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Modelling the patient flow in an Out Patient Department (OPD) of a hospital using simulation techniques

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Abstract. Hospitals are integral and vital entities of healthcare systems across the globe. Reduction of patient wait time is of utmost importance for the overall smooth functioning of any hospital. This paper discusses the analysis of the patient flow in the Out Patient Department (OPD) of a hospital. Data was collected with respect to patient arrival and service times in minutes. Input analyser was used to determine the distribution of the patient flow data collected at each section. A simulation model using Arena software was developed to study the patient flow in various sections of the OPD. The average waiting time and utilization of resources were determined for each sections. The results showed that there was a longer waiting time in billing section and Obstetrics and Gynaecology (OBG) section. Also there was high utilization of resources in these sections compared to the other sections of the OPD.

Keywords: Outpatient Department; Simulation model; Waiting time; Service time; Patient flow.

1. Introduction

Patient waiting time is a very serious concern for all the hospital administrations. Industrial engineering techniques can be effectively applied to reduce the waiting time and improve the system efficiency and enhance patient satisfaction. Several researchers have worked on studying the effect of patient wait time on the overall efficiency of the hospital patient flow. Simulation modelling has been effectively used by researchers to study the patient flow in various hospitals across the globe and has emerged as a powerful tool in identifying the bottle necks in a system.

A study on the use of mathematical-computer models in developing operating policies for a university-health-service outpatient clinic was done. A comparison on subsequent real-world results with those predicted by the models was made. An analysis of daily arrival patterns was used to schedule more number of appointment patients during periods of low walk-in demand in order to smoothen the overall daily arrivals. A Monte Carlo simulation model showed the effects of alternative decision rules for scheduling appointment periods during the day to increase patient throughput and physician utilization [1]. Total cash flow was proposed as a performance measure in addition to throughput, time in system, and queue times and lengths for analyzing a healthcare system. Scenario analysis and comparison of expenses were done to validate the results [2].

Discrete event simulation is one of the most widely used operations research tools. This encompasses selecting proper methods of collection and analysis of data, application of analytical techniques, verification of models, design and development of simulation experiments [3]. Arena is one of the most popular software tool used to build a simulation model. A systematic procedure to build a simulation model is



explained and illustrated [4]. A discrete event simulation model was developed to examine doctor schedule mixes and various appointment schedules. An optimization program was developed to reduce the patient waiting time without adding extra resources [5]. Sampling techniques which are an integral part of statistical analysis is thoroughly explained. The detailed description of determining the sample size based on relevant parameters is illustrated [6].

Modelling and simulation of the capacity of utilities was done to show the importance of using advanced control techniques in enabling intelligent scheduling and streamlining the patient flow. Optimal pathway for patients can be designed to reduce queuing length in the hospitals [7]. The authors studied the effect of various arrival patterns on the ability of emergency department to treat patients. Arena 10.0 simulation model was used to estimate the requirement of additional resources [8]. A mismatch between demand on outpatient services and clinic capacity was observed. A simulation based operation management was proposed to provide future visibility in OPDs for all stakeholders [9].

The behaviour of the patients and their relatives arriving at hospital were studied. A simulation model was developed and the results highlighted the counters with maximum queue lengths and waiting times [10]. OPD facilities were classified into two types; primary and support facilities. Both were hosted in separate buildings which resulted in reduction in congestion in the floor area of OPD clinics and capacity optimization in both the buildings [11]. The impact of clinical disciplines on wait times was studied using the patient flow analysis. Results revealed that a significant amount of patient's total stay in the system was related to waiting time for physical examination [12]. Fundamental concepts of simulation modelling and its application in several cases is demonstrated [13]. Application of various probability and statistical methods to engineering scenarios is shown [14].

Literature review shows that simulation modelling is an important tool being used in solving the problems related to patient flow management. Resources in a typical hospital scenario mainly consists of doctors and supporting staff. The focus of the study was to understand the patient waiting time and utilization of the above resources associated with each section. High utilization of certain resources infers that they are occupied during the shift. Hence imbalance in resource utilization value indicates uneven distribution of work load among the resources, which leads to bottle necks and hence increased queue length and patient waiting time.

In this paper, sections of OPD, namely admission, billing, initial test, orthopaedics, Ear-Nose-Throat (ENT), OBG, ophthalmology and prescription were considered for study, as they had high patient flow. In each station the distributions of arrival time, waiting time and service time in minutes were determined using input analyzer. Important factors affecting queues in the system were recorded from the output of Arena simulation model. The waiting time was observed to be more in the billing section and OBG consultation section compared to the other departments or sections in the OPD of the hospital.

