
Application of Waiting Line Model Using Simulation: A Hypothetical Case Study of A Hospital

KIRAN SONI and KARUNESH SAXENA

Geetanjali Institute of Technical Studies, Udaipur
FMS, MLSU, Udaipur

India is the second most populous country in the world after China. But numbers of hospitals per capita are very less. Consequentially, both public and private sector hospitals are experiencing severe pressure for delivering quality healthcare services. The complexities in delivering the services in the health care system requires focus on exploring such tools & techniques which can make it more simplified or could try to reduce the congestion in the various units of hospital industry. In this industry particularly the operation theaters have large number of patients who are waiting in line to operate which becomes a matter of life or death of patients.

In this research paper applicability of waiting line in Operation Theater of a hospital has been successfully demonstrated. Since waiting line model cannot be used without a set of assumptions therefore simulation model has been applied for solving waiting line model.

Towards the end of the paper a hypothetical case study concerning Operation Theater of a fictitious hospital has been successfully attempted. The result achieved by use of simulation model clearly indicate that both efficiency & effectiveness of working of a hospital can be tremendously increased leading to better healthcare services, being provided to its customers i.e. patients.

This paper has been divided into four sections. First section about Healthcare, hospital and emergency, second part includes the application of waiting line model, third section highlights the simulation and its application, fourth has focused on most important part which is a hypothetical case study and in last fifth section have been included the conclusion, suggestions.

Key Words: - Health Care System, Waiting Line Model, Simulation Patients Satisfaction, Decision-Making.

HEALTHCARE AND PATIENTS

Acute care is the treatment of a severe medical condition for only a short period of time and at a crisis level. Many hospitals are the centre of acute care facilities with the objective of discharging the patient as soon as the patient is deemed healthy and stable. The rising population has created a need to understand the relation between hospital resources and quality of services in acute care facilities in India as well as all around the world. To ensure an adequate level of access to care, it is important to examine future resource requirements. The accurate prediction of this count requires both the knowledge of future population demographics, which affects the demand for acute care services, and also an understanding of how the number of availability of resources (like; Bed) affects access to acute care (Mackay & Lee, 2005).

More specifically, Flows of patients is also a critical factor for examination, within the different departments of hospital system, and out of the hospital which affects access to acute care. This would enable us to estimate the required number of resources that would guarantee a certain access level. This is important, for a low hospital capacity leads to patients in need of care being turned away, and growing waiting lists cause stress on other hospital units. For example, when insufficient

Application of Waiting Line Model Using Simulation: A Hypothetical Case Study of A Hospital

medical beds are available to meet demand, emergency medical patients spill over into surgical beds; consequently, surgical waiting lists increase as planned admissions are postponed.

Attitude of Patients / Customers at the Service System

Patient Customers: Customer arrives at the service system, stays in the queue until served, no matter how much he has to wait for service.

Impatient Customers: Customer arrives at the service system, waits for a certain time in the queue and leaves the system without getting service due to some reasons like long queue before him.

Balking: Customer decides not to join the queue by seeing the number of customers already in service system.

Reneging: Customer after joining the queue waits for some time and leaves the service system due to delay in service.

Jockeying: Customer moves from one queue to another thinking that he will get served faster by doing so Bunday (1996).

The increasing population is asking for more emphasis on health care system, so the channels are continuously increasing the numbers of private & public hospitals. The complexities in delivering the services in the health care system requires focus on exploring such tools & techniques which can make it more simplified or could try to reduce the congestion in the various units of hospital industry. In this regard the Waiting Line Mode using simulation has been a prominent analytical technique in operations research for more than half a century.

Along this all, the waiting line with simulation is very useful in the medical field. The best use of the waiting line model is to assess the impact of settlement policy in hospital beds, the waiting time for services, and the probability of a patient exit from the queue without acquiring the service or

treatment. It is a study about the use of the waiting line model in hospital sector. Predicting and reducing the waiting time and rearranging the placement of staff could improve the patient satisfaction. Waiting line has been widely employed in many areas of healthcare such as emergency care center planning, and waiting lists for transplants and surgery.

