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

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Abstract

Background: Operating room 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. Operating room 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 operating room orchestration and analyze the cost and delay times that imposed by this loss of orchestrations.

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

Results: By identifying operating room 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 interconnection communication and on-time information.

Keywords: simulation, operating room orchestration, delay time, cost management.

Introduction:

The growing increase in health care costs is so that controlling them 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 assign more than 36 percent of government costs [2]. Operating room is one of the most important units for hospital managers [3] and it is essential to make appropriate decisions about services, patients, policies, information, processes, and employees [4]. Operating room management needs cooperative approach for care services that also associated with all hospital parts and its performance will effect on other parts performance too. Operating room 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 operating room management:

- **Time reduction:**

Time management is an important scenario in managing operating room 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 operating room [8]. The presence or participation 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 operating room after surgeon speed.

- **Work method change:**

Parallel processes increase operating room efficiency by reducing surgical non-operative time. Using separate rooms for anesthesia - a common practice in some countries- which reduces the non-operative time and leads to more patient’s assessment [12]. Performing anesthesia and patient exit can be done in a separate room at the same time with cleaning the operating room [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 operating room 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 reasons [16] and we can make some improvement by enhancing the surgeon and other team relationship.

- **Operating room performance monitoring:**

For achieving goals, operating room performance must be monitored regularly [17]. Useful performance indicators include the type of input/output scale [18], non-operative time [19], operating room 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. Measurement of waiting time is a key indicator to patient's greater satisfaction and safety.

- **Technical tools for management:**

Operating room 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 operating room 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].

- **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 operating room separately and in total. The volume of technology and new equipment, such as the process of endoscopic surgery in operating rooms, 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 operating room [26]. Sometimes work flow can be achieved by changing the ratio of nurses and surgeons [27]. Operating room activities require a high level of expertise and professional knowledge that needs to be constantly updated [28].

- **Surgical unit personnel:**

Operating room manager should consider all team members, the operational environment includes interactions between surgeons, anesthesiologists, nurses, technicians, and patients.

Related Works:

Dexter et al. [29] observed 22 surgeries and analyzed the operating room efficiency and found that equipment, environment and work process have the most impact on lack of orchestration in operating room. They found some problems in sterilization. Also lack of coordination among inside and outside of operating room makes some disruptions in surgery process. In a comprehensive approach for operating room scheduling [30] 24 heart surgeries and 20 orthopedic surgeries were analyzed; they found that loss of orchestration in operating room are mostly related to planning and workload management (37 percent), awareness of situation (34-42 percent) and teamwork errors (19 percent). Zeng Z et al, [31] compared orchestration in two 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 operating room efficiency [33]. We can consider operating room agents as a network that analysis of them can help us to reduce some coordination problems [34]. Operating rooms (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 operating room management, it can be concluded that the operating room is a complex environment in which various agents interacting each other with different and sometimes unpredictable behaviors. Delivering services in operating room can be seen as a chain of processes that needs orchestration in different chain levels to provide suitable care for patient. Therefore, operating room processes can be seen as interactions between people, equipment, procedures and materials [36]. This kind of internal communication in treatment processes requires orchestration between patients, service providers and various related departments at different levels.

Different factors are affecting on operating room orchestration. Some elements, such as human resource, information, materials, and procedures are system inputs. Operating room physical space, safety regulations, and medical equipment are system constraints. Other elements, such as patient arrival, equipment failure, patient diversity makes the system uncertain. Finally the operating room performance can be assessed by some indexes: patient waiting time, resource productivity, and patient stay time in system.

The loss of orchestration in operating room indicates that there is a mismatch between the actual and expected conditions in operating room cooperative ecosystem. Also, loss of orchestration is the main reason for the lack of successful completion of an activity in operating room 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 operating room as follows:

“Operating room 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 operating rooms has increased significantly. Mathematical and simulation models for scheduling, planning, patient flow analysis, and resource assignment, inventory control, patient flow management are the main topics in operating room management.

