Sharing and Viewing Segments of Electronic Patient Records Service (SVSEPRS) using Multidimensional Database Model

A thesis submitted for the degree of Doctor of Philosophy

by

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This Thesis is dedicated with deepest love and everlasting respect to my parents, my wife and my children.

Without their tolerate, support and encouragement I could not have reached this stage.

Abstract

The concentration on healthcare information technology has never been determined than it is today. This awareness arises from the efforts to accomplish the extreme utilization of Electronic Health Record (EHR).

Due to the greater mobility of the population, EHR will be constructed and continuously updated from the contribution of one or many EPRs that are created and stored at different healthcare locations such as acute Hospitals, community services, Mental Health and Social Services.

The challenge is to provide healthcare professionals, remotely among heterogeneous interoperable systems, with a complete view of the selective relevant and vital EPRs fragments of each patient during their care.

Obtaining extensive EPRs at the point of delivery, together with ability to search for and view vital, valuable, accurate and relevant EPRs fragments can be still challenging. It is needed to reduce redundancy, enhance the quality of medical decision making, decrease the time needed to navigate through very high number of EPRs, which consequently promote the workflow and ease the extra work needed by clinicians.

These demands was evaluated through introducing a system model named SVSEPRS (Searching and Viewing Segments of Electronic Patient Records Service) to enable healthcare providers supply high quality and more efficient services, redundant clinical diagnostic tests. Also inappropriate medical decision making process should be avoided via allowing all patients’ previous clinical tests and healthcare information to be shared between various healthcare organizations.

Multidimensional data model, which lie at the core of On-Line Analytical Processing (OLAP) systems can handle the duplication of healthcare services. This is done by allowing quick search and access to vital and relevant fragments from scattered EPRs to view more comprehensive picture and promote advances in the diagnosis and treatment of illnesses.

SVSEPRS is a web based system model that helps participant to search for and view virtual EPR segments, using an endowed and well structured Centralised Multidimensional Search Mapping (CMDSM). This defines different quantitative values (measures), and descriptive categories (dimensions) allows clinicians to slice and dice or drill down to more detailed levels or roll up to higher levels to meet clinicians required fragment.

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Declaration

The following papers have been published (or have been submitted for publication) as a direct or indirect result of the research discussed in this Thesis:

Journal Papers:

1. A. Jalal-Karim, W. Balachandran, “Sharing Electronic Patient Records’ Segments between federated Healthcare organizations based on multidimensional data model”. Submitted to: *Informatics for Health and Social Care’s journal*, Oct. 2008.

2. A. Jalal-Karim, W. Balachandran, “Proving the efficiency of client server model for sharing EPRs using mathematical induction theory,”. Submitted to: *Informatics for Health and Social Care’s journal*, Oct. 2008.

3. A. Jalal-Karim, W. Balachandran, “Centralised vs. Decentralise Healthcare system models,” (Manuscript in preparation).

Conference Papers:

4. A. Jalal-Karim, W. Balachandran, “Enhancing the quality of healthcare system throughout utilizing Electronic Patient Record (EPR) Categorization,” in *the proceeding of the1st Annual ReSCon Conference 2008, Brunel University-Uxbridge, UK*, 2008, pp. 58-59.

5. A. Jalal-Karim, W. Balachandran and M. AL Nabhan, “Storing, Searching and Viewing Electronic Patient Record’s Segments based on Centralized Single Repository,” in *proceeding of the 9th Annual PG NET Conference, 2008, Liverpool*, UK, 2008, pp. 44-45.

6. M. AL Nabhan, W. Balachandran, Z. Hunaiti and A. Jalal, “Wide Area Inverse DGPS Model for Improved Positioning and Tracking,” The Navigation Conference and Exhibition NAV08, London, October 2008.

7. A. Jalal-Karim, W. Balachandran, “Interoperability Standards: the most requested element for the Electronic Healthcare Records significance,” in *proceeding of the 2nd International E-Medisys Conference, sponsored by* IEEE, Sfax, Tunisia, October 2008.

8. A. Jalal-Karim, W. Balachandran, “The National Strategies for Electronic Health Record in three developed countries: General Status,” in *proceeding of the* 2nd *International E-Medisys Conference, sponsored by* IEEE, Sfax, Tunisia, October 2008.