APPLICATION OF WAITING LINE MODEL IN HEALTH CARE INDUSTRY

Queues or waiting lines or waiting line model, was first analyzed by A.K. Erlang in 1913 in the context of telephone facilities. The body of knowledge that developed from it after further research and analysis came to be known as "Waiting line model". It is extensively practiced or utilized in industrial setting or retail sector operations management, and falls under the purview of decision sciences. The decision problem involved here is balancing the cost of providing services with the costs of customer waiting. Use of waiting line model and other principles of operations management in healthcare are fairly recent. The reasons behind it are some drastic changes occurring in the healthcare delivery and reimbursement methods in US over the past two decades and the changes in demographic (provider and patient) and disease profiles and highly fragmented delivery system. The rising cost of healthcare can be attributed to not only to ageing population and new, expensive and advanced treatment modalities but also to inefficiencies in healthcare delivery. Waiting line model application is an attempt to minimize the cost through minimization of inefficiencies and delays in the system.

- Prerequisites of waiting line model

For application of queuing models to any situation we should first describe the "input process" and the "output process". An example is shown below with a brief description of both processes.

Application of Waiting Line Model Using Simulation: A Hypothetical Case Study of A Hospital

Table-1:-Input and Output processes of Queuing model in respect of a hospital

Setting	Input process	Output process
Hospital	Arrival of the patient at the registration counter	Assessment, triage, provision of services, discharge
PCP Office	Arrival at registration counter or front office desk	Assessment by PCP, prescription and tests, and collection of bills at the exit
ER	Ambulance arrival	Assessment, triage, assessment, triage to the inpatient setting or discharge after treatment
The Input or Arrival Process		The Output or Service Process
<ul style="list-style-type: none"> The input process is usually called The arrival process. Arrivals are called customers. We assume that no more than one arrival can occur at a given instant. If more than one arrival can occur at a given instant, we say that bulk arrivals are allowed. Models in which arrivals are drawn from a small population are called finite source models. If a customer arrives but fails to enter the system, we say that the customer has balked. If the customer arrives and waits in line but then decides to leave, we say that the customer has reneged. 		<ul style="list-style-type: none"> To describe the output process of a Queuing system, we usually specify a probability distribution – the service time distribution – which governs a customer's service time. We study two arrangements of servers: servers in parallel and servers in series. Servers are in parallel if all servers provide the same type of service and a customer needs only pass through one server to complete service. Servers are in series if a customer must pass through several servers before completing service.

- Waiting line model and healthcare

The health system's ability to deliver safe, efficient and smooth services to the patients didn't receive much attention until mid 1990's. Several key reimbursement changes, increasing critiques and cost pressure on the system and increasing demand of quality and efficacy from highly aware and educated patients due to advances in technology and telecommunications, have started putting more pressure on the healthcare managers to respond to these concerns. Reports like IOM's "To Err is Human" and "Crossing the Quality Chasm", and proven effectiveness of engineering tools in service sector have prompted calls for use of them in the healthcare sector. Waiting line model is an example of the use of such engineering tools in healthcare. It essentially deals with patient flow through the system. If patient flow is good then patient queuing is minimized, if it is bad then the system may suffer loss of business and patients suffer considerable queuing delays (Fomundam & Herrmann, 2007). Healthcare system can be

visualized as a complex queuing network in which delays can be reduced through:

- Synchronization of work among service stages (e.g., coordination of tests, treatments, discharge processes),
- Scheduling of resources (e.g., doctors and nurses) to match patterns of arrival, and
- Constant system monitoring (e.g., tracking number of patients waiting by location, diagnostic grouping and acuity) linked to immediate actions.

