Simulation analysis of patient flow management using electronic health records

M.Tech Major -II Project Report

Submitted in partial fulfillment of
the requirements for the award of the degree
of
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in
Computer Science department
by

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under the guidance of

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CERTIFICATE

This is to certify that Project Report entitled **Simulation analysis of patient flow management using electronic health records** submitted by Shalini Sheoran (2K15/CSE/16) for partial fulfillment of the requirement for the award of degree Master Of Technology (Computer Science and Engineering) is a record of the candidate work carried out by her under my supervision.

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DECLARATION

I hereby declare that the Major Project-II work entitled **Simulation analysis of patient flow management using electronic health records** which is being submitted to Delhi Technological University, in partial fulfillment of requirements for the award of degree of Master Of Technology(Computer Science and Engineering) is a bonafide report of M.Tech Thesis carried out by me. The material contained in the report has not been submitted to any university or institution for the award of any degree.

Shalini Sheoran
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(Shalini Sheoran)

ABSTRACT

This project aims to improve the patient flow in the queues in crowded hospitals of developing countries, using portable electronic health records. Transforming government hospitals towards digitization has its own challenges due to high footfall of patients which results in huge data size. Queue management is very challenging task as the queue is not followed, there is corruption and instances of identity fraud coupled with poor management of patients' records. Portable electronic healthcare records facilitates high availability and high reliability as they provide real time access to patients records at point of care. Portable health records are highly beneficial in hospitals, especially in case of developing countries where people visit different hospitals for different specialists. Portable EHRs has the capability to strengthen the relationship between patients and physicians. The meaningful readily available updated data will help health service providers in making insightful decisions and will eventually lead to better services for patients. With portable EHR (Electronic Health Records) a patient can have his records with him all the time on a smart phone or a smart card. This leads to efficient maintenance, faster service rate of doctors and also help in eliminating any errors on pharmacists side. Also to ensure interoperability across hospitals, we have proposed FHIR(Fast Healthcare Interoperability Resources) based electronic healthcare records. The initial patient flow model is generated considering the general current work flow of the government hospitals. On the basis of analysis of current flow of patients, we propose an efficient work flow scheme to improve the patient flow further.

We have proposed a smart digital kiosk based registration process which is based on using of portable smart cards. The smart and efficient healthcare system proposed by us, along with reducing waiting time for patients also ensure authenticity of patients' identity. We have simulated, compared and anaylsed both present system and proposed system design on Matlab and have found through simulation results that proposed system performs better in many dimensions. It has improved the scheduling process and help the department to refine the work procedure for better service quality and efficient utilization of resources.

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Chapter 1

Introduction

1.1 Overview

In present times of heavy competition, hospitals and other health care clinics strive to provide high quality services to patients. Considering ever increasing costs, low level of reimbursement and frequently updated regulatory norms, push Health care organizations to innovate in order to deliver efficient and quality care [1]. For achieving highly efficient patient flow, we need to look at various parameters such as patient waiting time should be less along with low total turnaround time coupled with low doctor idle time and maintaining reasonable staff utilization rates. The following domains have a major impact on patient flow are resource availability, scheduling of appointment, patient queue scheduling and appointments, patient management and doctors schedule. For optimal resource utilization, reduced health care costs and overall improved patient queue management, discrete-event simulation is a efficient and important mechanism that helps in decision making. It helps in effectively managing insufficient healthcare resources.

Discrete event simulation

Discrete event simulation [2] is a method of classifying the behavior of a large complex system in the form of ordered sequence of well-defined events. Here, an event includes a particular change in the system's state at a particular instance of time. Discrete-event simulation also works as predicting tool to predict and examine the possible effect of modifications on patient queue flow, to analyze the complicated correlation among various system dimensions i.e. patient service delivery rate or patient arrival rate and also to evaluate resource allocation requirements i.e. in clinics' staff levels or in physical resources capacity .Discrete-event simulation is an operations research modeling methodology. Stakeholders of the system for example, clinic administrators or hospital management can examine the efficacy of present healthcare management systems, to ask "what if?" questions, and to plan future innovative healthcare service provider systems.

Hospital management and system analysts make use of such information to enhance system performance and design, designing new systems without changing present system. This kind of information is also helpful in identifying viable options that can be effectively employed to redesign the present methods used by hospitals. The usage of discrete event simulation (DES) for the evaluation of hospital service delivery systems is gaining popularity among healthcare administrators and decision makers as a suitable method for increasing operational efficiency and help in cost reduction [3]. Discrete event simulation is gaining popularity mainly attributed to continuous improvements in simulation software modules which helps in easy application to healthcare domain.

Portable Health Records

As healthcare domain is moving towards digitization rapidly, EHRs prove to be next big step in its progress. When these EHRs are portable [4] across devices, they facilitates high availability and high reliability as they provide real time access to patients records at point of care. Portable health records are highly beneficial in hospitals, especially in case of developing countries where people visit different hospitals for different specialists. Portable EHRs has the capability to strengthen the relationship between patients and physicians. The meaningful readily available updated data will help health service providers in making insightful decisions and will eventually lead to better services for patients.

For example, the portable EHR helps in improving patient healthcare in following ways:

- It improves the accuracy and clarity of medical records and thus resulting in fewer medical errors.
- Portable EHRs keep patients well informed, helping them in taking timely decisions.
- Portable EHRs reduces duplication of efforts thus leading to faster and better treatment for patients.

1.2 Motivation

The smart environment contextualizes it's action according to its surrounding entities. It has the capability to influence total behavior of entities present in the environment. Considering ever increasing costs, low level of reimbursement and frequently updated regulatory norms, push healthcare organizations to innovate for delivering efficient and quality care. In present times, quality of services in national healthcare has become a important issue mainly attributed to the growing pressure to improve quality coupled with heightening patient burden. Hospitals are huge complex systems with indispensable social requirements and large cost structure. These costs are escalated due to inefficient hospital management processes, which are mostly due to overcrowding accompanied with long delays in access to healthcare services. Hence, a queuing-network is beneficial in analysis of hospital queuing system and in performance improvement.
The Quality of Service in healthcare usually includes two dimensions: efficient and quality service delivery and management of healthcare data.
Refining patient flow helps to improvise health services. An systematic and improvised patient flow has the ability to enhance the quality of services (QoS) and better usage of scarce resources. A smart environment can provide the patients a better experience in a hospital environment. Wireless sensor networks (WSN) [5] and smart hospital systems helps in building a smart hospital environment, having efficient capacity utilization scheme and better quality of services(QoS). The research follows a systematic modeling approach that could facilitate a quantitative analysis of given healthcare system.

With this project we aim to improve the patient flow in the queues in crowded hospitals of developing countries, using portable electronic health records. Transforming government hospitals towards digitization has its own challenges due to high footfall of patients which results in huge data size. For our project we have taken cue from workflow at RP(Rajendra Prasad) centre to simulate real world scenario. Presently for registration is paper based at AIIMS [6] and long queues are formed at registration counters. Manual registration system and paper based records have problems associated with them such as problem of identity fraud as bar codes could be copied, also there is lot of corruption during lines formed for doctor's consultation, increase in consultation time as paper based records are not managed properly by patients generally.

Hence, there are lot of problems associated with manual registration system and paper based records. So as a part of this project we have tried to mitigate some of these with smart registration process and usage of FHIR based portable records

Health records when stored and maintained in a proper format can lead to a varied amount of benefits. The portable electronic interoperable health records can help in diagnostics of patients going through the same ailment that has been cured before. The mapping of the behavioral health data can, not only help doctors in proper diagnostic of complex behavioral disease, but also for the patients who desperately search for a way out of their situation. The presence of an portable EHR system, that is compatible across hospitals, labs, chemists, crosses geographical boundaries, will revolutionize the way health system works in India. The driving factor behind this study was to devise a efficient queuing system for efficient flow management system and also explore the already existing standards, compare and contrast them with the latest one and prepare an interface to electronically map data into such a standard.

These technologies help to collect useful information to support a decision making process provided by a smart healthcare system. These FHIR [7] based portable electronic health records are syntatic and semantic interoperable. These records have a uniform vocabulary across various systems. These records are portable on various mobile devices. Portability of electronic health records help both medical professionals as well as patients in maintaining consistency in records.

1.3 Problem Statement

The main objective of this research work is to improve the scheduling process and help the department to refine the work procedure for better service quality and efficient utilization of resources. For ensuring that the results can be applied systematically to a real world scenario, we use simulation to develop workable models based on hospital setup and consider the stochastic variability of patient arrival, processing time, need for investigative tests and treatment events, and processing time. As part of smart healthcare management system proposed by us, we also propose a FHIR based portable electronic healthcare records.

With portable EHRs (electronic health records) a patient can have his records with him all the time on a smart phone or a smart card. This leads to efficient maintenance, faster service rate of doctors and also help in eliminating any errors on pharmacists side. We explored in depth the most recent healthcare Standard for end to end connectivity. FHIR based portable records are syntactic and semantic interoperable and can be used across the departments and hospitals. We have simulated both current system in place and our proposed system and have done analysis of both. A simulation approach allows us to model and analyze complex hospital processes which are otherwise intractable with analytical queuing models.

Chapter 2

Literature Review

2.1 Different Queuing Models

The main componenets of a queuing model are: the number of patients and the process or service system itself [12]. Delay in service is affected by the design of the queuing system. There are various components of a queuing system such as number of patient, service rate, arrival rate, and the scheduling methodology used for managing the queue and the hospital service system itself.

1. The Patient Population
The number of patients can be fixed or indefinite number. The population is considered to be finite, when new patients waiting in the queue are impacted by the no. of patients curently present in the hospital. And on the other hand, patient population is takes as infinite, when number of newly generated patients are not significantly impacted by number of patient already waiting in the queue.

2. The Service System
The service system is characterized by the service scheduling methodology, the arrangement of the servers, total number of queues, the total number of servers, the service rate and arrival rate patterns.
- The Number of Queues: Queuing systems can have single or multiple lines. Banks generally have multiple lines for customers. Patients in a hospital system wait in the queue until the doctor is available and subsequently proceed to doctor when their turn comes.