9. A. Jalal-Karim, W. Balachandran, “The Influence of adopting Detailed Healthcare Record on improving the quality of healthcare diagnosis and decision making process,” Accepted in the *12th IEEE International Multitopic Conference (IEEE INMIC 2008), Karachi, Pakistan, December 2008.*

10. A. Jalal-Karim, W. Balachandran, “The optimal network models performance for sharing Electronic Health record” Accepted in the *12th IEEE International Multitopic Conference (IEEE INMIC 2008), Karachi, Pakistan, December 2008.*

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List of Abbreviations

ANSI	American National Standards Institute
API	Application Programming Interface
ASP	Active Server Page
ASTM	American Society for the Testing of Materials
CBPR	Computer Based Patient Record
CEN	Comité Européen de Normalisation, responsible for European legislative standards
CGI	Common Gateway Interface
COMPETE	Computerization Of Medical Practices for the Enhancement of Therapeutic Efficacy)
CPR	Computer-based Patient Record
CPT	Current Procedural Terminology
DICOM	Digital Imaging and Communications in Medicine standard
ECG	Electrocardiogram/ graph
EDI	Electronic Data Interchange
EHCR	Electronic Healthcare Record
EDIFACT	Electronic Data Interchange For Administration, Commerce, and Transport
EHR	Electronic Health Record
EMR	Electronic Medical Record
EIS	Enterprise Information System
EPR	Electronic Patient Record
EU	European Union
GP	General Practitioner
HIMSS	Healthcare Information and Management Systems Society
HIS	Hospital Information System
HL7	Health Level Seven
HL7 (CDA)	Clinical Document Architecture
HTML	Hyper Text Mark-up Language
HTTP	Hyper Text Transfer Protocol
ICD	International Classification of Diseases
IEEE	Institute of Electrical and Electronics Engineers
IHE	Integrating the Healthcare Enterprise

IP	Internet Protocol
ISO	International Standardization Organization
ISP	Internet Service Provider
JDBC	Java Database Connectivity
JSP	JavaServer Pages
JVM	Java Virtual Machine
LAN	Local Area Network
LOINC	Logical Observation Identifiers Names and Codes
NEHTA	National E-Health Transition Authority
NHS	National Health Service
NPfIT	National Programme for Information Technology
ODBC	Open Database Connectivity
JDBC	Java Database Connectivity
OLAP	Online Analytical Processing
OLTP	Online Transactional Processing
PDA	Personal Digital Assistant
PHP	Hypertext Pre-Processor
RDBMS	Relational Database Management System
PROMIS	The Problem-oriented Medical Information System
RIM	Reference Information Model
RMRS	Regenstrief Medical Record System
SNOMED	Systematised Nomenclature for MEDicine
SOAP	Subjective, Objective, Assessment, Plan
SSIS	SQL Server Integration Services
STOR	Summary Time-Oriented Record
TCP	Transmission Control Protocol
UMLS	Unified Medical Language System
WAN	Wide Area Network
WWW	World-Wide Web
XDS	Cross- Enterprise Document Sharing
XMLITS	XML Implementation Technology Specification

Chapter 1

Introduction

1.1 Background and Motivation

Healthcare systems are extremely complex and information demanding area, creating and utilizing a huge amount of healthcare information, which implies an assertion that paper-based records, can no longer reach the requirements of advanced healthcare system [1]. Due to the emergent need to improve healthcare services, which is growing more to organize and deliver high quality services that paper-based records cannot be supported especially with an increasingly complex data entry. There is an increasing desire to improve the ability to access patient record information that is distributed across multiple sites by using the latest Information and Communication Technology (ICT). Computers have been used in healthcare organizations for decades to facilitate the integration and manipulation of patient's data and improve the clinical decision making process to be more promptly, surly and reasonably.

However, utilization of computers may affect the communication between healthcare providers and patients. A number of patients may feel calmed by the influence of technological, clinical and organizational assistance provided by computers contrasted to filing papers. Conversely, the computer monitor may act as an obstacle between healthcare providers and patients.

During the last decade, the healthcare environment has been enhanced with increased emphasis on preclusion and early recognition of disease at primary and secondary healthcare service, mental health, home care, and continuity of care. In such an active environment, information and communication technologies (ICT) are taking on a primary task and are presently having a major influence on healthcare system. The stimulant for improving the healthcare area, which has been implemented for several years, is anchored in the utilization of ICT. This is required for improved quality and efficiency of healthcare services and the suppression of associated costs.