Apart from the above points the rationale of using queuing models in healthcare are summarized below:

- Variability in arrival pattern of patients
- Variability in type and level of service needed
- Variability in service rate
- To minimize total costs

Despite these convincing rationales, there are very few instances of its use in healthcare. Some

Application of Waiting Line Model Using Simulation: A Hypothetical Case Study of A Hospital

of it may be due to ignorance and some due to apprehensions or other peculiar challenges of healthcare. With more than about forty models in market for different queue management goals and service conditions, sometimes it's better to be ignorant than to apply the wrong model (Weber, 2006).

Waiting line model can be fairly used in following settings:

1. Emergency Room Arrivals
2. Walk in of patients to physicians and outpatient surgeries in hospitals
3. Hospital Pharmacy and pharmacy arrivals
4. Inventory control
5. Disaster management
6. Public health

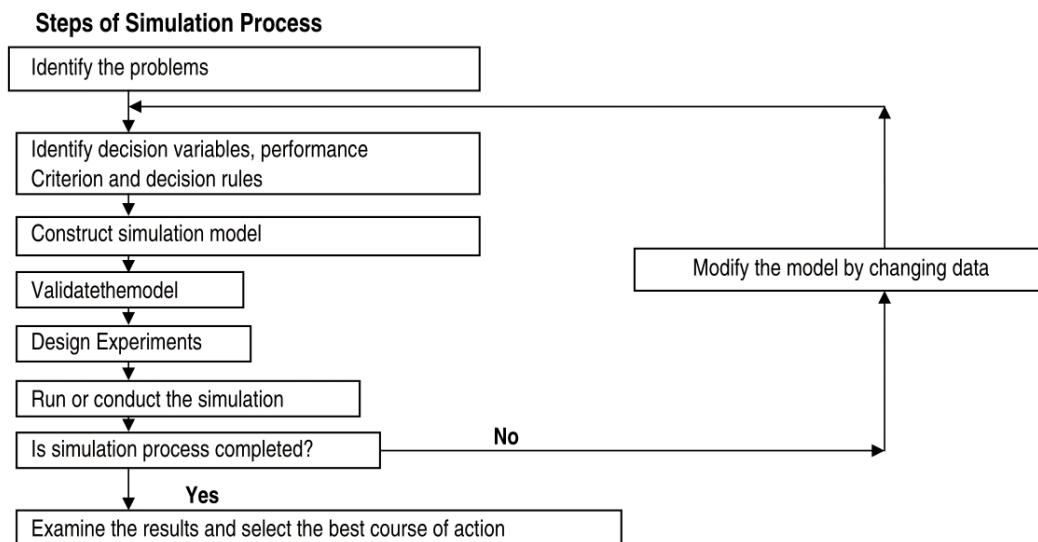
Common problems to be encountered in clinic system are as follows:

1. Long patient wait time
2. Wrong service might conveyed to patients
3. Congestion during disaster or during seasonal diseases
4. No proper schedule displays and no correct confirmation

5. Appointment overlap
6. Overtime of doctors
7. Dissatisfaction of patients and doctors as well
8. Improper management of service and other hospital issues.

SIMULATION

With advancements in computer technology, simulation has rapidly replaced many analytical models we cover in this and other management science courses. In the near future, with the costs of technology decreasing and further advancements in the area of real time information (and wireless communication), simulation will be part of everyday operations, anticipating events and planning production and services to meet customers satisfaction on a continual basis. Some of the more 'enlightened' companies already continuously collecting data from thousands or even millions point-of-sale (POS) terminals and feed that information to specialized simulation software as part of what lately is called business intelligence systems. All major corporations already depend on simulation to run complex business operations around the globe to optimize their supply chain, diminish the risk of disruption and increase safety in the delivery process (Sinreich & Marmor, 2004)

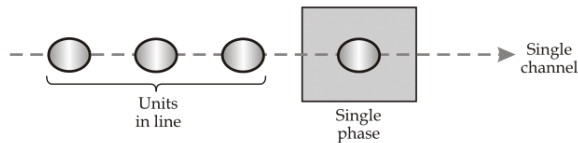


Source: J.K. Sharma 2005, *Quantitative techniques for managerial decision*

Application of Waiting Line Model Using Simulation: A Hypothetical Case Study of A Hospital

Simulation Example (Using single-channel, single-phase waiting line)

1) Process map



- 2) Time between arrivals (exponential distribution), service time (exponential distribution), objects = cars, elements = line and wash station
- 3) Maximum length for line, time spent in the system
- 4) Run model for a total of 100 cars entering the car wash, average the results for waiting time, cars in line, etc.