2. Data and Methods

The movement of patients as they entered the OPD was traced and recorded. Patient flow chart was prepared by observing the entire sequence of movement of patients in the OPD. Data for parameters required for building a simulation model were recorded during the entire working shift. Figure 1 illustrates the methodology adopted in approaching and solving the stated problem. The sections of OPD included in this study were admission, billing, initial test, orthopaedics, ENT, OBG, ophthalmology and prescription.

The sample size for data collection was determined using equation 1 which is based on sample size determination theory, where n is the number of samples required to achieve an accuracy (K) of 10%, \bar{X} is the mean, σ is standard deviation and α =significance level (5%).

$$n = \left(\frac{Z_{\alpha} \sigma}{K \bar{X}} \right)^2 \quad (1)$$

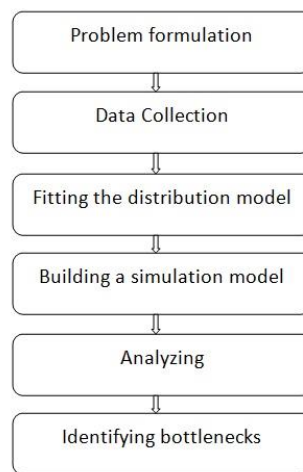


Figure 1. Methodology

Table 1. Number of data points required to achieve an accuracy of 10%

Section	Variable Considered	Mean (minutes)	Standard Deviation (minutes)	Required Number of Data
Admission	Inter-arrival time	4.87	4.22	289
Admission	Service time	2.7	1.39	102
Billing	Service time	2.37	1.22	102
Prescription	Service time	4.5	5.8	232
Initial Test	Service time	2.27	0.907	62
Orthopaedics	Service time	9.2	6.43	188
ENT	Service time	2.27	0.907	62
OBG	Service time	7.03	3.71	107
Ophthalmology	Service time	1	0.947	345

The entire process is simulated based on the inter-arrival time at the admission section, which is the input station and service time at successive stations. Table 1 shows the values of mean, standard deviation and number of samples required to achieve an accuracy level of 10%. Based on this, adequate data was collected and recorded for parameters such as arrival time, time between arrivals and service time in minutes. This data was fed in the input analyser to determine the distribution which fits the best for each section. Histograms plotted using MINITAB software shown in figures 2- 6 depict the frequency distribution of the inter-arrival/service times for all the sections considered for this study.

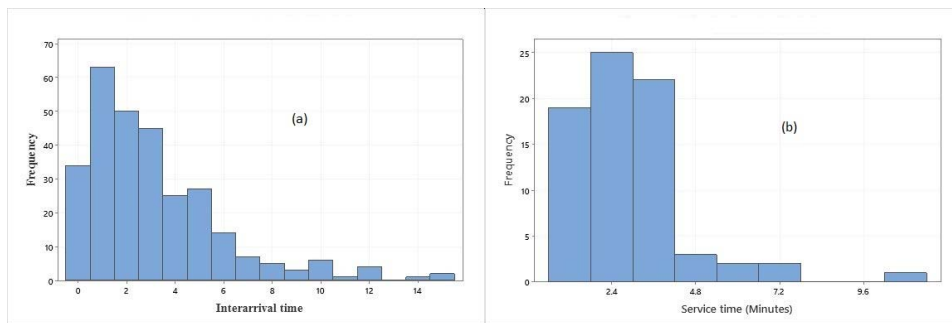


Figure 2. Histogram for admission section for (a) inter-arrival time and (b) service time in minutes

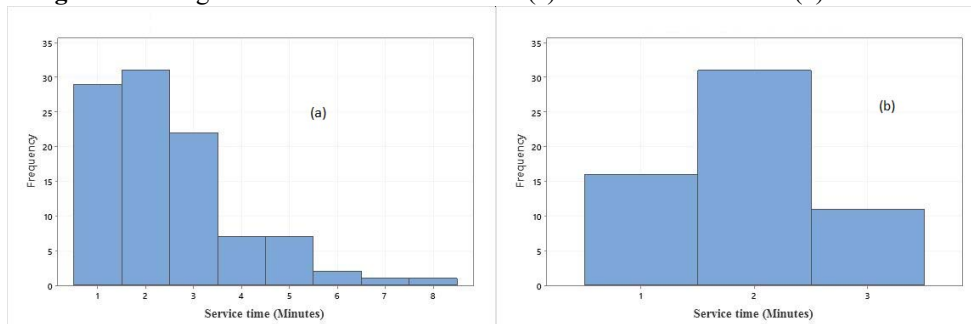


Figure 3. Histogram for service time in minutes (a) billing section (b) initial testing section