- The Number of Servers System serving capacity can be determined by two factors i.e. server proficiency and no. of service counters. Queuing systems can be either single-server (single-channel) or multi-server (multi-channel).

Multi-server systems use multiple simultaneous service providers offering the exact same service. The Arrangement of the Servers Services need a single activity or a series of activities and are identified by the term phase.

- The Arrangement of the Servers:
Services require a single activity or a series of activities and are identified by the term phase. In a single-phase system, the service is completed all at once, such as with a bank transaction or a grocery store checkout. In a multiphase system, the service is completed

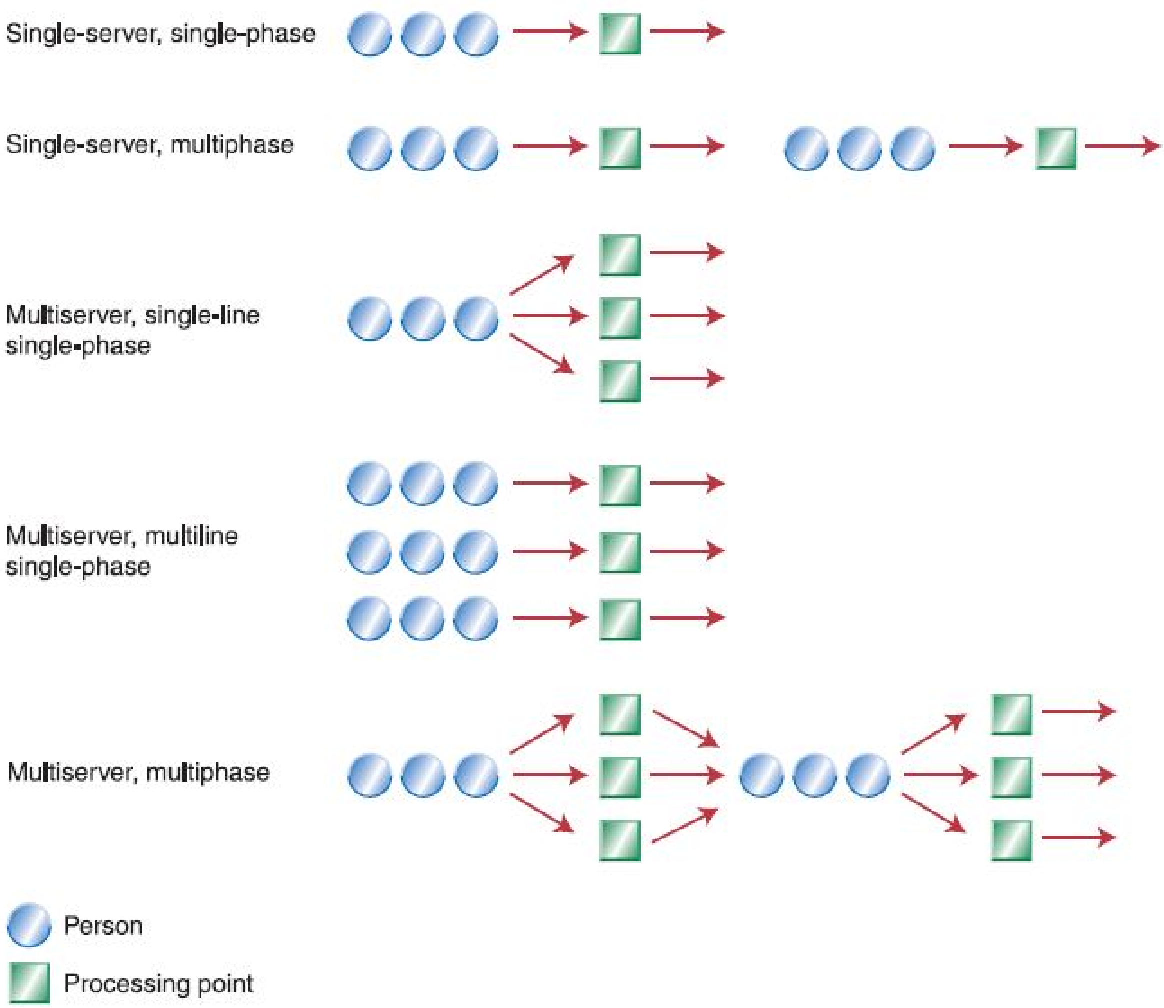

Figure 2.1: Examples of various Queuing systems

in a series of steps, such as at a fast-food restaurant with ordering, pay, and pick-up windows or in many manufacturing processes. In addition, some queuing systems [13] have a finite size of the queue. Sometimes this happens in multiphase systems.

Arrival and Service Patterns:

- Arrival rate: The average number of patients arriving per time period.

- Service rate: The average number of patients that can be served per time period. It is the difference in arrival rate and service rate which leads to Queues. Queues are formed when at the same time many patients request for service. A Queue develops when there is temporarily surge in number of patients, which in turn results in overloading of the service system. Queuing models that assess the performance of service systems usually assume that patients arrive in the system according to the Poisson probability distribution [14], and service times are represented by an exponential distribution. The Poisson distribution gives the probability that a specific number of patients will arrive in a given time period, say per hour. The exponential distribution specifies the service times as the probability that a particular service time will be less than or equal to a given amount of time.

Queuing system priority rules:
Queuing system priority rule determines next patient to be served by the system [15]. A most commonly used priority rule is - first come and first serve. This scheduling rule selects patients based on their arrival time. The one who arrives first is served first. Generally, first-come, first-served is considered as a fair method by most patients for determining priority. However, there are many other criterion which are used. Such as giving priority to child patients first, highest-risk patient first, emergency patient first [9], old age patients, and so on. While every priority rule has its own merits and demerits, one should opt for criteria that suits most to a organization's needs. For example, a first-come, first-served rule is not ideal case for a hospital emergency room and it could cause unnecessary deaths [8]. Although, first-come, first serve is mostly considered fair, yet it is biased against patients requiring short service times.

Different performance measures are used to gain useful information about queuing systems. These performance measures are:
1. The average no. of patients waiting in a queue and in the system. The number of patients waiting in line can be interpreted in several ways. Constant arrivals of patients can result in short waiting lines i.e. when there are no spikes in demand for resources or when the system has excess resources. Otherwise, low resource availability, long queues and low server efficiency and significant surges in demand can lead to increase in waiting times of queues.

2. The average time patients spend waiting, and the average time a patient spends in the system. Patients generally link high waiting time to mismanagement and low quality service. Here the smart technology solutions can help to a great extent in reducing the average time a patient spends inthe hospital. Also alternative option could be to alter the demand pattern, when long waiting times occur.

3. The system utilization rate. System utilization rate depicts the percentage of time the servers are busy.

We calculate these measures for two different queuing models: the single-server and multi-server. The easiest waiting line model involves a single-server, single-line, single-phase system.

2.2 Discrete Event Simulation

Discrete event simulation allows the user to define the system, evaluate service and arrival patterns, and various other dimensions of the system. The simulation helps to replicate the actual behavior of the system in reality, and the results are evaluated to determine system performance. Discrete event simulation utilizes a mathematical/logical model of a physical system that portrays state changes at precise points in simulated time. Both the nature of the state change and the time at which the change occurs mandate precise description. Patients waiting for service, the management of parts inventory or military combat are typical domains of discrete event simulation. Each event occurs at a particular instant in time and marks a change of state in the system. Between consecutive events, no change in the system is assumed to occur; thus the simulation can directly jump in time from one event to the next.

In queuing theory, a discipline within the mathematical theory of probability, an M/M/1 queue [16] represents the queue length in a system having a single server, where arrivals are determined by a Poisson process and job service times have an exponential distribution. The model name is written in Kendall's notation.

Model Definition
The M/M/1 model is most basic of various queuing models available and an promising object of study. For many metrics of interest in this model a closed-form expressions can be obtained . M/M/c queue is the extension of this simple model, this model has c no. of servers, where c is greater than 1.

An M/M/1 queue is a stochastic process whose state space is defined by set 0,1,2,3,... here the values in set is the no. of patients present in the system, it also includes currently in service.

$1/\mu$ is the mean service time.

The process moves from state i to i+1 and arriving of patients occur according to poisson distribution function at rate λ. Rate parameter is μ in M/M/1 queue and service times are determined according to exponential distribution.

A single server serves patients one by one from the front of the queue, according to a first come, first serve priority rule. No. of patients reduce as patients leave the hospital on completion of service.

Transition of states in M/M/c waiting lines and corresponding probability
For M/M/c queues, service rate depends on the no. of servers [2] and the arrival rate is similar to M/M/1 waiting lines. The service rate of system would be nμ for n less than equal to c. As soon as the no. of patients is more than c, the service rate will be μc as depicted in below figure.