Data Collection, Simulation requires extensive data gathering on costs, productivities, capacities, and probability distributions. Typically, one of two approaches to data collection is used. Statistical sampling procedures are used when the data are not readily available from published sources or when the cost of searching for and collecting the data is high. Historical search is used when the data are available in company records, governmental and industry reports, professional and scientific journals, or newspapers.

CASE STUDY: HAND COMPUTED SIMULATION OF AN OPERATING SYSTEM

This case study concerns the scheduling of patients in a hospital operating room of a hypothetical hospital. The following case describes the utilization of Operation Theater on any given day say Wednesday.

Simulation model has been effectively used in this case study which has been adapted from Levin & Rubin (1986).

XYZ HOSPITAL SIMULATION

Wednesday's schedule for Operation Theater no.-3 (O T no.-3) at XYZ memorial hospital is shown in Table 2.

Table 2: Schedule of Operation Theater no.-3 (O T no.-3)

TIME	ACTIVITY	EXPECTED TIME
8.00 A.M.	Appendectomy	40 min
8.40	Cleanup	20 min
9.00	Laminectomy	90 min
10.30	Cleanup	20 min
10.50	Kidney Removal	120 min
12.50 P.M.	Cleanup	20 min
1.10	Hysterectomy	60 min
2.10	Cleanup	20 min
2.30	Colostomy	100 min
4.10	Cleanup	20 min
4.30	Lesion Removal	10 min
4.40	Cleanup	20 min

From looking the schedule head of Operation Theater nurse concludes that it may not be possible to finish the operating and cleanup schedule by 5 P.M. the time at which Operation Theater must be available for emergency night service.

The hospital management analyst, Mausmi Sheeran, suggests that simulation might indicate whether the schedule for Wednesday is workable and, if not what charges could be made in it. Mausmi reviews past records to find out that patients do not always arrive at the scheduled time in Operation Theater. Mausmi's investigation of the log of Operation Theater indicates that arrival expectations are about as shown in Table 3.

Application of Waiting Line Model Using Simulation: A Hypothetical Case Study of A Hospital

Table 3: Arrival Expectations

Patients arrives on time	.50 probability
Patients arrives 5 minutes early	.10 probability
Patients arrives 10 minutes early	.05 probability
Patients arrives 5 minutes late	.20 probability
Patients arrives 10 minutes late	.15 probability

Mausmi finds that operating times also vary according to surgical difficulties encountered, differences in surgical skills and the effectiveness of surgical team in general. An analysis of operations scheduled over the past few months produces the results shown in Table 7, which gives a good indication of this variation.

Table 4: Operation Time Expectations

Operation completed in expected time	.45 probability
Operation completed in 90% of the expected time	.15 probability
Operation completed in 80% of the expected time	.05 probability
Operation completed in 110% of the expected time	.25 probability
Operation completed in 120% of the expected time	.10 probability

Mausmi also recognizes that any variation in the expected cleanup time will affect the schedule, and she checked the record once again. Here she finds that about half the time the cleanup crew finishes in 10 minutes. The other half of time, it takes them 30 minutes. With her data, she is ready to begin the simulation.

Generating the variables in the system (Process Generators)

Mausmi needs a way to generate arrival times, operating times, and cleanup times. The method is called process generators. And for this she uses random number table.

