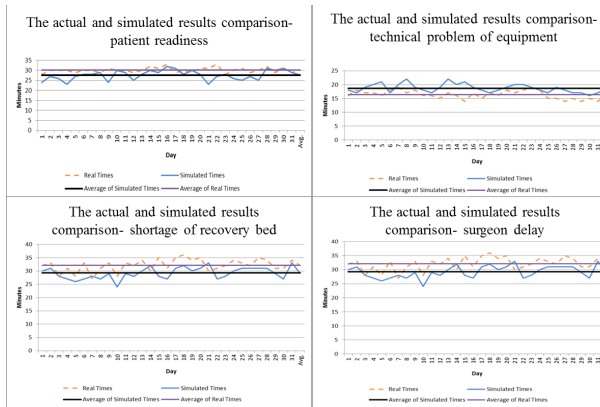


Figure 2. Comparison of Simulated Results and Actual Results for Some Agents.

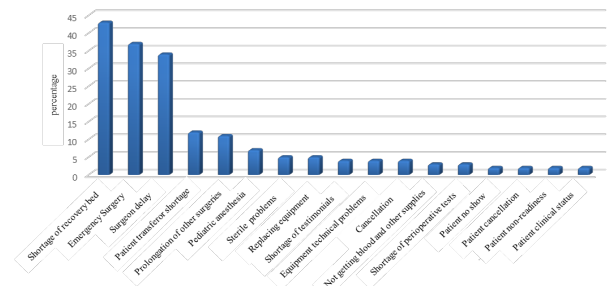


Figure 4. Average Delay Time in Surgery by Each Loss of Orchestration Factor.

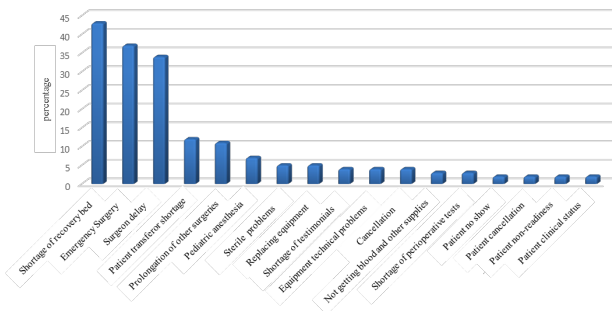


Figure 3 -Frequency of OR Loss of Orchestration

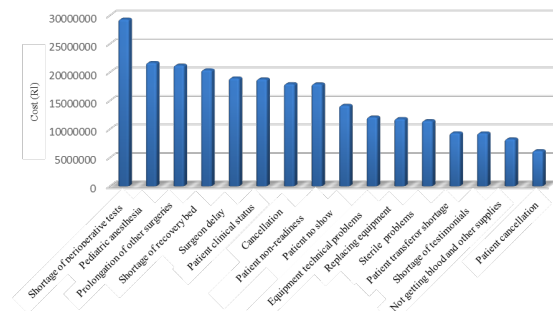


Figure 5. Hospital Costs

to the inadequacy of patient tests, anesthesia and pediatric surgery, prolongation of other surgical procedures, and lack of recovery beds. Also the patient cancellation, shortage of testimonials and patient transferor shortage have the less average delay time in surgery.

In Figure 5, noting to the average delay time of each loss of orchestration factors resulted from our observations and data collections and also interviewing experts in Hasheminejad OR, and the cost data about each agent in OR, the cost imposed to hospital is shown. As it can be seen, the highest hospital costs were due to inadequate preoperative tests, prolongation of other operations and shortage of recovery beds; and the lowest hospital costs were shortage of patient transferor and the lack of necessary testimonial.

Applicability and Significance in Hospital

The proposed model and framework will help hospital managers to simulate the OR ecosystem with simulation. Also because of agent based simulation flexibility, any situation can change and some sensitivity analysis can perform. The proposed framework also defines a comprehensive definition about OR orchestration and the situations that loss of orchestration occurs. This can help hospital managers to analyze the effect of this factors on OR performance especially with time and cost approach.

Managerial Insights

By doing this analysis some managerial suggestions can be presented that could improve performance of OR:

- Improving coordination between OR and preoperative care unit makes some improvement and reduces the number of lack of necessary test.
- Assigning another patient transferor can help to reduce the delay time and make the patient flow smoother.
- Recovery bed shortage makes some delays and the next surgery will start later, so considering an extra bed in recovery will reduce the delay time.
- After finishing uncertain activities in surgery, it is better to inform the preoperative care unit for readiness of next patient. This scenario will decrease the delay time.

Conclusion

As a general conclusion, the most influential factor is related to ward management that better results can be obtained by improving the communication and in-time notification. The results of this study and similar cases indicate that current and traditional methods of preparation of surgery list from previous day need a serious overhaul. In fact, it

can be said that performing surgical operations not merely include surgical technique but there are several aspects that should be considered and try to resolve negative factors and strengthen positive ones. In addition to the above mentioned conclusions, the following suggestions can be effective in managing the OR:

- On time information to patients about the delay or cancellation of the operation.
- Follow-up testing, consulting or preparation of the tools needed for the surgery by ward responsible and precise applying of the pre-operative consulting instructions.
- Improvement of the quality and quantity of communication between departments and the OR in terms of information to enhance the capacity of the OR.
- Avoid placing patients more than possible in the operation list for replacement.

This research tried to propose an approach for reducing loss of orchestration. In this paper, the loss of orchestrations and their factors were analyzed by delay time and cost effect comparing to previous studies in OR that only some qualitative analysis were performed. Also by considering OR in general, the previous research are more concentrated on scheduling but present study tried to solve the real problem in hospital with a new and flexible method named agent based simulation, this approach makes sensitivity analysis easier and helps analysis of loss of orchestration in OR.

Abbreviations

(OR): Operating Room; (PCNL): Percutaneous Nephrolithotomy.

Authors' Contributions

According to some literature reviews about application of operation research in OR and studies mentioned, most of researches in OR focus on scheduling and they don't offer a comprehensive approach for managing all OR agents. Also most of studies about coordination are qualitative and don't analyze the effect of this loss of orchestrations on performance of OR. In this study we used agent based simulation because of its flexibility to define all OR agents and analyze the impact of each agent's loss of orchestrations on delay time and cost of OR.

Competing Interests

The authors declare no competing interests.

Acknowledgements

The author thanks the hospital staff who participated in the study. We would like to thank the nursing, the

administrative and secretarial staff of Hasheminejad operating room for their contribution to the maintenance of patient record without which this project would have been impossible.

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Please cite this article as:

Masoumeh Saeedian, Mohammad Mehdi Sepehri, Pejman Shadpour, Ammar Jalalimanesh, Sheida Hayatbakhsh. Cost and Delay Time Analytics in OR: A Simulation-based Approach. International Journal of Hospital Research 2018, 7(2): 1-10. doi:10.34172/ijhr.2018.xx.