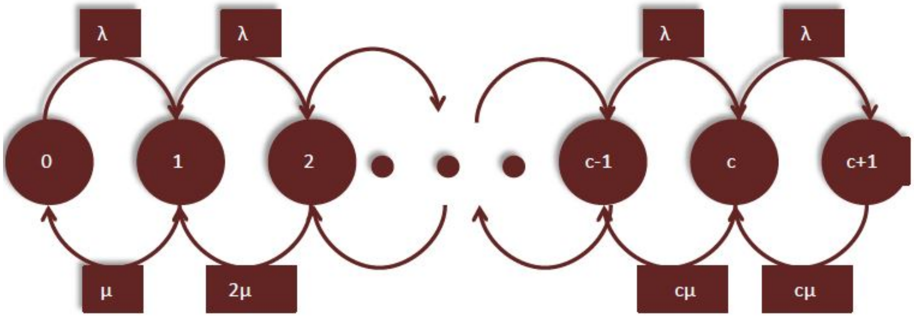

Figure 2.2: Service Rate of Patients

The service rate of the system, μ_c here would be,

$$\mu_c = \begin{cases} (n\mu) & n < c, n = 1, 2, 3, ... \\ (c\mu) & n > c, n = c, c+1, c+2, ... \end{cases}$$

The probability of having n patients in the service system can be written in same method as for M/M/1 model but with revised service rate.

$$P_n = \left(\frac{\lambda}{\mu_c}\right)^n \times P_0$$

Or $$P_n = \begin{cases} \left(\frac{\lambda^n}{\mu(2\mu)(3\mu)............(n\mu)}\right) P_0 \text{ if } n < c \\ \left(\frac{\lambda^n}{\mu(2\mu)(3\mu)............(c\mu)(c\mu)^{n-c}}\right) P_0 \text{ if } n \geq c \end{cases}$$

$$P_n = \begin{cases} \left(\frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right) P_0 \text{ if } n \leq c \\ \left(\frac{1}{c!}\left(\frac{\lambda}{\mu}\right)^c \left(\frac{\lambda}{c\mu}\right)^{n-c}\right) P_0 \text{ if } n > c \end{cases}$$

Performance measures of M/M/c Queuing model

First, we will determine the number of patients in the queue, L_q. In a system, there will be no queue formed till the number of patients are less than or equal to the number of servers. The patient will enter in the queue when on the arrival in the system a patient will find all the servers busy. Hence, n-c represents the number of patient in the queue. We can write L_q as given below.

$$L_q = \sum_{n=c}^{\infty} (n-c) P_n$$

To determine Lq, substitute j=n-c or n=c+j in the above equation as shown below.

$$L_q = \sum_{n=c}^{\infty} (n-c) P_n$$

Pc+j can be written as,

$$P_{c+j} = \left(\frac{\lambda}{\mu} + \frac{\lambda}{2\mu} + ... + \frac{\lambda}{c\mu}\right) \left(\frac{\lambda}{c\mu}\right)^j P_0$$

which can be again written as,

$$= \left(\frac{\rho^{c+1}}{c!Xc^j}\right) X P_0 X \frac{\partial\left(\sum_{j=0}^{\infty}\left(\frac{\rho}{c}\right)^j\right)}{\partial\left(\frac{\rho}{c}\right)}$$

$$= \left(\frac{\rho^{c+1}}{c!Xc^j}\right) X P_0 X \frac{\partial\left(\frac{1}{1-\frac{\rho}{c}}\right)}{\partial\left(\frac{\rho}{c}\right)}$$

$$L_q = \left(\frac{\rho^{c+1}}{(c-1)!(c-\rho)^2}\right) P_0$$

After determining $\mathrm{L_q}$, using Littles law we can determine the waiting time in the queue $\mathrm{W_q}$ as shown below.

$$W_q = \frac{L_q}{\lambda}$$

Patients waiting in the service system will be sum of $\mathrm{W_q}$ and service time.

$$W = W_q + \frac{1}{\mu}$$

The number of patients in the service system,

$$L = \lambda W \quad (Using \quad Little's \quad law)$$
$$= \lambda W_q + \frac{\lambda}{\mu}$$

2.2.1 Poisson Distribution

The Poisson distribution [16] is a discrete event probability distribution that keeps track of no. of events that occurring randomly for a given period of time or space.
If say X = The no. of events occurring in the system in a given period,
And, if the average no. of events for a given period of time is λ,
The probability of observing x events in a given interval is given by where λ is the average number of occurrences per unit of time λ = np.
Condition for Poisson distribution Poisson distribution is the limiting case of binomial

$$P(X = x) = e^{-\lambda}\frac{\lambda^x}{x!} \qquad x = 0, 1, 2, 3, 4, \ldots$$

distribution under the following assumptions:
1. The probability of success p for each trial is indefinitely small.
2. The number of trials n should be indefinitely large.
3. np= λ , should be finite where λ is constant.

Properties of Poisson distribution
1. Poisson distribution is defined by single parameter λ.
2. Variance = λ .
3. Mean = λ. Mean and Variance are equal.

Examples
The Poisson distribution is used to depict events such as: The number of meteors more than 10 m radius which strike Earth in a given year. The no. of patients that arrive in the emergency department between 2 and 4 am.

When is the Poisson distribution an appropriate model
The Poisson distribution is most suitable model if the following assumptions are true:
• The rate at which events occur is constant. The rate cannot be higher in some intervals and lower in other intervals.
• K is the number of times an event occurs in an interval and K can take values 0, 1, 2,....
• The occurrence of one event does not affect the probability that a second event will occur. That is, events occur independently.
• Two events cannot occur at exactly the same point of time.
• The probability of an event in a small interval is proportional to the length of the interval.
Or
• The actual probability distribution is given by a Binomial distribution and the number of trials is sufficiently bigger than the number of successes one is asking about (see Related distributions).
• If these conditions are true, then K is a Poisson random variable, and the distribution of K is a Poisson distribution.
A Poisson random variable can take on any positive integer value.

2.3 Electronic Health Records (EHR)

An Electronic Health Record (EHR) is an electronic version of a patients past medical records, which is maintained by the hospitals, and it contains various key healthcare data records important for a patients' care under a specific healthcare provider. Records mainly consists of vaccinations, demographics, diagnosis, problems, medicines, vital health signs, previous medical records, laboratory report data and MRI scans, etc. Electronic health records have the capability to make physicians' workflow efficient and also can automate access to useful information. Also, at the same time, the EHR has the capability to maintain several healthcare-related activities, using different kind of interfaces such as outcome dependent report generation, proof based decision-support system and quality assurance.

For sharing healthcare records data and also maintaining the medical logic of a users' made contributions within it, interoperability standards are needed to meet these requirements. In present times, patients also desire to participate actively in their own health related data management, so they want to have access to their own up to date EHR data [17]. Since, in present times, the pivot is shifting more towards personal space of patient from community hospitals and specialist settings, electronic health records have become more important.

2.3.1 HL7

HL7 (Health Level 7) [18] is message exchange protocol that facilitates healthcare applications to exchange information. In healthcare domain, data exchange is a very challenging task since each application and user is in their own unique domain with no compatibility among data-sets.

HL7 Version 2 is most widely adopted health information exchange standard. It uses "segments" to represent data. HL7 V2 is granular in approach and focused on reusable components. However V2 does not support semantic interoperability. It lacks a formal approach for defining data standards, well defined application and data model. Yet it is a big step towards standardizing health information exchange.

HL7 version 3 [18] introduced a data type model,common reference information model a set of vocabularies along with health standards development strategy. FHIR is more closer to HL7 V3 as it also built on RIM model. HL7 stores data in XML format. It is more closer in approach towards a formal methodology, defined data models. However it is not backward compatible with V2.

FHIR is built upon HL7 version 2 and version 3 and is next step in moving towards standard semantic and syntatic interoperable electronic health records.

2.3.2 Fast Healthcare Interoperability Resources

FHIR (Fast Healthcare Interoperability Resources) is a draft standard which describes resources and data formats. It defines an Application Programming Interface (API) for processing and storing Electronic health records (EHR). Health Level Seven International (HL7) health-care standards organization created this standard.

FHIR is next step towards achieving standardization and it is next verion of standards like HL7 [19] version 3.x and HL7 version 2.x. It employs latest internet-based suite of

API technology. Also it has HTML and Cascading-Style-Sheets for user interface integration, a HTTP-based RESTful protocol, JSON/XML for data representation, and Atom for results. It provides interoperation among legacy health care systems. It facilitates in providing health care information to health care professionals and organizations on a diverse set of devices such as mobile phones, computers, various other hand held devices. It also facilitates in developing third-party applications, and these applications are compatible with present systems and provides easy integration with legacy applications.

FHIR defines discrete data elements as services and thus provides an alternative approach to document-centric methods. Resource URLs are used to retrieve and change the essential components of healthcare domain such as patients' bio-data, lab reports, diagnosis and medicines.

Resource is the basic element of FHIR. All exchangeable data is defined in the form of a resource. These set of characteristics are shared by all resources:
-The same set of metadata.
-The common method to define and represent resources. FHIR builds them from data types which define common reusable patterns of elements.
-The human readable part.

The FHIR Resource is similar to a V3 Common Message Element Types (CMET) or an HL7 Version 2.x Segment. FHIR Resources are:

- Simple every resource is self explanatory and can be implemented without any additional tools or infrastructure.
- Granular these resources have a transaction scope of their own and are the smallest unit of operation.
- Independent In order to understand the content of a resource, references to other resources is not required.
- Flexible resources can be moved in and out of RESTful paradigms as required and can also be used in other contexts, such as SOA architecture, messages or document.
- RESTful resources can be used in context of RESTful exchange.
- Extensible resources can be extended without impacting on interoperability, for using in local requirements
- Web Enabled open internet standards are used in FHIR for data representation
- Open Source the FHIR architecture and specification is implementes as open source and thus anyone can implement FHIR or derive related specifications without any IP restrictions.

FHIR Architecture and Implementation

Fast Health Interoperable Resources (FHIR) is the most recent standard from HL7 [19]. Some of its most striking features are support of built-in terminologies and for popular

web standards and the user friendly implementation.
The Fast Interoperability Healthcare Resources (FHIR) has been proposed as the solution for overcoming the implementation and learning curves integrating the HL7v3-based technologies. It encompasses Application Programming Interface (API) technologies, which includes a Hypertext Transfer Protocol (HTTP)-based full Representational State Transfer (RESTful) protocol, HyperText Markup Language (HTML) and Cascading Style Sheets (CSS) for user interface integration. FHIR data can be represented in XML or JavaScript Object Notation (JSON). The open protocol OAuth was chosen for authorization and Atom, the default format for the Google Data Protocol, for query results [7].