Generating arrival times, she decided to use first two digit of each 10 digit number. Since there are 100 possible two digit numbers from 00 through 99, she

relates these two-digit numbers to arrival variation like this:

Table 5: Process Generator for Arrival Times

Random Numbers	Arrival	
00-49	On time	.50 probability
50-59	5 minutes early	.10 probability
60-64	10 minutes early	.05 probability
65-84	5 minutes late	.20 probability
85-99	10 minutes late	.15 probability

Generating operating times, now Mausmi decides to use the last two digits of each 10-digit number. She relates these two-digit numbers to operating times in this way:

Table 6: Process Generator for Operating Times

Random Numbers	Operating Times	
00-49	On time completion	.45 probability
50-59	Completion in 90% of expected time	.15 probability
60-64	Completion in 80% of expected time	.05 probability
65-84	Completion in 110% of expected time	.25 probability
85-99	Completion in 120% of expected time	.10 probability

Generating cleanup times, since the random variable takes on only two values here, Mausmi decided to use a single digit, the fourth digit of each 10-digit number. If it is an odd number, she will let that represent a 10-minute cleanup; an even number will represent a 30 minute cleanup.

Mausmi proceeds with simulation. First she generates an inter-arrival time observation for the patient; then she generates an operating time observation for the first operation; finally she generates a cleanup time for that operation. She continues with the process until the last operation has been performed and the Operation Theater cleaned up for the final time. The result of her simulation is shown in Table 7.

**Application of Waiting Line Model Using Simulation:
A Hypothetical Case Study of A Hospital**

Table 7: Results of simulation of activity in Operation Theater no.-3 (O T no.-3)

Random Numbers	First Two Digit	Last Two Digit	Fourth Digit	Meaning	Outcome
15	X			On the time arrival of appendectomy patient	Appendectomy begun at 8.00 A.M.
96		X		Appendectomy completed in 120% of expected time (48 min)	Appendectomy completes at 8.48 A.M.
1			X	Cleanup done in 10 min	Room Ready at 8.58 A.M.
09	X			On the time arrival of Laminectomy patient 9.00 A.M.	Laminectomy begun at 9.00 A.M.
82		X		Laminectomy completed in 110% of expected time (99 min)	Laminectomy completes at 10.39 A.M.
8			X	Cleanup done in 30 min	Room Ready at 11.09 A.M.
41	X			On the time arrival of Kidney patient 10.50 A.M.	Kidney Removal begun at 11.09 A.M.
56		X		Kidney Removal completed in 90% of expected time (108 min)	Kidney Removal completed at 12.57 P.M.
2			X	Cleanup done in 30 min	Room Ready at 1.27 P.M.
74	X			Hysterectomy Patient arrives 5 min late (1.15 P.M.)	Hysterectomy begun at 1.27 P.M.
68		X		Hysterectomy completed in 110% of expected time (66 min)	Hysterectomy completed at 2.33 P.M.
7			X	Cleanup done in 10 min	Room Ready at 2.43 P.M.
00	X			On the time arrival of colostomy patient 2.30 P.M.	Colostomy begun at 2.43 P.M.
58		X		Hysterectomy completed in 90% of expected time (90 min)	Colostomy completed at 4.13 P.M.
9			X	Cleanup done in 10 min	Room Ready at 4.23 P.M.
72	X			Lesion Patient arrives 5 min late (4.35 P.M.)	Lesion begun at 4.35 P.M.
40		X		On time completion of Lesion operation (10 min)	Lesion operation completed at 4.45 P.M.
5			X	Cleanup done in 10 min	Operation room schedule for Wednesday completed at 4.55 P.M.

- Assumptions and Caveats

Mausmi simulated the day's operation only once, and it is very dangerous for us to draw general conclusions from such a short simulation. If she had repeated day's simulation with different number several times she could feel better about generalizing from her result. Mausmi also assumed that variables in simulation were independent to each other. If this is not the case, her simulation is not valid. Finally Mausmi used discrete distribution of the three variables.

- Conclusion of case study: So it can be recognized by the examination of the case that the applicability of waiting line using simulation helps to optimize the availability of resources which is directly linked with quality of services and satisfaction of patients.