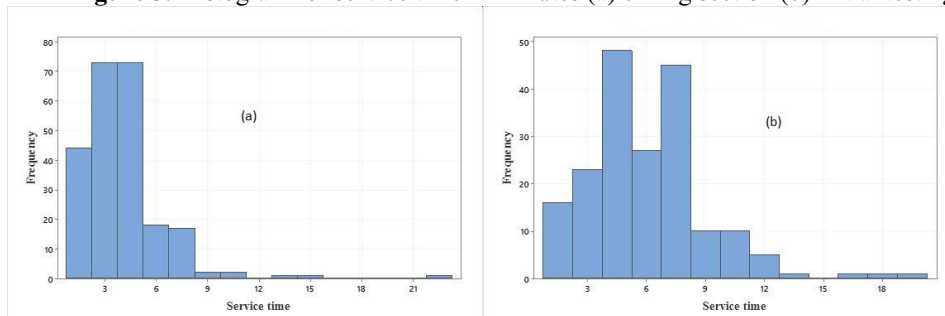


Figure 4. Histogram for service time in minutes (a) Orthopaedic section (b) ENT section

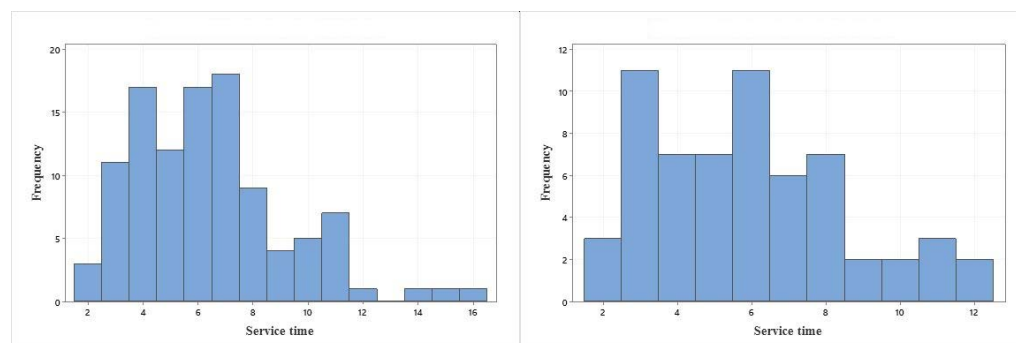


Figure 5. Histogram for service time in minutes (a) OBG section (b) Ophthalmology section

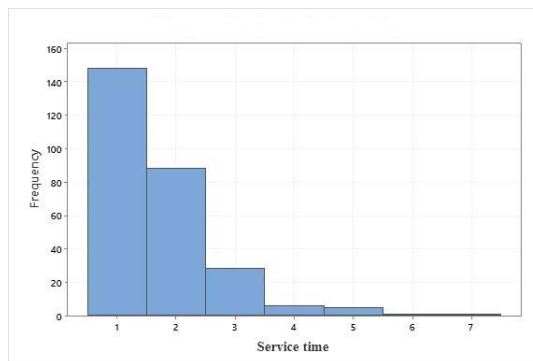


Figure 6. Histogram for service time in minutes for prescription section

The probability density functions of service time in minutes for the concerned departments are depicted in figures 7-11. These are obtained from the results of input analyser and give the type of probability distribution which best fits for the given set of data. The type of the best fitting distribution to be considered for further analysis along with the expression to be used are shown in table 2.