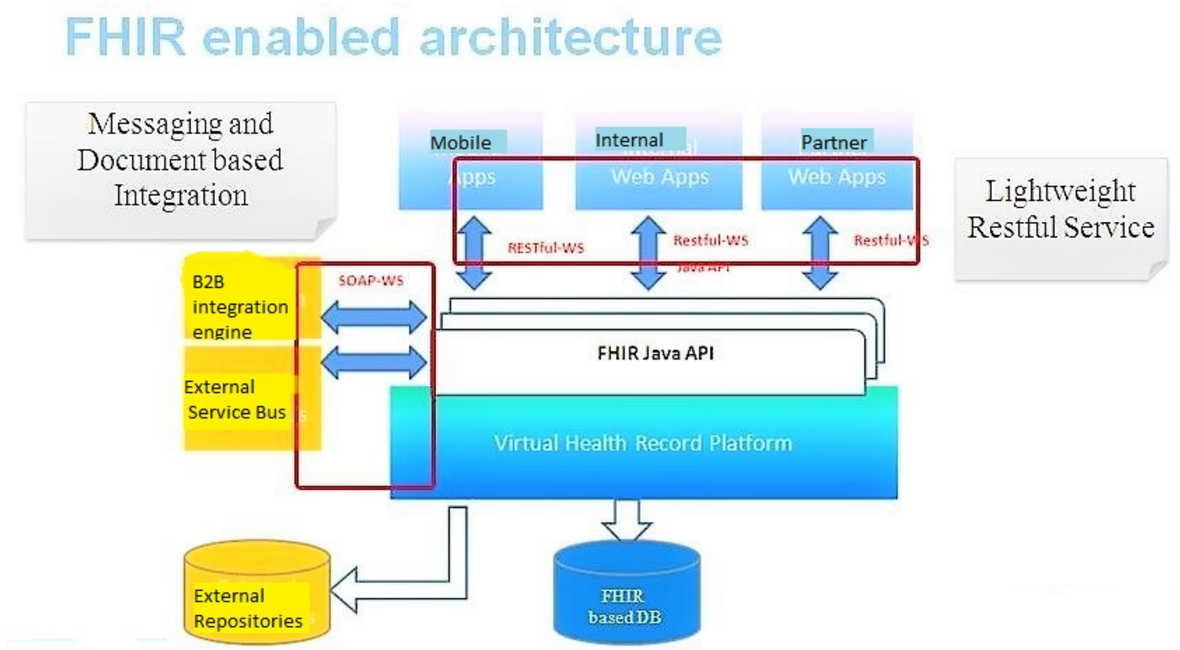

Figure 2.3: FHIR Enabled Architecture
[18]

Sample FHIR data

Observation Example


```xml
<Observation xmlns="http://hl7.org/fhir">
  <id value="observation-example-eeg.xml"/>
  <meta>
     <versionId value="1"/>
     <lastUpdated value="2016-11-10T12:18:59.401+05:30"/>
  </meta>
  <text>
     <status value="generated"/>
     <div xmlns="http://www.w3.org/1999/xhtml">Sept 17, 2012: Systolic
Blood pressure 107 mmHg (normal)</div>
  </text>
  <status value="final"/>
  <subject>
     <reference value="Patient/p1"/>
  </subject>
  <valueSampledData>
     <origin>
        <value value="0"/>
        <system value="http://unitsofmeasure.org"/>
        <code value="uV"/>
     </origin>
     <period value="100"/>
     <factor value="2.5"/>
     <dimensions value="1"/>
     <data value="-4 -13 -18 -18 -18 -17 -16 -16 -16 -16 -16 -17 -18 -18 -1
-17 -16 -16 -16 -15 -13 -11 -10 -10 -9 -6 -4 -5 -5 -3 -2 -2 -1 1 2 7 8 9 10
11 12 13 15 17 19 21 23 25 27 29 30 30 31 34 37 40 43 45 4 46 46 46 46 47
49 51 53 55 57 59 60 59 58 58 58 57 56 56 56 57 57 5 53 50 47 45 74 51 38
33 31 2 25 21 16 14 15 13 9 7 4 1 -1 -3 -4 -6 -10 -12 -13 -12 -12 -17 -18 -
18 -18 -19 -20 -21 -20 -20 -20 -20 -2 2 1 0 0 0 1 2 2 1 1 1 0 -1 0 1 1 1 1
2 E"/>
  </valueSampledData>
 </Observation>
```


Figure 2.4: Observation Example

Semantic Interoperability

If two or more systems are capable of communicating with each other, they exhibit **syntactic interoperability** when using specified data format, communication protocols. With the advent of standards like xml, sql which are accepted for systems independent of software or architecture, achieving Syntactic interoperability has become simpler [20]. Since our data in FHIR are XML formatted structured data, Syntactic interoperability has been achieved.
Semantic Interoperability is defined as integration of resources which are developed using different set of vocabularies and different user perspectives on the given data. In order to achieve semantic interoperability [17], hospital systems should be able to exchange data through such method that the most accurate meaning of the data is easily available and the data itself can be translated by any system into a form that it understands.

For presently implemented health informatics standards, this is represented by two sets of semantic resources proposed for recording health data:

- Information models - Provide standardized structure such as entry, section, cluster, etc. and context such as medicines, diagnosis, previous medical records for the data obtained for a particular situation at a specific point of time. Information models are representational components of the system

- Vocabularies - is a mechanism to define and provide systematic meaning of terminologies that provide standard meanings of terms, with the common distinctions between ontologies that gives descriptions of the related properties and relations of domain entities, as defined by domain terms, thesauri that provides semantic relations among a set of terms and classifications of terms that facilitates exhaustive partitions for analytical applications.

FHIR is a highly standardized version with clear codes on how the data should be structured. it is has semantic interoperability. Because of structuring of data into resources and usage of rest API's. this is possible.

Chapter 3

Related Work

In the healthcare domain, improvement in patient queuing system has always been part of research. With the advent of latest technologies, such as Internet of things, smart environment, big data, cloud computing, and others, there are wide improvements and a lot of research is going on in patient flow management with the help of these technologies.

Shao et al. [8] have proposed a workflow of surgical operations in order to reduce the disturbance by designing a Continuous-Time-Markov-chain (CTMC) model and then they have solved Markov chain to conduct the related performance analysis. CTMC model has the capability to anticipate system performance in future on the basis of properties mentioned in the Markov process. This paper uses CTMC to directly generate the model using CTMC. The drawback of such direct modeling approach comes from the state-space explosion problem when a system has complex behaviors or large number of instances. For this specific reason, PEPA is used to model the patient flow.

Chong et al. in their research work [9] have proposed a dynamic approach for demonstrating strategy used in complicated scenarios of hierarchical and societal frameworks. For evaluating efficiency, they have analyzed patterns of various quality and safety results in the Emergency ward of hospital, for ensuring the end goal to assess the efficiency of hospital systems. Similarly our research work also tries to improve efficiency of hospitals but we have used portable health records to achieve efficiency in the system.

M.Fam et al. in their research work [10] have taken Wuhan Smart Health as a case to describe the typical smart health construction mode in big city of central China. They have described one network dedicated network for smart health and common platform for all services, i.e. a smart health information platform, which is the core of the whole project. It contains the municipal and district information platforms, and three kinds of smart health cloud services (healthcare, public health, medical management). The former needs cloud computing and cloud storage technology; the latter is based on the EMR and EHR database. However, in their Wuhan smart health care system nowhere they have considered portability and interoperability of electronic health records.

Nikakhtar et al. [11] in their research work have used simulation techniques to examine various aspects of patient queue management. They have also evaluated the patient flow in a particular social network and the various network characteristics corresponding to it. They have proposed a simulation model to mimic the proposed patient queue and have analyzed its performance. However, there are also some drawbacks of simulation such as, when there are huge number of instances, or when the target model of simulation has complex behavior and complex system interactions, then debugging of such complicated system becomes difficult. Also at the same time it is very time consuming process. Thus, a systematic approach could prove to be better for maintaining high efficiency in building large and complex models and generating efficient and comparable analysis.

In their work J.feng et al. [10], have analyzed a discrete-time queue to study hospital inpatient flow management, where the customer count process captures the inpatient census. They have used Steins method framework, to identify a continuous random variable to approximate the steady-state customer count. The continuous random variable corresponds to the stationary distribution of a diffusion process with state-dependent diffusion coefficients. Simulation of queue is done in Matlab by the authors. Here the authors have tried to simulate optimized discrete queues in hospital environment but have not focused on other aspects of healthcare facilities like data management and resource utilization.

In their research work Yom-Tov et al. [14] have analyzed a queuing model that named as Erlang-R, where the R stands for reentrant customers. Erlang-R accommodates customers who return to service several times during their stay within the system, and is used in time-varying environments. It is based on healthcare systems, in which offered-loads vary over time and patients often go through a repetitive service process. Erlang-R, which accommodates returning customers in a time-varying environment. Although the authors have restricted them to one scenario in queuing model, but the model proposed by authors provides insights in queing processes in healthcare systems.

In all the above research work, portability of records for queue management is not considered. Also identity frauds are not considered that are prevalent in crowded hospitals of developing countries. Our research adopts a systematic approach to design optimal method for queue management using portable electronic records. Also, we have performed a simulation analysis of the proposed system in Matlab and compared it with existing system. The main issue in the ophthalmology department is to improve the quality of service by redesigning the scheduling process in the queue, and to make available all the records of patients available all the time.

When these EHRs are portable across devices, they facilitates high availability and high reliability as they provide real time access to patients records at point of care. Portable health records are highly beneficial in hospitals, especially in case of developing countries where people visit different hospitals for different specialists. Portable EHRs has the capability to strengthen the relationship between patients and physicians.

Portable smart health card facilitates high availability and high reliability as they provide real time access to patients records at point of care. The use of smart cards could improve serving efficiency by scheduling patients in terms of the real time status. Furthermore, we also propose an efficient queuing for the allocation of patients for each position in the department. The dynamic scheduling policy that takes into account separate category of patients requiring early attention which helps in improve the efficiency and utilization of consulting service and reduce patient waiting queue.