In the context of improving the quality, efficiency and consistency of healthcare service, creating, storing and sharing the patient healthcare information among different healthcare systems has been assigned as high priority in various nations, which can be achieved by using Electronic Health Record (EHR) [2, 3].

The EHR will be constructed and continuously updated from the contribution of one or many EPRs that are created and stored at different healthcare locations such as acute Hospitals, community services, Mental Health and Social Services [4].

Healthcare organisations, medical schools, employers and even the governments have appreciated the significance of computerising the various components of the patient health records.

Electronic Health Records (EHR) is one of the significant initiatives set out by Healthcare organizations which will inevitably replace the paper record at some point in the near future. The successful national strategies for EHR are assisted by various factors that must be in place in order to achieve the required electronic healthcare records. This includes communications infrastructure [5], interoperable standards [6] and implementation plans [7]. However, other aspects, such as cost, politics and extensive geographies may inhibit completion and supporting of the agreement on the structure and continuing financial support of EHR projects [8, 9].

With such a common encouragement to adopt EHR, a very large portion of the healthcare environment is going to make a conversion away from the way clinical records have been stored in the previous decades. Instead, they are going towards adopting other ways to keep and share these records. The idea of electronic healthcare record has been around for approximately 30 years. This has increasingly evolved towards collaborative tools between various healthcare providers and patients in continually growing networked environments, implying the need for high quality information managements. However, healthcare organizations did not directly adopt the EHR. Many of the former systems are still not paperless, as healthcare professionals applied both an electronic and paper-based healthcare record systems [10]. However, EHR that do not offer reliable or relevant patient healthcare information to the healthcare provider when needed could divert the correlation between the providers and consumers [11].

It has been emphasized that an individual is likely to interact with different healthcare organizations, especially, when (1) specialized care is needed (2) patients relocate and changes General Practitioners (GP) more frequently, and (3) treated by a variety of care professionals in a range of locations throughout their life as many patients no longer have a single GP who provides their total care [12]. This leads to the fact that healthcare information will be scattered across various healthcare organizations within one or more regions.

The contents of patient healthcare information is normally large, diverse and of variable quality. Various types of information in the patient records have different application for different kinds of users. The current healthcare environment is evolving quickly into a multi-provider service model which dictates a new demand regarding access and sharing patient information between multiple locations within a given practice. This evolution in such an interactive environment leads to a challenge that in order to achieve efficient clinical decisions in the most cost-efficient way, healthcare providers at the point of care require suitable and accurate way to share a growing amount of healthcare information that is held in various healthcare locations [13, 14].

EHRs are varying between different applications and between different nations. This fact indicates that the structure of EHRs and the techniques used for sharing process may differ considerably, which has developed into a barrier for sharing patient healthcare record. The obvious solution for this obstacle is by standardizing the structure, the contents of EHRs and even the method used for sharing [15, 16]. Reviewing the states of standardisation, which deals with the interoperability of EHRs, indicates that significant efforts has been considered by different nations such as Canada [17], Australia [18] England [19] and United States [20] and different projects like Health Level Seven (HL7) [21], European Committee for Standardization (CEN) TC251 [22], OMG [23] and the International Organization for Standardization (ISO) TC 215 [24].

1.2 Problem and Significance

The mobility of patients between healthcare professionals has led to heterogeneous patient's healthcare information stores (islands of information), which are making access to the vital information by healthcare providers whenever and wherever they need becomes a crucial strategy for various healthcare foundations.

Previously, patient healthcare information placed in discrete healthcare organizations was unavailable online for the clinicians.

The only way to get into EPRs was to order the clinical papers by post. In addition to the expenses and lengthy delivery time, the challenge was to known which healthcare systems contained the required relevant information.

With weak interoperability, even by using e-health system, clinicians face deficiency during the process of accessing healthcare information. Therefore, when a consumer visits more than one healthcare professional, no one recognize precisely what the other clinician is doing.

The questionnaire survey (Appendix A) that was completed during the research period revealed the fact that accessing Detailed Patient Record plays the main role toward achieving high quality healthcare services. However, according to a recent internal Department of Health document NHS CRS consent/dissent: information sharing rules, shows that the database will be unable to fulfil some of the National Programme for Information Technology's (NPfIT) expectation. It will not be possible for clinicians working in one "instance" to access the detailed care records (DCR) made by clinicians in another "instance" [25]. In other words, it will not be possible to share (DCR) between trusts from different clusters, even if they are close to their boundary and adjacent to each other.