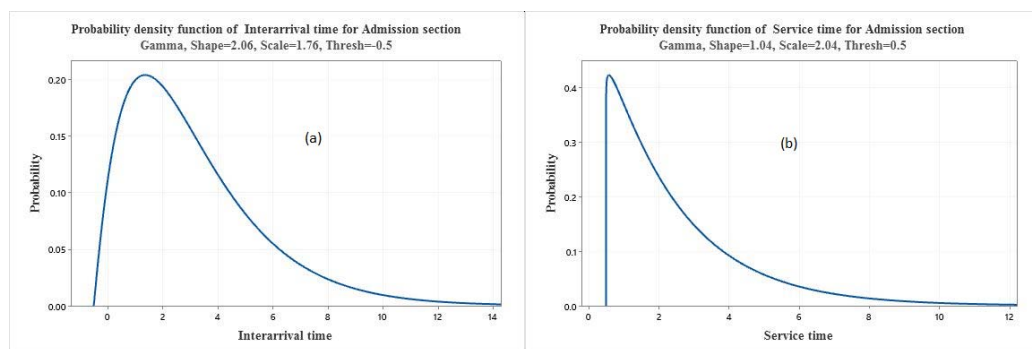


Figure 7. Probability density function for admission section considering (a) Inter-arrival time in minutes (b) Service time in minutes

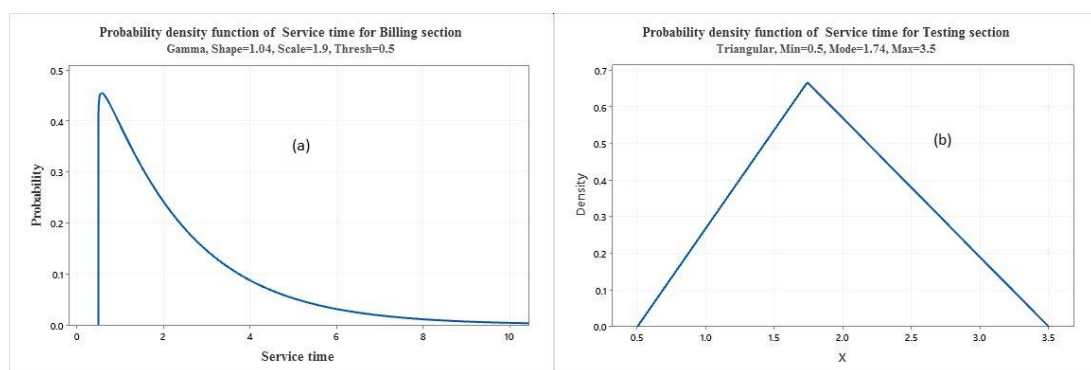


Figure 8. Probability density function of service time in minutes for (a) Billing section (b) Initial testing section

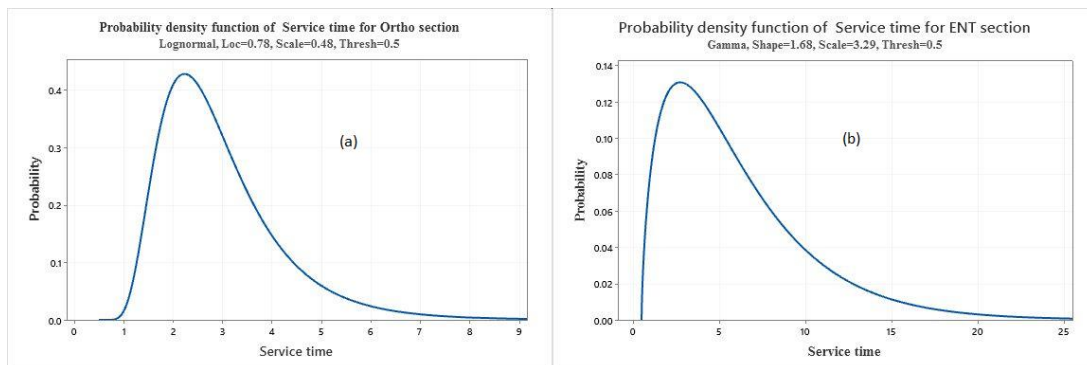


Figure 9. Probability density function of service time in minutes for (a) Orthopaedic section (b) ENT section