Chapter 4

Proposed Work

4.1 Present workflow of system

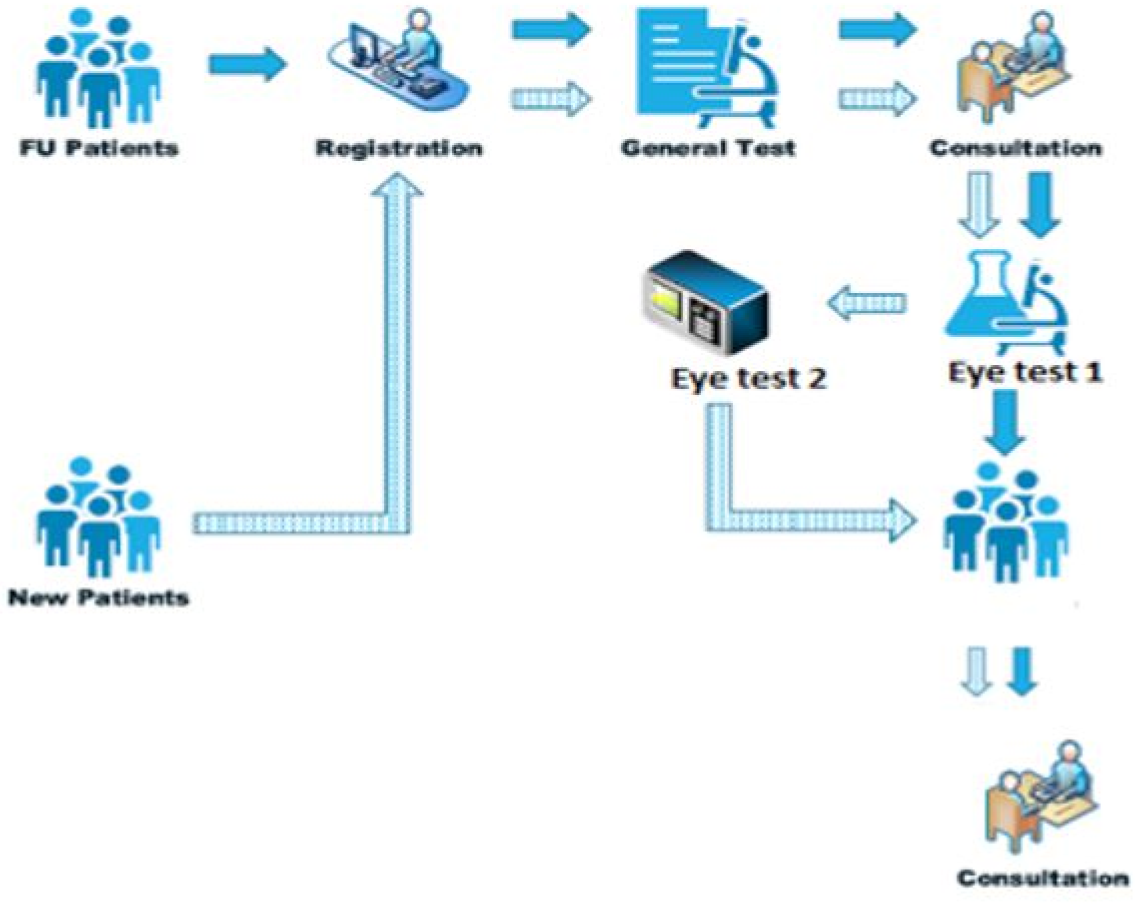

Figure 4.1: General flow of patients in department

Dr. Rajendra Prasad (RP) Centre for Ophthalmic Sciences [6] is department under All India Institute of medical Sciences(AIIMS). For our project we have taken cue from workflow at RP centre to simulate real world scenario.

Presently for registration is paper based at AIIMS and long queues are formed at registration counters. The paper registration slips contain bar code on them and these bar codes are scanned at counters.

After going through patient flow in RP Centre for ophthalmology, we are able to devise a generic flow of patients. In this flow firstly two types of patient queue on registration counters one is new patients and another one is follow up patients. Since the registration time is from 9 AM to 11 AM. At any given time there are around 10-15 patients at each counter. Which leads to long waiting time for patients. After registration patients line up for consultation with doctors, from where they are directed to get different tests done, where again queues are formed. And here also due to mismanagement of queues and non compliance of queue [21], long queues are formed and leads to wastage of resources.

There are various drawbacks of using manual registration system and paper based records such as :
- Problem of identity fraud as bar codes could be copied and are not secure against frauds.
- Also there is lot of corruption during lines formed for doctor's consultation.
- There is no provision for giving priority to old age or child patients.
- Queue which is supposed to work in first come first serve manner is not followed.
- Patients usually forget or loose their medical records.
- Lot of resource wastage as patient need to go for tests again due to loss of lab reports.
- Long waiting times hence leading to long queues.
- Increase in consultation time as paper based records are not managed properly by patients generally.

Hence, there are lot of problems associated with manual registration system and paper based records. So as a part of this project we have tried to mitigate some of these with smart registration process and usage of FHIR based portable records [4].

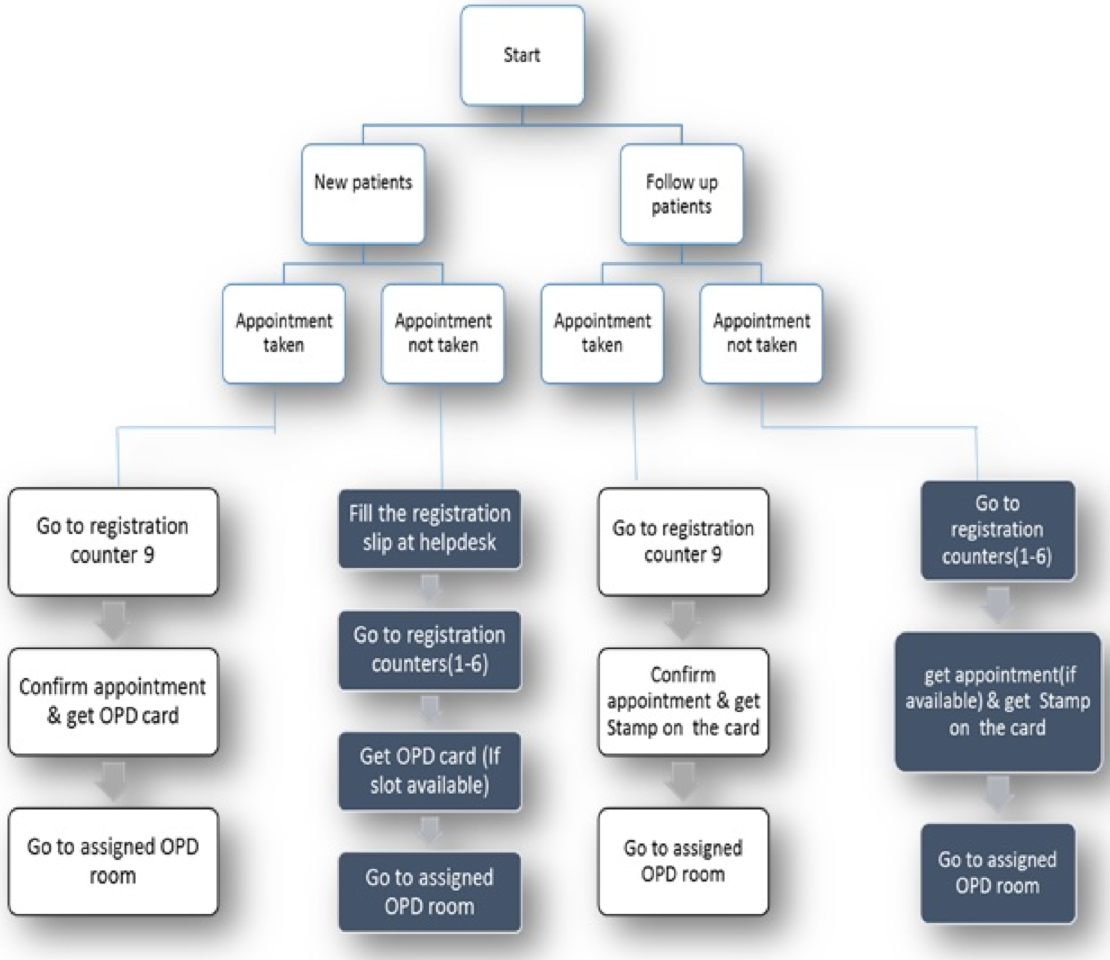

Figure 4.2: Current registration process

4.2 Proposed workflow of system

In our research work, the patient flow is modeled for the queuing of patients in order to generate a performance analysis by measuring patient waiting time in queue in the department. On the basis of analysis of current flow of patients, we intend to propose an efficient work flow scheme to improve the patient flow further. The initial patient flow model is generated from the current work flow of the RP Centre for ophthalmology department of AIIMS. The main goal our research work is to improve the scheduling process and help the department to refine the work procedure for better service quality and efficient utilization of resources.

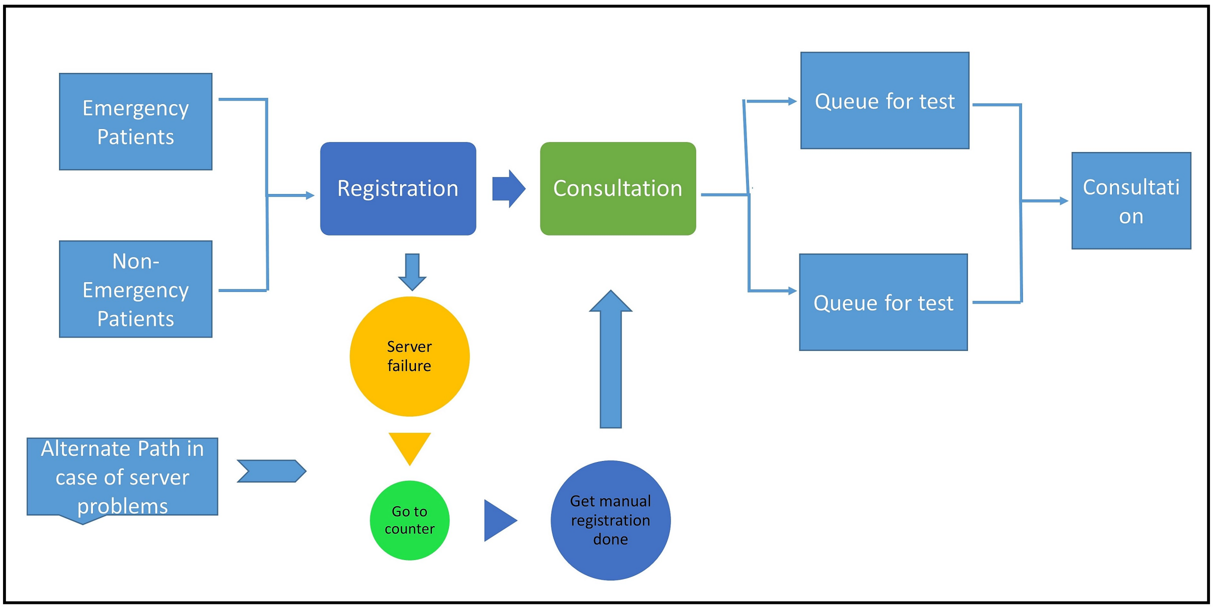

Figure 4.3: Proposed work flow of department

Main components of our research work:-

4.2.1 Smart Registration process

We propose a smart queuing system in which patient after taking appointment online or from any of 5 available methods i.e. web portal, IVRS, mobile app, call centre or AIIMS counter can go directly to self -service Kiosk where they tap their portable smart cards [4]. This has more efficient scheduling ability to avoid long waiting queues in the registration counters. The simple tapping of smart cards on kiosks will prove to be very efficient in managing long and mismanaged queues that build up in hospital premises. Portable smart health card facilitates high availability and high reliability as they provide real time access to patients records at point of care. The use of smart cards could improve serving efficiency by scheduling patients in terms of the real time status. Furthermore, we also propose an efficient queuing for the allocation of patients for each position in the department.