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 operating room, 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 hospital specially operating rooms. This technique also used for poisoning [40], Intracellular topics [41], Also, non-medical areas such as transportation management [42], social sciences [43], economic [44], healthcare management [45].
According to literature about application of operation research in operating room and studies mentioned above, most of researches in operating room focus on scheduling and they do not offer a comprehensive approach for managing all operating room agents. Also most of studies about coordination are qualitative and do not analyze the effect of this loss of orchestrations on performance of operating room.
In this research, Hasheminejad operating room 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[\] surgery to model the process more accurately. The important problem was analysis of cost and delay time related to loss of orchestrations. Most of the related studies analyzed this problem just with some qualitative approaches and it is necessary to present some extra quantitative analysis of their effects on cost and delay time. In this study a comprehensive definition for operating room resource orchestration is developed and agent based simulation is used due to its flexibility to define all operating room agents and analyze the impact of each agent's loss of orchestrations on delay time and cost of operating room.
The purpose of this research is reducing waiting time resulting from loss of orchestrations and costs related to them.
In following our materials and method will be described, model agents in Hasheminejad operating room will be defined and the factors effect on orchestration in operating room will be identified. Research methodology has been described and then the results for PCNL surgery in Hasheminejad hospital are shown. After that the model is described and validation of model and the results are explained. The conclusions are in the last part of this paper.

Materials and method:

This research is a case study with aim of reducing waiting time and cost related that caused by loss of orchestration of operating room resources. Operating room entities include surgical team, anesthesiologist, and patient and ... are all 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 is 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 operating room are as following:

- Surgery fellow
- Anesthesia Resident
- Anesthesiologist
- Scrub
- Circulator
- Recovery Nurse
- Ward Nurse
- Operating room Clerk
- Internal Patient Transferor
- External Patient Transferor
- Cleaning Crew
- Patients

\ Percutaneous Nephrolithotomy (PCNL)

The classification of loss of orchestration factors:

Using follow-up of patients in operating room 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 the following table:

Table 1- Loss of orchestrations factors in operating room

Management	Hospital	Planning	Shortage of bed after surgery
		Material	• Shortage of medicine • Lack of tools and surgical instruments
	Ward	The lack of notification	The lack of notification between ward and operating room for patient readiness
		The lack of patient readiness	• Not getting the drug at the right time • Other necessary readiness
		Experiments and Testimonials	• Lack of necessary testimonials • Inadequate testing before surgery • Need to do or repeat test
	Operating room	Scheduling	Prolonging other surgical procedures and lack of time
		Personnel	• Lack of patient transferor • Lack of other personnel
		Lack of coordination outside the operating room	Disruption in work with personnel leaving the operating room because of some problem outside.
Technology and tools	Equipment	• Technical problem • Inaccessibility	
	Tools and materials	Inaccessibility of tools and materials	
		Tools and materials Sterile problem	
Organizational and process factors	Planning	• Late start of first surgery	
		Lack of resources: • Lack of recovery bed • Lack of patient transferor • Lak of operating room	
	Education and culture	Inadequate training for a new entrant	
		Weak culture about the requirements during the surgery	
	Communication and teamwork	Lack of coordination and proper connection of the surgical team	
		Collaboration and teamwork problems	
		Poor connection between ward, operating room and etc.	
	Technical	Fatigue and distraction	
		Insufficient ability to perform tasks	
		Pull down the necessary steps	
		Misunderstanding of relevant information	
Human resource	Doctor	Anesthesiologist	Delay or now show
		Surgeon	Delay or now show
	Personnel	Nurses and anesthetists	Nurses and anesthetists errors
			Nurses and anesthetists no show
			Nurses and anesthetists shortage
			Multi task
		Recovery	Recovery personnel shortage
		Service clerks	Clean Service clerks shortage
			Patient transferor shortage
		Patient	Clinical change and lack of tests
Environmental factors	Unrelated conversations and etc.		

Also the costs of each agents was collected. The summary of the above table is described 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.

- Operating room 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 operating room until the patient exit, the recovery and transfers to the department is considered. Patients enter the operating room according to Poisson distribution. 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.

In this section, after completing the modeling and investigating the results in terms of time, the cost of effective factors in the operating room is also examined. After obtaining these reasons, their impact on the model is applied and for each agent, the cost, delay, and etc. were considered. After that, the results of the model output were verified with reality, and the degree of matching of the results with the actual data collected was checked and confirmed on the results.

The below figure shows the developed model for simulation of the operating room with NetLogo software.