The failure to rapidly access patient's past and current detailed healthcare information has the impact to hamper the diagnosis process, encourage the redundant repeat of clinical tests, and upsurge the cost of healthcare services.

However, reviewing clinician's use of EPRs has failed to reveal any obvious decrease in the time consumed on physician-patient encounters [26]. To prevent wasting time, a dynamic searching model for patient records must be introduced as an enormous advantage of EPRs contrasted to the typical EPRs proposed by different national strategies.

The interviews with a number of healthcare consultants revealed that the clinicians usually had almost access to the index pages of the EPR. But, this access did not involve the ability to immediately view the most relevant notes or fragments of a selected EPR. Patients who suffer from chronic diseases have their EPRs typically filled with many progress notes and clinical tests. This is often conquered by redundancy of information and the healthcare providers struggle with attaining the adequate overview. Several of the interviewed physicians indicated that it is problematic to track earlier episodes and view selected fragments in the EPR:

"The common difficulty that I face is the low availability of the information inside the EPR, especially when I deal with the case of chronically sick patients or patients with continued visiting times (Dr. Ameer Almucktar)."

Healthcare providers during the interviews have also revealed that searching for already created and stored information such as discharge notes, clinical and results on laboratory tests take a long time. Instead, some physicians appeared to count on their own memory or attained the required information by requesting the patients directly. Practically healthcare providers nowadays, read the EPR through reviewing the previous attached comments before asking patients to attend the encounter.

1.3 Research Questions

Based on the earlier barrier's overview, the following research questions have been revealed:

- What is the most practical way of creating, storing and sharing the vast quantity of patient healthcare information?
- The availability of electronic patient records will be enhanced, but what is the availability of the most required segment within each record?
- How can electronic patient record systems improve the quality of medical diagnosis and avoid medical errors without consuming a long time during the encounter session?
- Are the current proposed electronic healthcare record systems more compatible with searching on the most required fragments? And what are the effects of multidimensional search models on the quality of care provided to patients?
- What are the impacts of deficiency in utilizing detailed patient record on the quality of healthcare service provided?

1.4 Aims and Objectives

The main aim of this Thesis is:

> **To introduce an online web-based EPR system model that provides rapid and immediate search and access twenty four hours a day from any healthcare organisation. This system should provide the capability to view the most required fragments of patient healthcare information necessary and support service provided, taken from various distributed healthcare locations based on multidimensional search mechanisms.**

The specific objectives are:

1. To provide substantial improvements to the quality and efficiency of healthcare services provided, especially for patients who suffer from chronic illnesses.
2. To facilitate healthcare record management needs.
3. To enhance the capabilities for multipurpose healthcare systems.
4. To interrogate the contents of EPRs.

By addressing the above objectives for sharing EPR fragments, a substantial number of important contributions have been made via introducing a reliable and successful system model named Searching and Viewing Segments of Electronic Patient Records Service or SVSEPRS.

1.5 The proposed model

The development process of sharing EPRs is not an easy issue. Healthcare services are vast, concerning millions of encounters between healthcare consumers and providers every day. One of the main ambitions that healthcare service providers aim to accomplish is to reduce medical diagnosis errors [27]. This is done through improving the healthcare management by using dynamic search to select and view vital and accurate information from the comprehensive scattered EPRs. Thus, there is a need for better access to the most required segments of patient information as it will have a positive outcome on the healthcare quality. This requires a system with scalable searching ability for promoting the healthcare workflow and may ease the extra work needed by clinicians and probably permitting to consume more time with the patient during encounter session.

The Internet as essential facilitating tool for sharing and communication data can be employed at any healthcare organization. The WWW without doubt, has acquired broad acknowledgment on different fields.

By addressing the above challenges, a proposed model named SVSEPRS (Searching and Viewing Segments of Electronic Patient Records Service) has been introduced to meet the objectives and to enable a seamless, cross-organizational access to vital segments of patient records. In this context, Electronic Patient Segment is considered to be any clinical observation, examinations, measurement, recording, diagnosis, therapy or description of the anatomical, physiological, or mental condition or history of consumers and any clinical assumptions or judgments made in the time of the healthcare delivery.