We have proposed a smart registration process as a part of our research work. Here every patient after taking appointment online needs to just scan their smart cards on automatic registration kiosks set up at hospital and a queue number will be assigned to that patient for the corresponding department. All the patient data is stored on a private cloud [21] of hospital. As soon as patient registers at kiosk data is synced with consultant's system informing him/her about upcoming patients and also queue numbers could be displayed at LCD screen for maintaining transparency in the system and efficient management of system. Also smart health card provides for privacy of patients' electronic health records along with portability of records across devices.

Figure 4.4: Registration using smart kiosk

NFC (Near Field communication)
NFC [22] is wireless technology that provides simple interfaces for device to device communication along with access to NFC, RFID and smartcard tags. NFC enabled mobile device can operate in three modes: i) Reader mode: in which device can read and write to NFC based passive tags. ii) Peer to Peer (P2P) mode in which NFC devices can interact and exchange information with each other iii) Card emulation mode: in which NFC device can operate as a contactless card.

Security Feature
Also, to ensure authenticity and validation of identity, in our proposed system we have put an additional measure of validating identity by fingerprint of patient at kiosk and matching it with Aadhar data. With the help of this measure identity frauds could be stopped at hospitals.

4.2.2 Portable Health Records

As part of smart healthcare management system proposed by us, we also propose a FHIR based portable electronic healthcare records. FHIR based portable health records are syntactic and semantic interoperable and can be used across the departments and hospitals. FHIR also supports portability of records across sub-systems [7]. With portable EHR (electronic health records) a patient can have his records with him all the time on a smart phone or a smart card. This leads to efficient maintenance, faster service rate of doctors and also help in eliminating any errors on pharmacists side.

FHIR also facilitates security of electronic records by providing authentication, access control and audit log of data access in the system.
With a smart environment, patients need register their smart phones in system or be issued a smart card including a sensor [5]. This type of registration is only one time as opposed to current system wherein patient needs to visit registration counter every time he visits hospital. Their location can be traced by detectors deployed. For the department, it is easy to know the progress of each incoming patient and estimate the time of

completion so that appointment system can efficiently arrange up-coming patients. Furthermore, systems can schedule consultants for different patients based on the real time information of their progress.

High availability and resiliency of records even in case of server failure
We have also taken in account possibility of server failure or server overload in the system. Also since we are using portable smart cards, even in case of server failure data records are available on the device of patient which includes his past medical history, vaccination, lab reports, medical bills, etc. So even in case of some ransomware or malware attack on hospital system database, patient has always his records with him on his portable smart card. In case of kiosk malfunctioning server overloading the patients can go to manual managed counters and their information could be updated by manually by person managing counter and it can be synced, when the system is up again.

Data back up on cloud
In case of loss of mobile device or smart card by patient, a new smart could be issued and the lost data of patient could be recovered back from cloud. data is backed up on cloud at regular interval. this ensures high availability and reliability of patients electronic records.
Thus when a patient is using portable smart card, he need not worry about loss of medical records as is in the case of paper based manual records.

Chapter 5

Experimental Results

5.1 Experimental Environment

For the purpose of comparing different approaches simulation is done on Matlab 2015 version.
–Simulink is used to replicate the real world scenario.
–For generating entities entity generator of simulink is used which randomly generates patients according to poisson distribution function.

Table 5.1: Simulation Environment statistics

	Parameter	Value
1.	Simulation duration	4 hours
2.	Probability of kiosk failure	1/100
3.	Probability of server outage	1/50

We have taken simulation duration as 4 hours, since generally O.P.D time in government hospitals is 9 AM to 1 PM.
In our smart registration kiosk system we have taken a probability distribution of 1/100, i.e. out of every 100 patients, kiosk doesn't work for 1 patient due to server bring not responsive or some technical problem.
For our simulation purpose, we have taken a probability of 1/50 i.e. for every 50 patients, server is not responding and data records are not retrieved.

5.2 Simulation of present system

As part of current work flow, for registration patients queue up at manual counters and get their registration slips with a barcode on it. This process takes usually 3-4 minutes for a patients as it involves manual entry of data of patients by person at the counter and according to simulation results it takes an average of 6.2 minutes of waiting time for patients standing in the queue.

Also, there are several cases of fraud identity and in the present system that is there in department there is no method to ensure authenticity of identity of patients. After registration patients queue for consultation and further tests. Here, patients are served in first come first serve manner but queue is often not followed. There are several patients who use corrupt practices and break the queues.

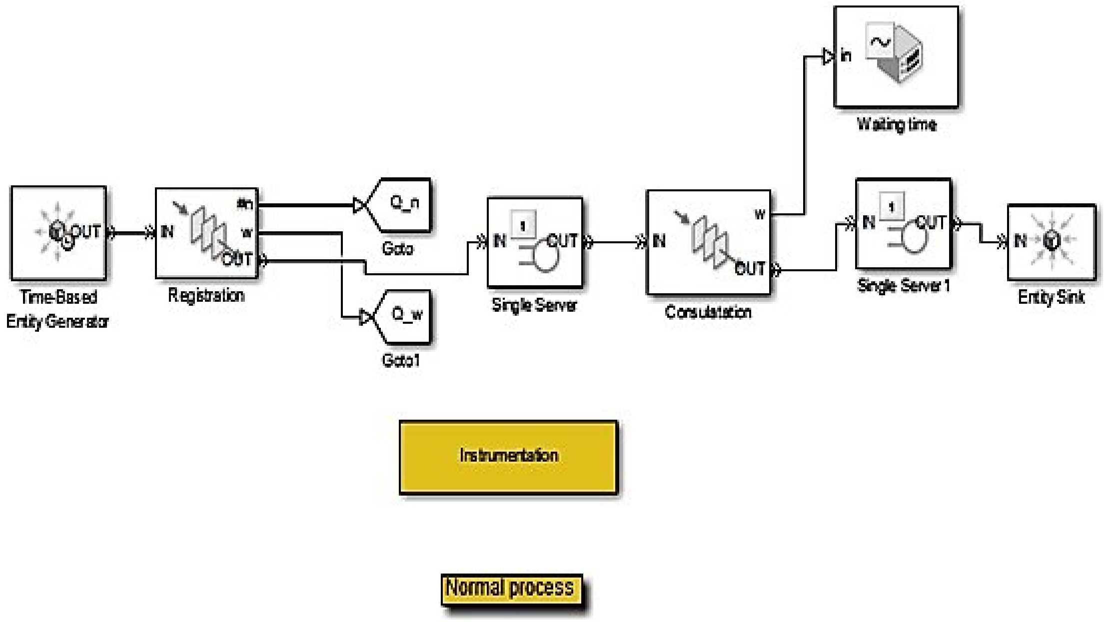

Figure 5.1: Screenshot:Present workflow of department

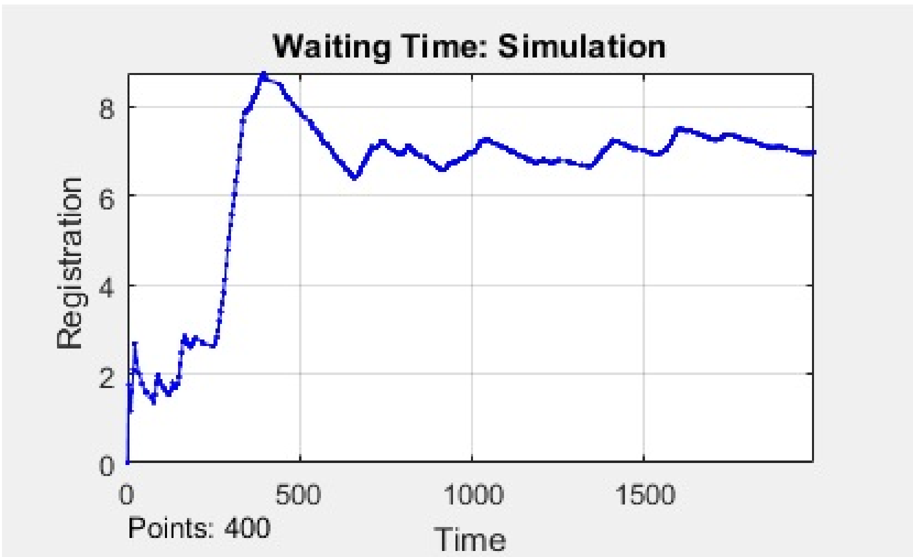

Figure 5.2: Waiting time for registration process

Also, the doctors, go manually through patients records which increases consultation time for the patients and at the same time there are chances of error on pharmacy due to poor quality of manual records.