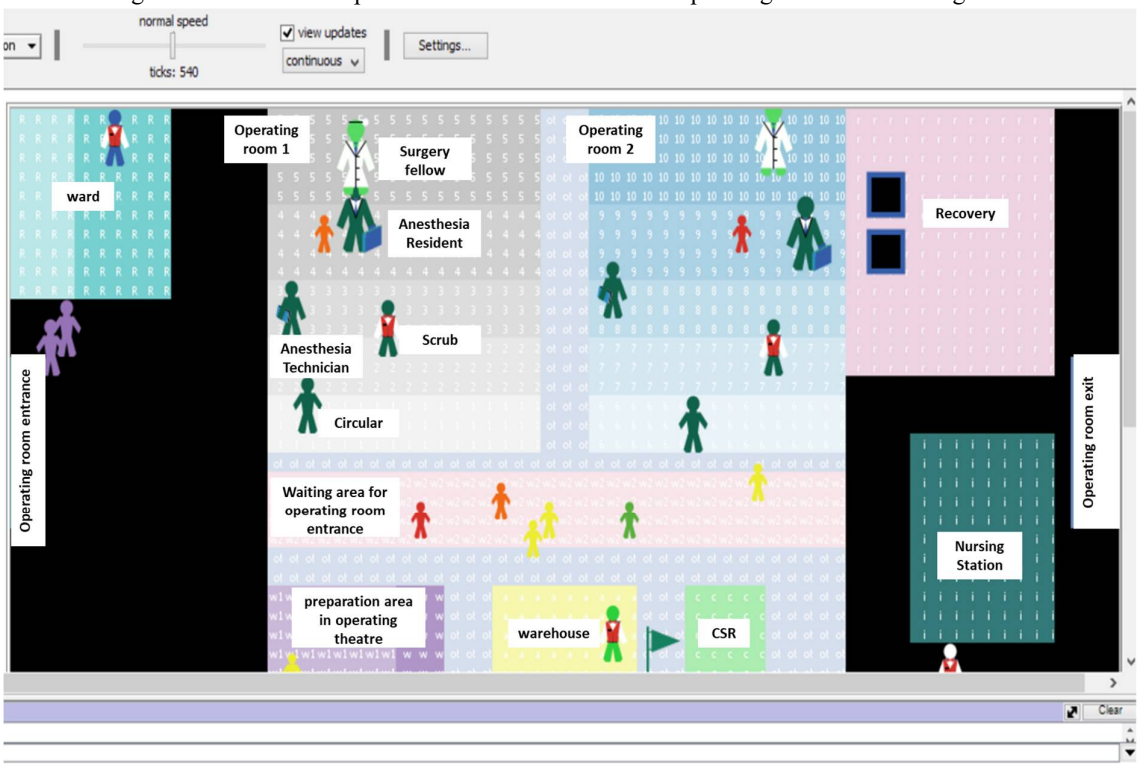

Figure 1. Model designed by NetLogo to do cost and delay time analytics in operating room.

In the following, the cost conditions and the delay of each agents are described. Any delay causes 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, the time elapsed in minutes is calculated, and by considering cost variables for agents, the cost of loss of orchestrations are calculated by the model.

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 operating room at this time is calculated. 2: patient no show. In this condition, the next patient is transferred for surgery to the operating room; in this case, the patient's delay time and the cost of all the agents of the operating room 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 operating room 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 operating room).

Ward management

Patient's non-readiness, shaving, fasting, lack of necessary testimonials, inadequate tests, make the patient some requirements to do some examinations. In this case, in addition to waste of time and delays, it creates surplus costs for the hospital, because all the agents and equipment in the operating room are present, and during this time, the cost of all agents is calculated by the model.

Operating room management

1. The technical fault in the operating room 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 operating room. 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 operating room. This special cases are defined in the model.