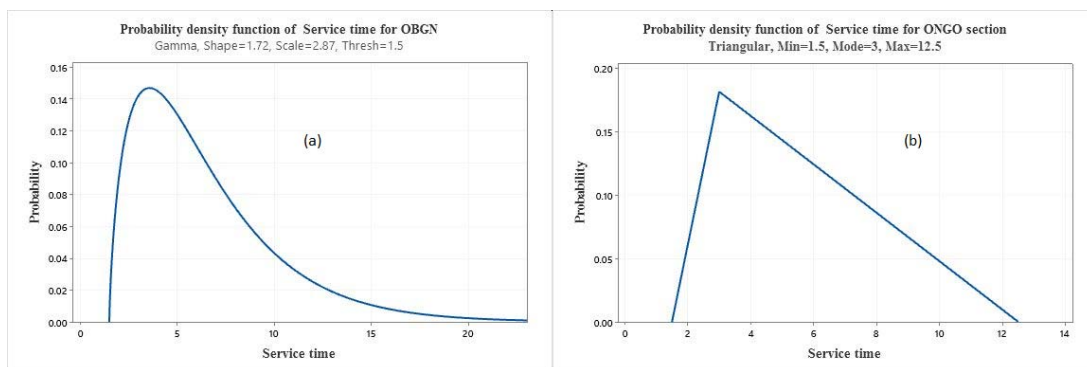


Figure 10. Probability density function of service time in minutes for (a) OBG section (b) Ophthalmology section

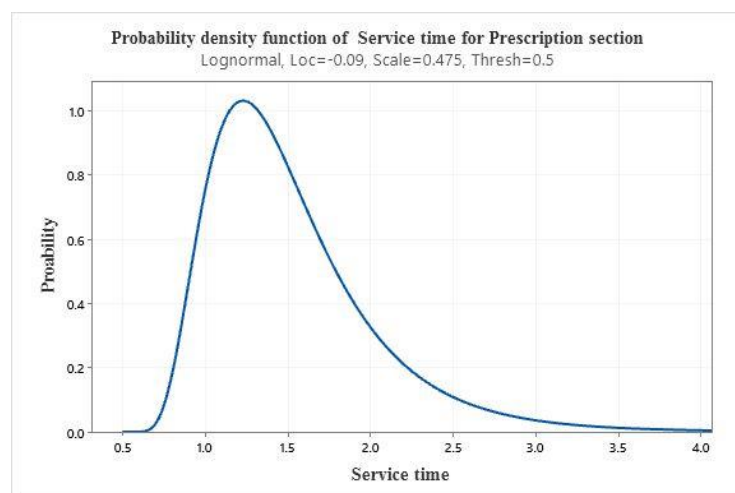


Figure 11. Probability density function of service time in minutes for Prescription section

Data for various sections was collected based on the sample size determination formula. The purpose was to ensure that a sound probability distribution is obtained for the various variables. In order to conduct the study, a histogram needs to be obtained and based on the histogram a chi-square test was conducted and accordingly the distribution was obtained. Input analyser software was used to assess the type of

distribution. The choice of the appropriate distribution was based on the shape of distribution obtained using histogram, mean square error, chi-square test statistics and the p value.

Figures 2 to 6 show the histograms for the various variables considered. It can be seen that for the inter-arrival time at admission section there is variability as evidenced by a long tail, however service time has lesser variability. Likewise it can be seen that billing, testing, prescription section have moderate variability. This is partly because of the automation process involved, and if more automation can be considered then there is further possibility of reducing the variability at these sections. The area where more variability can occur would be at the doctors section. It can be seen from figure 4a and 9a that there is less variability for the orthopaedic section and large variability for the remaining three sections. The variability at these sections can create more waiting time for patients in the system.

In order to conduct the simulation study, it would be necessary to obtain an appropriate distribution for the data set. Various distributions were obtained using input analyser based on mean square error, shape of the histogram, chi-square value and p value. There were cases where the input analyzer would provide a low mean square error, however the chi-square value was large and the p value was small. In such cases the chi-square value with a smaller value coupled with a large p value was chosen. MINITAB software was used to generate these plots.

Table 2. Distribution, Chi Square, P value and Parameters for each section

Section	Variable Considered	Type of Distribution	Chi Square Statistics	P value	Parameters
Admission	Inter-arrival time	Gamma	6.33	0.402	$\alpha = 2.06, \beta = 1.76$, Threshold = 0.5
Admission	Service time	Gamma	2.43	0.49	$\alpha = 1.04, \beta = 2.04$, Threshold = 0.5
Billing	Service time	Gamma	1.57	0.224	$\alpha = 1.04, \beta = 1.9$, Threshold = 0.5
Prescription	Service time	Lognormal	0.756	0.413	$\mu = 1.17, \sigma = .928$ Threshold = 0.5, Scale = -0.09, Shape = 0.475
Initial Test	Service time	Triangular	0.0176	0.577	Minimum = 0.5, Mode = 1.74 Maximum = 3.5
Orthopaedics	Service time	Lognormal	6.67	1.69	$\mu = 3.58, \sigma = 2.25$, Threshold = 0.5, Scale = 0.78, Shape = 0.48
ENT	Service time	Gamma	6.59	0.477	$\alpha = 1.68, \beta = 3.29$ Threshold = 0.5
OBG	Service time	Gamma	5.57	0.238	$\alpha = 1.72, \beta = 2.87$ Threshold = 1.5
Ophthalmology	Service time	Triangular	2.93	0.575	Minimum = 1.5, Mode = 3 Maximum = 12.5