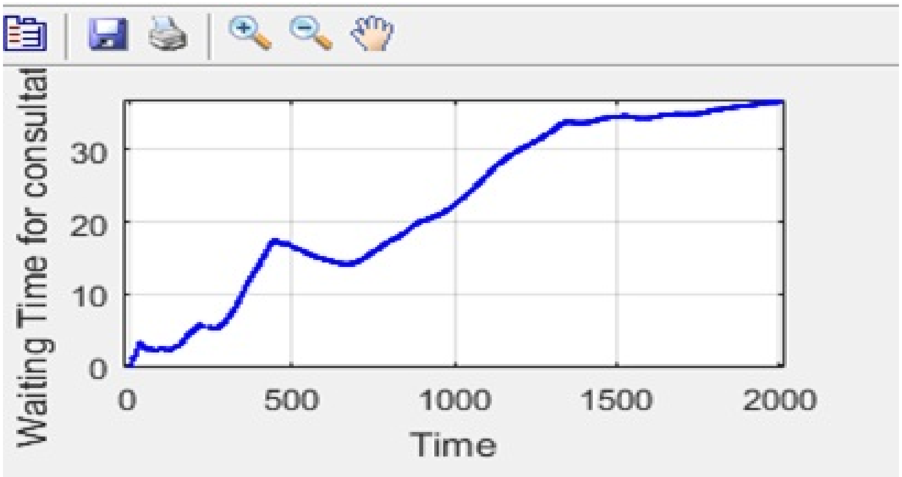

Figure 5.3: Waiting time for consultant

5.3 Simulation of proposed system

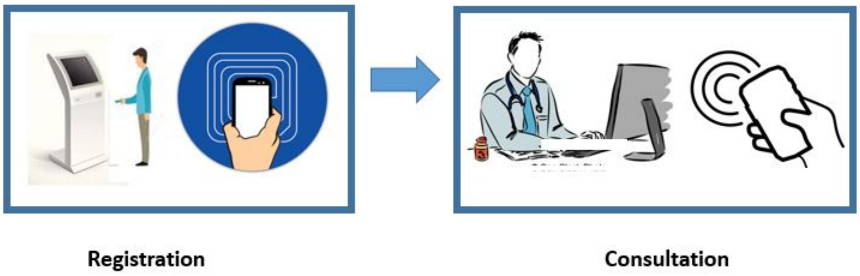

Figure 5.4: Proposed system with portable electronic health records

As shown in seen in Fig 4.4, we have simulated end to end work flow of hospital department, starting from registration process upto patient leaving the department. In our smart queuing system, as shown in fig 3.3 patients after taking appointment online or from any of 5 available methods i.e. web portal, IVRS, mobile app, call centre or AIIMS counter [23] can go directly to self -service Kiosk where they can enter their UID no. and can scan their smart cards. This has more efficient scheduling ability to avoid long waiting queues at the registration counters. The use of smart cards could improve serving efficiency by scheduling patients in terms of the real time status.

Here to avoid mismanagement of queues and corruption, we have from starting incorporated two types of patients requiring consultation i.e one is non-emergency patients and another category is emergency/ preferred patients (old age, children requiring urgent attention).

For incorporating such patients in our simulation, we have taken a uniform probability distribution of of such patients as 1/20. That is for every 20 non-preferred category patients we have 1 preferred/emergency patient.

5.3.1 Kiosk Failure

For server failure/technical failure probability, we have considered a uniform probability distribution of 1/100, i.e. out of every 100 patients, kiosk doesn't work for 1 patient due to server bring not responsive or some technical problem.
In this case then patient is redirected to manual counters and this scenario is also taken into account while simulating patient flow.
Patient arrival in the department is simulated using Poisson distribution.

As can be seen from fig 4.5, waiting time for registration process is less than 1 minute.

As can be seen from fig 4.6, waiting time for registration process is 6-8 minutes.

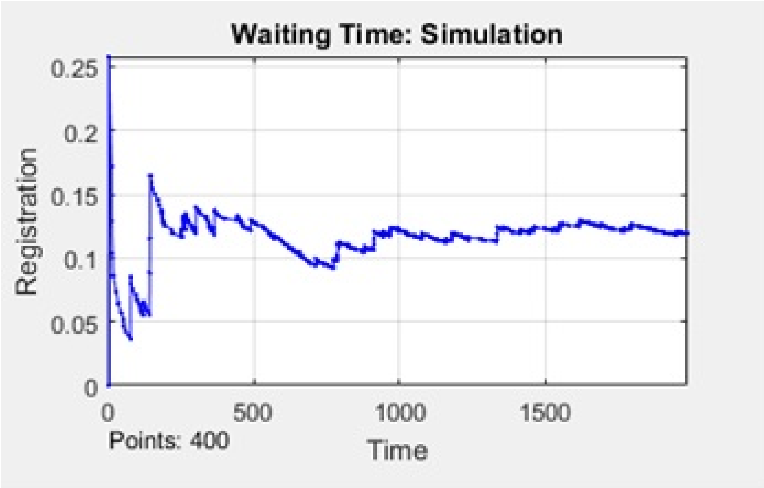

Figure 5.5: Waiting time for registration

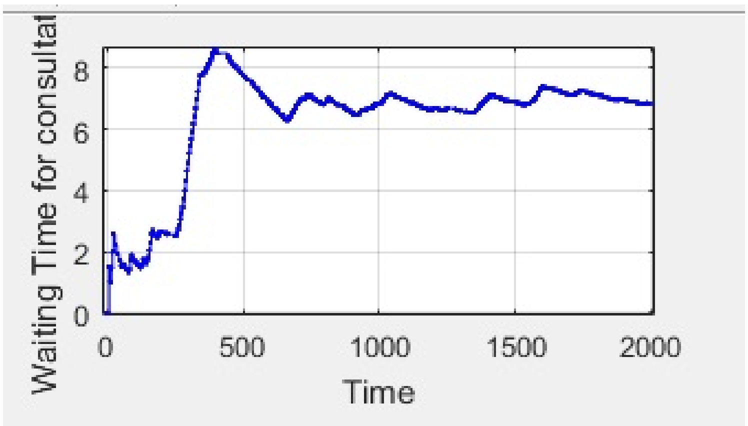

Figure 5.6: Waiting time for consultant

5.3.2 Server crash or Power failure : Records not available at consultant's system

We have also taken in account possibility of server failure or server overload in the system. Also since we are using portable smart cards, even in case of server failure data records are available on the device of patient which includes his past medical history, vaccination, lab reports, medical bills, etc. So even in case of some ransomware or malware attack on hospital system database, patient has always his records with him on his portable smart card. In case of kiosk malfunctioning server overloading the patients can go to manual managed counters and their information could be updated by manually by person managing counter and it can be synced, when the system is up again.

Since we are simulating government hospitals, where patient footfall is very high exceeding the available resources and hence data size of patients records would also be high. So it might happen that server is overloaded during a particular time and does not respond and doctor is not able to access records.

For our simulation purpose, we have taken a probability of 1/50 i.e. for every 50 patients, server is not responding and data records are not retrieved. So the time for consultation goes up.

In case of server crash or data failure, since patient is carrying records on his device having portable smart card, time taken during consultation is still less than time taken when paper based records are used. As all records, including medical history, past consultations and lab records could be accessed from patient's device.

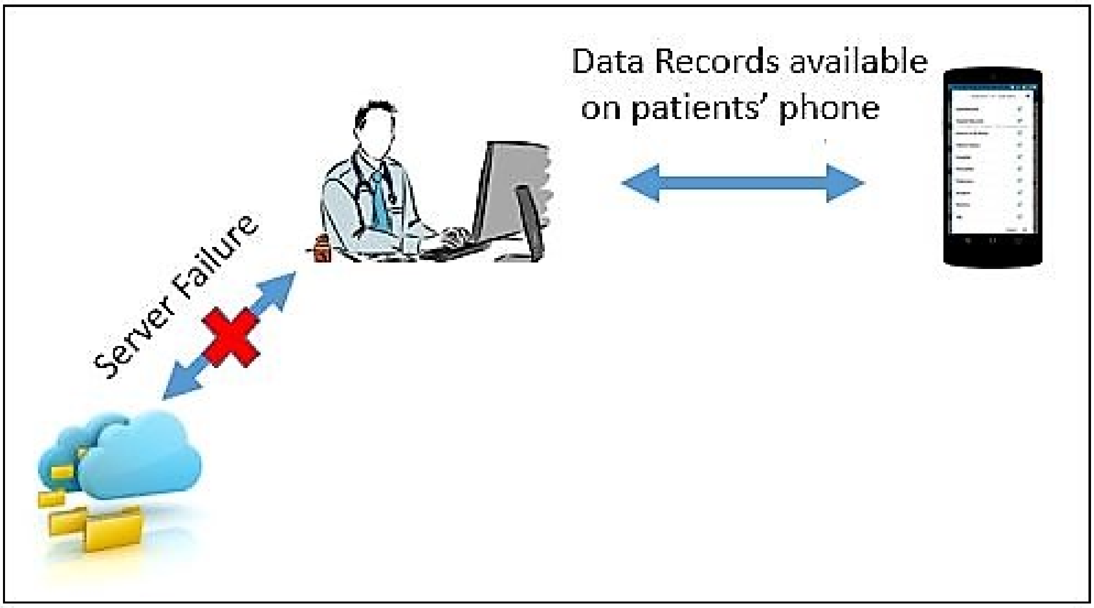

Figure 5.7: Server outage scenario

5.4 Comparative results

5.4.1 Registration time

As shown in graph in fig 4.8, the average registration time is very high in present system due to manual counters leading up to long queues in front of counters. As compared to this when we deploy smart kiosk, where registration could be done with just tap and go method, average registration time substantially reduces.