Results

In this stage, after modeling operating room 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 $\alpha = 0.05$. The statistical factors are calculated as follow:

$$\mathbf{T} = \frac{\overline{\mathbf{x_2}} - \overline{\mathbf{x_1}}}{\mathbf{S_p}\sqrt{\frac{\mathbf{1}}{\mathbf{n_1}} + \frac{\mathbf{1}}{\mathbf{n_2}}}} \quad (1)$$

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

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

$H0: \mu 1 = \mu 2$ $\}\rightarrow \lvert T\rvert > T(\frac{\alpha}{2}, n_1 + n_2 - 2)$ $H1: \mu 1 \neq \mu 2$	(3)

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

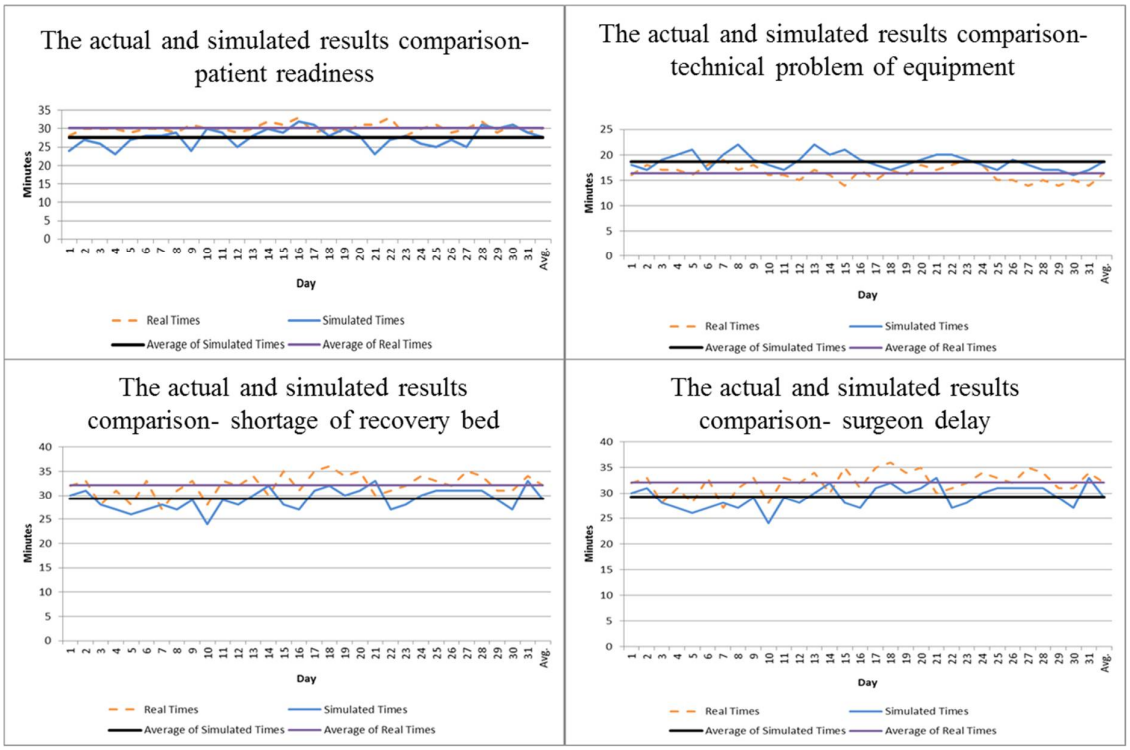

Figure 2. Comparison of simulated results and actual results for some agents

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 operating room 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. So with preparing some improving scenarios loss of orchestration in operating room can decrease.