The case study of XYZ hospital is presenting the use of simulation to schedule the activities of an operation theater to ensure the availability of Operation Theater to ensure the availability of O.T. for night services. Factors recognized which mainly affects the O.O. schedule are:

Application of Waiting Line Model Using Simulation: A Hypothetical Case Study of A Hospital

1. Surgical Difficulties
2. Difference in surgical skills
3. Variation in clean up times
4. Effectiveness of surgical team

Random number table is used for process generators. The process of simulation is proceeds in following steps:

Step 1: Inter arrival time observation for patient.

Step 2: Operating time observation for the first operation.

Step 3: Generation of cleanup time.

Step 4: Continue the process till least operation.

As the result, it was found that operation theater activities could be completed before the time and operation theater availability could be ensured for night service before time.

CONCLUSION

Waiting line model is an effective engineering tool to improve the effectiveness of a service system. Its applicability in health care sector helps to synchronize the work among service stages, scheduling of resources and also helps to monitor the system performance constantly. Apart of these issues points like variability in arrival pattern of patients, variability in type and level of service needed, variability in service rate, total costs etc are the rationale of using queuing model in health care. Applicability of waiting line model with reference to hospitals could be wide under various settings like emergency rooms, walk in of patients, pharmacy arrivals, inventory control, public health etc.

With the advancement of information and computer technology the concept of Simulation was emerged with the basic advantage of anticipation of events and planning on a continual basis. The integration of waiting line / waiting line model and simulation concept is delivering a proper mix for effective management of organization operations and diminish the risk of disruption.

REFERENCES

- Au-Yeung, S.W.M., Harrison, P.G., & Knottenbelt, W.J., (2006), A queuing network model of patient flow in an accident and emergency department, Department of Computing, Imperial College of London, August 15, 2006.
- Bunday (1996), B.D., "An Introduction to Waiting line model", New York: Halsted Press,
- Carter, M.W., (2006), Operations research in healthcare or who let the engineers into the hospital?, RCHE Pioneers in Healthcare Engineering Colloquium, April 2006.
- Levin R.I., Rubin D.S. and, Stinson J.P. (1986), "Quantitative Approaches to Management" (6th edition), McGraw Hill Book company
- Mackay, M. & Lee, M., (2005), "Choice of models for analysis and forecasting of hospital beds", Healthcare Management Science 8, 221-230, 2005.
- Samuel Fomundam, Jeffrey Herrmann, A Survey of Waiting line model Applications in Healthcare, University of Maryland, 2007.
- Sinreich, D. & Marmor, Y.N., (2004), "A staffing emergency; keeping emergency departments quickly and efficiently with simulation", Industrial Engineer Magazine, May 2004.
- Weber, D.O., (2006), "Queue Fever", Hospitals & Health Network, 2006.

BIOGRAPHIES

Kiran Soni is Assistant Professor in Operations Research and Quantitative Technique Area at Geetanjali Institute of Technical Studies (GITS), Udaipur, Rajasthan. She is UGC NET and Ph.D on "A Study of Applicability of Waiting Line Model in Selected Hospitals of Southern Rajasthan" from the department of Faculty of management Studies (FMS), Mohan Lal Sukhadia University, Udaipur. She is backed by 5 years of teaching experience with exemplary track record in structural teaching. She has publications in various National and International Journal.

Karunesh Saxena, Ph.d. is Director (CDC and Professor) and Current Chairman, Faculty of Management Studies, Mohanlal Sukhadia University, Udaipur. He has about twenty five years of research and teaching experience at various universities in India and a corporate experience of five years. He is constantly teaching and guiding Ph.D. students and twenty eight Ph.D. have been already awarded and six are under process. He has been awarded Major Research Project by UGC, New Delhi on Emotional Intelligence. He has published four books and Monograph. Along with this he has published/presented/delivered keynote address about seventy eight research papers in various reputed journals of the field/ International Conference/ National Conference/ Seminars. He has recorded more than hundred seventy higher educational films made for UGC center for Educational Consortium (CEC) Countrywide Classroom Programme. He has conducted more than 50 Management Development Programs (MDP's) for various companies.