Figure 5.8: Average Registration time

5.4.2 Consultation time

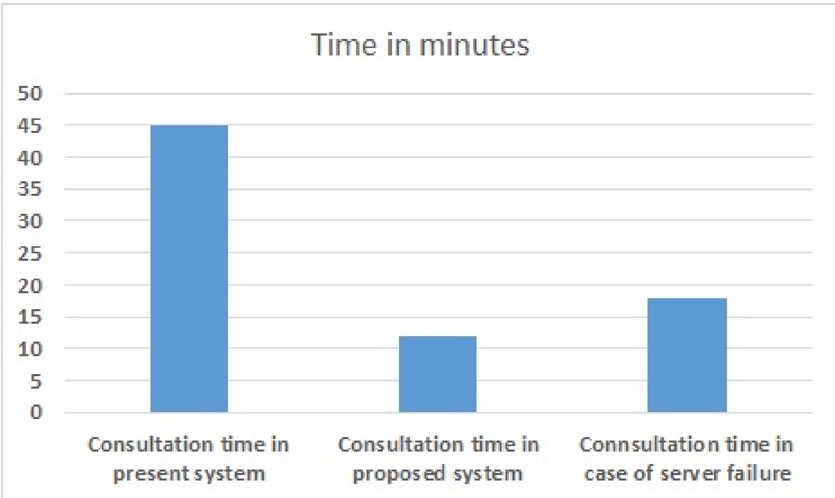

Figure 5.9: Average Consultation time

As shown in graph in fig 4.9, the average consultation time i.e. time spent in waiting for their turn by patients and time spent with doctor, is considerably high in present scheme of things. As compared to this when we use a smart queuing system backed up by smart cards containing portable health records average consultation time is dropped considerably.
And when during our proposed set of schemes there is server failure or data records are not available at doctor's system due to power failure, records can be accessed from patients' smart device. Although, in this case time with doctor increases slightly but is still very efficient as compared to present workflow.

5.5 Sample patient Record

As a part of our experimental evaluation of FHIR, we set up record for data of patients as shown in fig 4.10. These records are in FHIR [19] message XML format. We checked for syntatic and semantic inter-operability in these records. This record is of EEG data of patient.

In each FHIR message, patients attributes are represented by XML format. FHIR uses


```
<title>next of kin (other)</title>
<id>http://hl7.org/fhir/Patient/11</id>
<link rel="self" href="http://hl7.org/fhir/Patient/11/history/1"/>
<updated>2012-05-29T23:45:32Z</updated>
<author>
  <name>Grahame Grieve</name>
</author>
<content type="text/xml">
  <Patient xmlns="http://hl7.org/fhir">
    <text>
      <status value="generated"/>
      <xhtml:div xmlns:xhtml="http://www.w3.org/1999/xhtml">Relative
        444999999</xhtml:div>
    </text>
    <identifier>
      <label value="SSN"/>
      <system value="http://hl7.org/fhir/sid/us-ssn"/>
      <value value="444999999"/>
    </identifier>

    <name>
        <use value="official"/>
        <family value="Relative"/>
        <given value="Ralph"/>
      </name>
valueSampledData>
   <origin>
      <value value="0"/>
      <system value="http://unitsofmeasure.org"/>
      <code value="uV"/>
   </origin>
   <period value="100"/>
   <factor value="2.5"/>
   <dimensions value="1"/>
   <data value="-4 -13 -18 -18 -18 -17 -16 -16 -16 -16 -16 -17 -18 -18
```


Figure 5.10: Screenshot: Sample patient Record

RDF (resource development framework) graphs to link patient's records and make meaning out of them to ensure interoperability. The key aspect of the information exchange at this level is right content. For example, two devices, one which measures and transmits weight and another which receives and analyzes it are not interoperable if one device measures pounds but the other interprets kilograms. Another example is an ICU monitoring station set up to receive readings from a pulse oximeter may also have alarm capabilities to alert physicians in case the patients oxygen saturation over time or at some point in time is reaches an unsafe value at defined the settings and the associated algorithm.

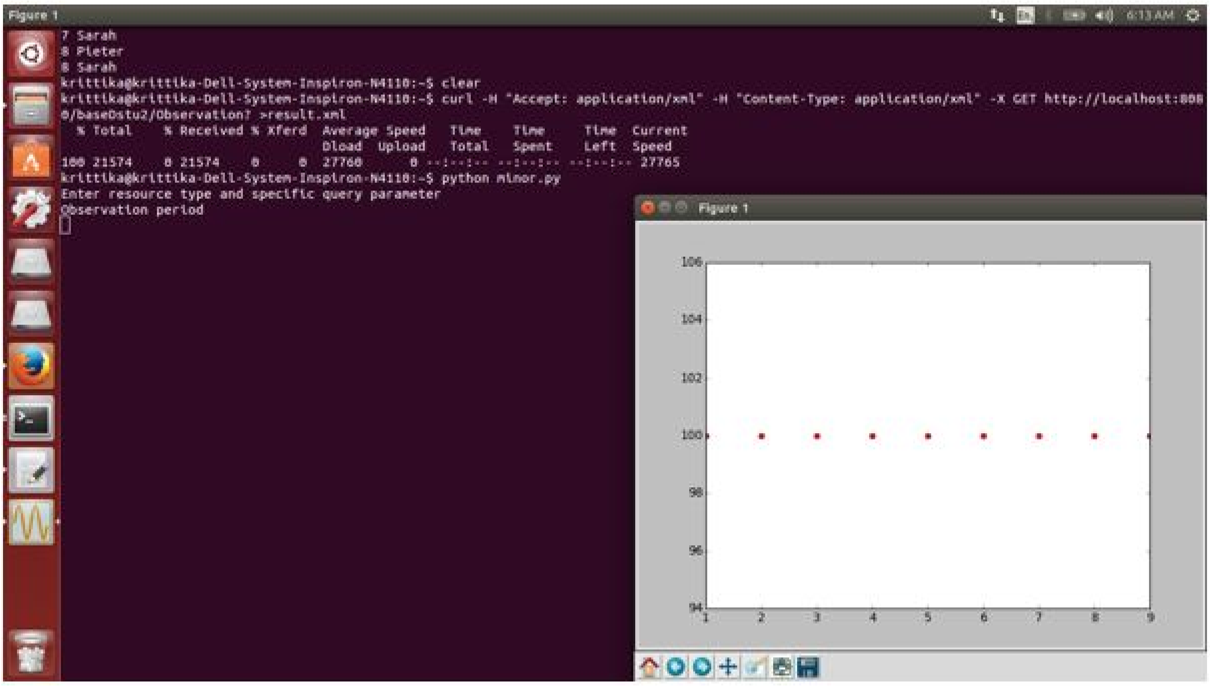

Figure 5.11: Screenshot:Visualization of particular observation fields on the FHIR Server

FHIR records could be mapped using FHIR server as depicted in fig 4.11. FHIR server helps in visualizing records. There are many RESTful API based FHIR servers available online. HAPI server is also a FHIR server which is servlet based.

Chapter 6

Conclusion and Future Work

For improving the patient queuing system, a smart environment can be applied to support behaviours of patients and management of work-flow in the hospital. Smart environment can be created using various technologies available such internet of things , cloud computing, smart cards, etc.

Our research work aims to propose a smart solution applying a smart environment for the ophthalmology department in order to improve its patient flow and work flow. This research, firstly, explores a smart digital kiosk based registration process. The registration process proposed by us, along with reducing waiting time for patients also ensure authenticity of patients' identity. It helps in fraud management and corruption in the system. The dynamic scheduling policy that takes into account separate category of patients requiring early attention which helps in improve the efficiency and utilization of consulting service and reduce patient waiting queue. Secondly, an evolved work flow and a new capacity plan are developed for the ophthalmology department which can improve the efficiency and quality of service.

The scheduling model is created on the basis of the department patient flow so as to refine the queuing process. We have simulated, compared and anaylsed both present system and proposed system design and have found through simulation results that proposed system performs better in many dimensions. We also propose a FHIR based portable electronic healthcare records. FHIR based records are syntactic and semantic interoperable and can be used across the departments and hospitals. With portable EHR (electronic health records) a patient can have his records with him all the time on a smart phone or a smart card. This leads to efficient maintenance, faster service rate of doctors and also help in eliminating any errors on pharmacists side.

When these EHRs are portable across devices, they facilitates high availability and high reliability as they provide real time access to patients records at point of care. Portable health records are highly beneficial in hospitals, especially in case of developing countries where people visit different hospitals for different specialists. Portable EHRs has the capability to strengthen the relationship between patients and physicians. The meaningful readily available updated data will help health service providers in making insightful decisions and will eventually lead to better services for patients.

As part of future work, these portable FHIR records can be integrated with machine learning and data analytic algorithms for predicting patterns, and demonstrating patients behaviour and history. Also we are planning to store FHIR data on hadoop to leverage its capability of replicating, scalablility and faster processing of data.

Appendix A

A.1 AIIMS Report reference

Some of the statistics related to Dr. Rajendra Prasad (RP) Centre for Ophthalmic Sciences department under All India Institute of medical Sciences(AIIMS) are given below in table A.1 and A.2.

Table A.1: Statistics for specialty clinics [6]

	Specialty Clinic	New cases	Old Cases	Total
1.	Cornea Clinic	5959	11524	17483
2.	Lens Clinic	825	1955	2780
3.	Uvea Clinic	1079	3667	4746
4.	Contact Lens Clinic	985	2239	3224
5.	Glaucoma Clinic	3759	11195	14954
6.	Oculoplasty Clinic	3305	2493	5798
7.	Paed. Ophthalmology Clinic	418	36	454
8.	Retina Clinic	3883	4904	8787
9.	Neuro-Ophthalmology Clinic	2584	2328	4912
10.	Vitreo retinal Clinic	2478	2282	4760
11.	ROP	830	1124	1954
12.	Ocular Oncology Clinic	378	1329	1707
13.	Low visual Aid	2798	464	3262
14.	Orthoptic Clinic	2211	21265	23476
15.	Squint Clinic	5205	19982	25187
16.	Refraction	40644	40644	40644
	Total Cases	36697	127431	164128

Table A.2: Total Cases in Dr. Rajendra Prasad Centre for Ophthalmic Sciences at AIIMS [6]

		New Cases	Old Cases	Total
1.	General O.P.D.	152455	99349	251804
2.	Emergency	8799	-	8799
	Total Cases	161254	99349	260603

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