It is also to be noted that there were quite minimal differences between the mean square values of some of the closest distributions. Based on the above mentioned criteria the corresponding distributions were obtained. Table 2 provides the details of the various distributions fitted with the corresponding parameters. Figures 7-11 provide the corresponding probability density function for the various variables. It can be seen that density function plots are similar in shape to the histogram from figure 2-6, thereby justifying the choice.

Table 3. Expressions used in order to build the simulation model (time in minutes)

Section	Variable Considered	Expression
Admission	Inter-arrival time	$-0.5 + \text{GAMM}(2.06, 1.76)$
Admission	Service time	$0.5 + \text{GAMM}(1.04, 2.04)$
Billing	Service time	$0.5 + \text{GAMM}(1.04, 1.9)$
Prescription	Service time	$0.5 + \text{LOGN}(1.17, 0.928)$
Initial Test	Service time	$\text{TRIA}(0.5, 1.74, 3.5)$
Orthopaedics	Service time	$0.5 + \text{LOGN}(3.58, 2.25)$
ENT	Service time	$0.5 + \text{GAMM}(1.68, 3.29)$
OBG	Service time	$1.5 + \text{GAMM}(1.72, 2.87)$
Ophthalmology	Service time	$\text{TRIA}(1.5, 3, 12.5)$

Once the distribution is created the values are fed to the model using the expression given by the input analyzer. Table 3 provides details of the expression used in order to create the model. The simulation model using Arena software was built based on the distribution of data, constraints in the system such as departments, number of resources, resource availability and flow of patients. The output of the simulation model was analyzed to obtain the values pertaining to queue length, average waiting time, average service time and resource utilization. The results obtained for various sections of the OPD were compared and the sections with high queue length and those that were either over or underutilized were identified.

3. Results and Discussions

Simulation model was built as per the patient flow process and the expressions shown in table 3. Relevant modules were used for each service point encountered during the patient movement in OPD. Decision modules were created based on the data at sections such as at admission / registration, initial testing, department allocation and prescription. The simulation model developed is shown in figure 12.

The focus of this study was to understand the waiting time and utilization of resources such as doctors and supporting staff associated with each section. In order to build a simulation model for this process, the following time measurements are considered based on the literature. Inter-arrival time (i.e. time between arrival of successive patients) is measured at the beginning of the process, i.e. at admission section. Service time (time required to attend a patient by the resource stationed at that section) is measured for all other successive sections.

The model was run for 30 numbers of replicates for a single shift of OPD operation. The results obtained were recorded. Significant parameters such as patient waiting time and resource utilization were studied. Patient waiting time is an important aspect which has to be addressed by the hospital management as it impacts the satisfaction of the patient. Longer waiting times may have adverse effect on the patient satisfaction.

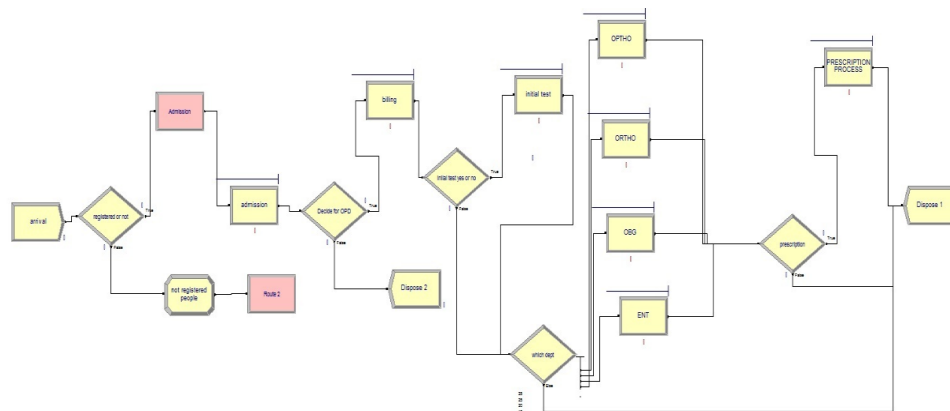


Figure 12. Arena simulation model of patient flow in OPD

Imbalance in resource utilization leads to uneven distributing of queue lengths and variation in patient waiting time across the sections. This leads to overall drop in system performance and hence induce stress in resources.