The proposed model (SVSEPRS) is a successful technique that helps clinicians to search easily and more effectively using Centralized Multidimensional Search Mapping (CMDSM), and view EPR segments virtually. It is the most valuable procedure during or even outside encounter's time to share EPRs between various healthcare organizations. This is done via a centralised coordinator server, rather than integrating local healthcare systems that creates and stores EPRs into a single massive data warehouse. The proposed model allows healthcare providers to access Detailed Patient Records in order to provide and control the reliability and efficiently of complex healthcare delivery.

SVSEPRS, which should be under well defined agreement, hides the complexity from the clinicians and facilitate the access and view of the vital and more accurate parts of detailed EPRs allocated on different locations.

1.6 Contribution to knowledge

This thesis makes several contributions to both the storing management and sharing EPRs. The main contribution to knowledge presented in this Thesis has been achieved by proposing the SVSEPRS model, which can be described as a coordinator among federated healthcare systems with a central web server that holds outlined EPR segments to be used by participant's users for searching purposes via the CMDSM. The participant healthcare professionals are assured, twenty four hours a day, navigation through CMDSM and performing the processes of drill-down and roll up the dimensions hierarchy to view the valuable and needed critical EPRs' fragment. This is taken from any healthcare location to finalize the query forms which will run using the attached links to the source of the selected EPRs fragment. CMDSM therefore will facilitate the process of searching for the vital and valuable EPRs' field stored at many different local institutions.

The contributions have been brought together to present the requirement, design, and implementation of the main concepts and evaluate the performance of the proposed model, which consequently may be of interest to both scholars and healthcare providers. A prototype has been built that support the execution of SVSEPRS queries that open access over decentralized healthcare location using CMDSM.

Synchronized access using web-based system to various and divers EPR segments by multiple clinicians and enhanced readability contrasted to scripting are obvious contribution of the proposed SVSEPRS model. Adoption of clustering techniques and using Java servlet technology allows the SVSEPRS to activate in a scalable, reliable and robust manner as well as increasing the availability and security of the service. Further details about these contributions are covered in chapters 6, 7 and 8. Potential challenges to the proposed model are that different medical vocabulary used by different institutions, inadequate EPR structure at local systems, and incorrect software or hardware at local sites.

1.7 Research Methods

The work of this Thesis reflects an extensive research investigation coping with the challenges of sharing EPRs, optimal requirements, healthcare information models and general remarks regarding prototype implementation of centralised and decentralised healthcare integrations.

The general research methodology was accomplished in three phases:

1.7.1 Literature review

A two-phased approach was used to conduct a literature review to determine what is already known about e-Health Care Record techniques.

- First, general search was conducted to explore what general information was available on Health Care Record system sampling that did not focus on the specific compounds of interest for this research.

- The second phase of the literature search was more determinative and based on concise components of interest for this research such as sharing EPRs, Interoperability, EHR standardisation, medical errors, medical diagnosis, etc. Databases available through a regular library system were used to conduct these researches.

1.7.2 Questionnaire survey

A questionnaire survey was adopted and sent to each of 130 physicians to investigate their views about the effect of **sharing fragments** of **Detailed Patient Record (DPR)** among healthcare providers on improving the quality of clinical diagnosis and avoiding medical decision errors.

A reminder and another copy of the questionnaire were sent to those who had not replied within 2 weeks. The questionnaire is given in Appendix A.

1.7.3 Regular meeting with healthcare providers

Although the work of this research presented here was undertaken at Brunel University, the author had regular and beneficial contact with a number of healthcare professionals at different healthcare organisations, (illustrated in the following table):

Healthcare provider	The specialities	Healthcare organisation
1- Ameer Almukhtar	Consultant surgeon	Balfur Hospital, Kirk wall, Orkney KW15 1BH
2- Zuhair Alnahar	Dentist	Care Dental Practice 118 Hammersmith Road, W6 8BS
3- Khudair Abbas	General Practitioner	Lynwood Medical Centre, 3 Lynwood drive, Collier Row, Romford, Essex RM5 3QL
4- Talib Abbas	Consultant Psychiatrist	Lordswood Community & Health Living Centre, Sultan Road, Chatham ME5 8JT

Table 1.1: *Healthcare Advisors*

Regular open-ended interviews were conducted with the above Clinicians, which helped to direct the focus of the research in Electronic Healthcare Record and various other related topics.

The meeting with those clinicians was an excellent opportunity for me to present my research finding that comprises a number of new contributions to knowledge, ensuring that the outputs are well recognised and gain in-depth knowledge of fundamental principles and the latest trends in the e-medical systems.