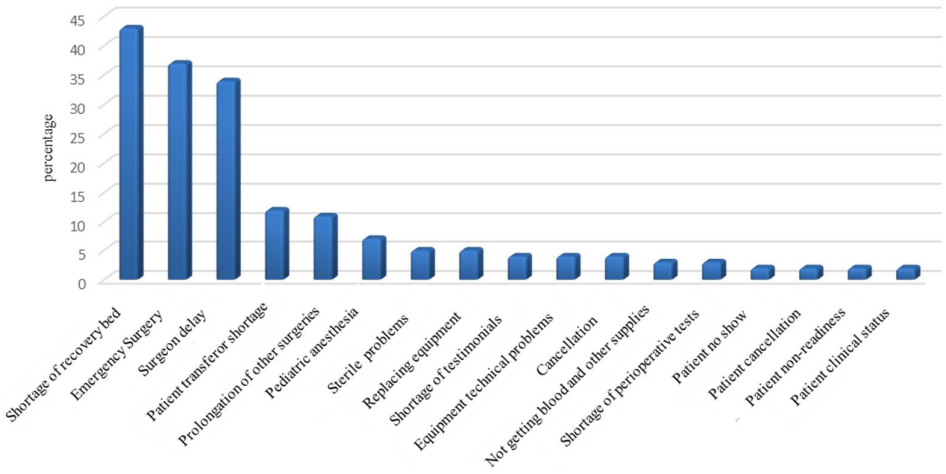

Figure 3 -Frequency of operating room loss of orchestration

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

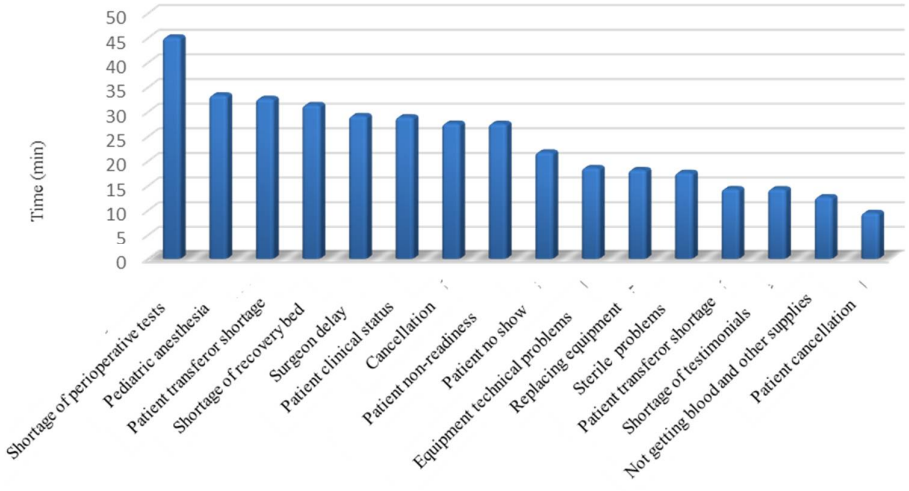

Figure 4 -Average delay time in surgery by each loss of orchestration factor.

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 operating room, and the cost data about each agent in operating room, 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.

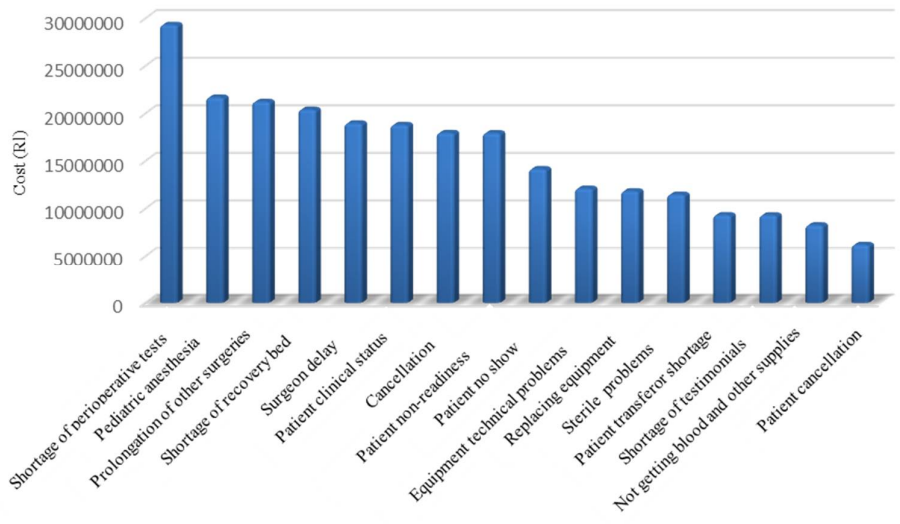

Figure 5 – Hospital Costs

Applicability and significance in hospital

The proposed model and framework will help hospital managers to simulate the operating room 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 operating room orchestration and the situations that loss of orchestration occurs. This can help hospital managers to analyze the effect of this factors on operating room performance especially with time and cost approach. They can manage these problems and consider some solutions for them. Due to the importance of operating room performance in hospital, any minor improvement will lead to a significant result.

Managerial Insights

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

- Improving coordination between operating room 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 is 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 operating room:

• 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 operating room in terms of information to enhance the capacity of the operating room.
• Avoid placing patients more than possible in the operation list for replacement.

This research tried to propose an approach for reducing lack of orchestration. In this paper, the lack of orchestrations and their factors were analyzed by delay time and cost effect comparing to previous studies in operating room that only some qualitative analysis were performed. Also by considering operating room 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 operating room.

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