Also resource utilization needs to be addressed as over utilization may lead to fatigue in doctors and other staff which in turn may reduce their efficiency. Under utilization indicates wastage of resources and loss to the organization.

Table 4. Average waiting time, half width, minimum and maximum average times

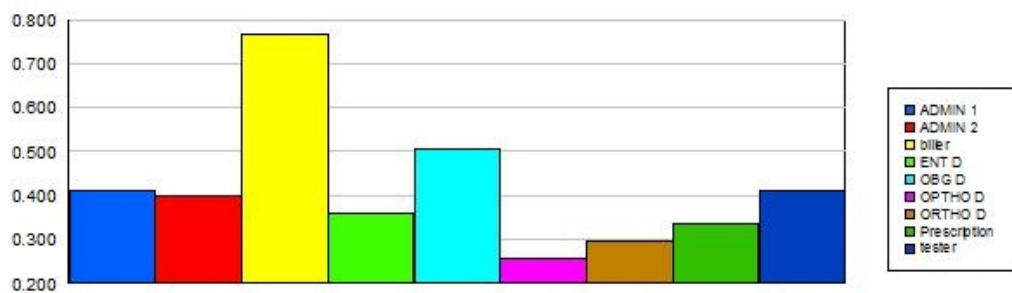
Section	Average waiting time (minutes)	Half Width	Minimum Average Time (minutes)	Maximum Average Time (minutes)
Admission	0.3119	0.06	0.1081	0.6904
Billing	4.5067	0.63	1.9673	8.5607
Prescription	0.3661	0.06	0.1304	0.7913
Initial Test	0.2774	0.04	0.1667	0.5660
Orthopaedics	0.8760	0.19	0.2701	2.5690
ENT	1.6822	0.42	0.2105	4.9511
OBG	3.8111	1.09	0.2893	13.7036
Ophthalmology	0.8758	0.28	0	3.4124

Table 4 shows the average waiting time, half width, maximum and minimum average time for the various section of the OPD. In Arena, output variability is reported via the half width, which is half of the 95th percentile confidence interval for the metric. It can be seen that in case of billing and OBG sections the average waiting time of patients is significantly higher than other sections. Also the half width at these sections is higher which indicates that there exists a high variability in the data.

Table 5 shows the utilization of resources at these sections. It can be observed that billing and OBG sections have high resource utilization compared to others. Resources which are not optimally utilized are to be streamlined to avoid over stressing of the doctors and other staff members. Figure 13 illustrates the comparison of resource utilization in various sections of the OPD.

Table 5. Resource utilization at various sections of the OPD

Section	Average Utilization	Half Width	Minimum Average Time (minutes)	Maximum Average Time (minutes)
Admission	0.4109	0.01	0.3569	0.4551
Billing	0.7681	0.02	0.6385	0.8478
Prescription	0.3373	0.01	0.2696	0.3977
Initial Test	0.4088	0.01	0.3393	0.4831
Orthopaedics	0.2967	0.02	0.1672	0.3977
ENT	0.3595	0.02	0.1938	0.5088
OBG	0.5055	0.04	0.2279	0.7092
Ophthalmology	0.2562	0.02	0.1312	0.3816

**Figure 13.** Comparison of Resource utilization in various sections of the OPD obtained from Arena results

4. Conclusions

This paper considered the Out-Patient Department of a hospital for studying the patient flow and issues related to waiting time and service time at various sections. Simulation model of the patient flow across the OPD was built considering the best fitting probability distribution. The results obtained the simulation model was analysed. It was observed that there was a higher waiting time at billing and OBG sections. Also the resource utilization at these sections was comparatively higher. This study was for the entire process covering all the sections and considering it as one system. The entire process was simulated based on the inter-arrival time at the admission section, which is the input station and service time at successive stations. To understand the variation within a section and from section to section, further investigation needs to be done by considering different scenarios and analyzing the obtained results. Reduction in patient waiting time will directly impact the satisfaction of the patients. Resource optimization to improve the efficiency of the doctors and staff can be further done after validating the model. The findings from further investigations can be used to improve the quality of service to the patients and improve the overall service of the hospital.

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