1.8 Overview of the structure of the Thesis

The Thesis is structured as follows:

Chapter 2: This chapter presents an overview of relevant published literature and research on subjects associated to or may have potential relevance to the Electronic Patient Record (EPR) and Electronic Health Record (EHR).

Chapter 3: The aim of this chapter is to overview the characteristics and significance of electronic healthcare record with particular attention to the current situation within interoperability and standardization issues that need to be adjusted for accessing, storing and sharing processes of EPRs.

Chapter 4: This chapter summarises the EHR national strategies carried out by three selected countries, so that the knowledge acquired from these systems, their EHR programs and their answers to barriers may present useful guidelines for other researches or projects to learn from.

Chapter 5: In this chapter the following idea is explored: greater sharing of more detailed healthcare information has the potential to improve the quality of patient care instead of minimizing the current system into summary healthcare record is explored.

Chapter 6: The aim of this chapter is to present an approach for sharing EPRs based on centralized system model. It uses an Online Transactional Processing (OLTP) and Online Analytical Processing (OLAP) systems to store into and access detailed health records from massive data warehouse storage.

Chapter 7: The chapter presents the SVSEPRS model. The requirements, design and architecture towards building a Client Server, Web and Java based collaborative system model with suitable open architecture for successful collaboration among several dispersed healthcare system organizations are described.

Chapter 8: This chapter describes the evaluation of the model's performance in the light of the show results.

Chapter 9: This chapter present the overall conclusions and the recommendation for future work.

The precise elements of the work, and their connection to the Thesis chapters, are revealed in table 1.2**.**

Chapters	Research phase	The main tasks of the chapter
Chapter 1	**Exploratory Phase**	❑ Explore the need for research. ❑ Set the main challenge and Solution. ❑ Set research aims and objectives. ❑ Outline the Thesis Contribution to knowledge. ❑ Set the research methods.
Chapter 2		❑ Review the main published literatures related to the research.
Chapter 3		❑ Describe the fundamental knowledge of EHR and EPR. ❑ Discuss the Interoperability and standardization terms for EHR.
Chapter 4		❑ Review the EHR national strategies carried out by three selected countries (Canada, Australia and England).
Chapter 5		❑ Explain the significant of accessing detailed patient record instead of summarized patient record.
Chapter 6	**Centralized Model Phase**	❑ Discuss the process of sharing EPR using centralized system model. ❑ Review the architecture of this model. ❑ Overview the advantages and disadvantages of this model.
Chapter 7	**Proposed Model Phase**	❑ Discuss the requirement, architectural design and implementation of the proposed mode (SVSEPRS).
Chapter 8		❑ Assess the scalability, reliability and availability performance of the proposed model. ❑ Assess the performance of the model based on first experiment evaluation. ❑ Introduce the second series of experiments based on OPNET simulation runs.

Table 1.2: *Thesis outline*

Chapter 2

Literature Review

2.1 Introduction

This chapter introduces a number of published literatures and researches on subjects associated to or may have a potential relevance to the term Electronic Patient Record (EPR) and Electronic Health Record (EHR).

For the review objectives, and the discussion that follows, the survey was categorized into five themes:

1- Definitions of various terms that are introduced in the literature to explain the electronic patient's healthcare data.
2- The Inevitability and deficiency of electronic healthcare record
3- Interoperability Standardizing of healthcare records
4- Healthcare communication and Sharing electronic healthcare records
5- Implementing electronic healthcare records

A substantial number (over 150 papers) of important literature on the above topics, were reviewed. Various contributions have not been available as academic papers, but as official reports or national healthcare strategies distributed by different organisations. The collected literature was reviewed to place the state-of-the-art research in these fields and the outcomes were too large to be cited comprehensively here. However, we have sifted this literature, focusing mainly on those publications that have, based on author's estimation, had an important influence on the above themes and on the results reported. Thus, a mixed strategy to identify vital contributions to the literature has been identified.

The purpose of this chapter is to place this research in relation to existing literature, and to give the background theory for the proposed model that will be introduced at the later chapters of this Thesis.

2.2 Definitions

The recent expansion of the national strategy for healthcare system gives the impression to include an evolution in the working definition of an electronic patient's healthcare record. Several terms are introduced in the literature to explain the electronic patient's healthcare data such as Electronic Health Records (EHR), Electronic Patient Records (EPR), Electronic Medical Records (EMR) and Computerized based Patient Records (CPR).

Based on a discussion between stakeholders in Australia and New Zealand, these countries decided to develop a Standard as an Australian Standard instead of an Australian/New Zealand Standard. In 2005, a report showed that Electronic Healthcare Record Standard was prepared by the Joint Standards Australia and New Zealand Committee IT-014, Health Informatics. In the definition section of EHR, it realized that ''there is as yet no one internationally accepted definition of the electronic health record'' nor the electronic patient record [28]. This is mainly because of the definitions provided by those organisations referred to different terms for the EHR such as the EHCR, EPR, CPR, and EMR, as each of these names are from time to time given diverse shades of meaning in various nations and various healthcare environments.

Several different terms illustrating systematic electronic record storing for patient healthcare information have been used at different times, by different nations, authors and different organizations. This diversity is due to the difficulty of encapsulating numerous features of EHR, and because the differences between these terms are not very obvious. Thus, it is essential to agree on the meaning of these expressions, which are often used to illustrate related concepts [29, 30].

The most common definitions for the EHR, EPR, CPR and EMR from a range of different countries, authors and organizations are listed in this section.

The term CPR is mostly used in the U.S. and it has similar function as EMR or EPR. However, in 1991, Institute of Medicine (IOM) published a report, in which, CPR definition presented as “an electronic patient record that resides in a system specifically designed to support users through availability of complete and accurate data, practitioner reminders and alerts, clinical decision support systems, links to bodies of medical knowledge, and other aids” [31]. The report aims to enhance the Electronic Patient Record and clarifies thinking about the computer-based patient record (CPR). It recommended that the functionalities described in the definition of the CPR can be used as the standard for electronic medical records.

In 1998, Marietti indicates that these terms illustrate systems that provide a “structured, digitized and fully accessible patient record” [32]. This was an answer to HIMSS Leadership Survey (1998), in which they claimed that there is no commercial definition for CPR. He presents the history and the source definitions for these terms.

The Canadian Advisory Council's final report, (Canada Health Infoway, Paths to Better Health, Feb 1999) provides definition of EPR as "Person-specific information in provincial and territorial administrative systems should (in the context of effective privacy legislation and stringent security safeguards) provide a basis for creating the information resources for accountability and continuous feedback on factors affecting the health of Canadians" [33].

Hannan (1999) describes EPR as “an essential tool for collecting and integrating medical information in order to improve clinical decision-making” [34]. EPR has also been described by Hassey et al., (2001) as “general practice records containing data on an individual with a list of entries about the individual’s medical health” [35], while Nøhr et al., (2001) says that the main role of EPR is to improve teamwork and patient focus [36].

Grimson (2001) and Ueckert et al. (2003) refer in their description of EPR “to meeting new patient demands” [37, 38].

Grimson (2001) outlined the existing situation of research into Electronic Healthcare Records. He stated that the main obstacles to develop an Electronic Health Record are the need to develop methodologies of software engineering, the lack of usable standardization, and the deficiency to recognize the influence of record systems on the healthcare system itself. He concluded that the “next generation of EHCR (Electronic Healthcare Record) will be a longitudinal cradle-to-the-grave active record readily accessible and available via the Internet, and it will be linked to clinical protocols and guidelines to drive the delivery of healthcare to the individual citizen” [37].

The report provided by Health Information Network for Australia (HINA, 2000) defines EHR as “An electronic longitudinal collection of personal health information, usually based on the individual, entered or accepted by health care providers, which can be distributed over a number of sites or aggregated at a particular source. The information is organized primarily to support continuing, efficient and quality health care. The record is under the control of the consumer and is stored and transmitted securely.” [39].

This report describes the fundamentals of building a national health information network to support a system of electronic health records to ensure that information is used to help patients obtain the best Healthcare. It highlights the possibility of EHR to improve the health of Australians via access to accurate and immediately accessible information.

Australia’s planned system of electronic health records (HealthConnect) has defined the EHR as: ‘‘a series of event summaries, each containing key information about a specific healthcare event such as a general practitioner consultation, hospital admission or discharge, community health centre visit, pathology test of a pharmacy dispensing a prescription’’ [40]. The European Committee for Standardization (CEN 13606, 2000) introduces EHR by a simple definition as “a healthcare record in computer readable format” [41].

Similarly, the Advisory Committee on Health Infostructure of Canada, (2001) has defined an EHR as “a longitudinal collection of personal health information of a single individual, entered or accepted by healthcare providers, and stored electronically. The record may be made available at any time to providers, who have been authorized by the individual, as a tool in the provision of healthcare services. The individual has access the record and can request changes to its content” [42].

In 2002, John D. and W. Dale stated that the terms EMR and CPR are used interchangeably. They define EMR as “solely an electronic representation of data that makes up a medical record” while CPR as “more of completely searchable representation of a patient and their care. It is almost a complete model of the patient,” [43]. They reported that some practitioners and healthcare organizations thought that such EMR and CPR are too costly to implement and many of them decided to develop their own system. The authors concentrated on the implementation aspects but never mentioned the interoperability process in detail.

ISO/TS 18308 (2003) report lists different definitions for the Electronic Health Record from different countries and introduces a top-level definition for EHR as “A repository of information regarding the health of a subject of care, in computer processable form” [44]. This report is published in seven discrete definitions for the Electronic Health Record; some of these definitions use terms rather than EHR, such as EMR, EPR, CPR, etc.

A better and coherent definitions of EPR and EHR were presented by “Information for health: an Information strategy for the modern NHS 1998-2005” [45], which defines EPR as “the record of the periodic care provided mainly by one institution. Typically this will relate to the healthcare provided to a patient by an acute hospital. EPRs may also be held by other healthcare providers, for example, specialist units or mental health NHS Trusts”.

The EHR as “Electronic Health Record (EHR) is used to describe the concept of a longitudinal record of patient’s health and healthcare, from cradle to grave. It combines both the information about patient contacts with primary healthcare as well as subsets of information associated with the outcomes of periodic care held in the EPRs”.

The main similarities between these different terms are all used to gather, store and manage healthcare patient information. EPRs and EMRs have patient’s healthcare information collected from a single location. EHR record will be constructed from EPRs which are created and stored at different clinical locations, such as Acute Hospitals, Primary healthcare, Mental Health and Social Services. In other words EHR is a combination of different EPRs spanning the whole life of a patient, from cradle to grave.

Unfortunately, most of the above definitions did not clearly illustrate the relationship between EHR and EPR, except the definition from the strategy for the modern NHS 1998-2005, which was the most comprehensive. Therefore, this definition will demonstrate the model of this Thesis.

2.3 The Inevitability and Deficiency of EPR

The significance of EPR has been constantly determined by many countries with several successful implementations. Jonher et al, 2000 developed a model which brings together the electronic documents that can be collected online by scanning the full paper-based patient record after patient is discharged. They conclude that this model enhances the process of data access, which will save costs and it is acknowledged by clinicians [46].

Berg (1999a) pointed out that Electronic Patient Record can have a key point in facilitating and determining vital enhancements in healthcare systems through providing accumulating and coordinating functions, which are needed for exhaustive cooperation between health care professionals in the process of providing care [47]. He described and evaluated the success of standardization and technical realizations’ researches. He concluded that the lack of success in formulating an acceptance was due to its technological bias. Other reason for the failure in EPR projects is the lack of insight into important characteristics of the legal and organizational environment. Berg added that in order to design and implement EPR, the uniqueness of the clinician’s association and the role of such association must be realized.

Some literature proposes that EPR systems present variety of functions, for instance: facilitate process of making orders for medical tests and assisting coordination between different healthcare organizations. Salford Royal Hospital introduced as case study of using EPR showed an encouraging improvements that contributed by EPR to professionals work [48].

On the other hand, the restrictions of EPR systems have been highlighted by other researchers. Benson (2002) argued that the incomplete usability and inadequate security are the main reasons for the lack of success of EPRs in large environments such as hospitals [49]. Benson discusses the reasons and the consequences of not using computer systems by healthcare professionals at hospitals while every General Practitioner has their own system. He concludes that in order to link computer based health services, the government should supply suitable encouragement to hospital clinicians, which will complement the linking processes.

Walsh (2004) pointed out that at the same time we gain clear advantages from using of EPR; a paperless approach is not necessarily better than a paper-based record system. He declared that “reading from a computer screen is up to 40% slower than reading from printed text”. He talks about the obstacles of health record data entry and how it requires more work from the clinicians. He encouraged clinicians to utilize computers in health care organization and suggested ways to choosing clinical computer systems. His conclusion was that healthcare providers have the option to choose either paper or electronic records [50].

Lærum & Ellingsen (2001) reported that the usage of EPRs in hospitals by physicians is becoming less popular [51]. They compared the use of three electronic medical records systems in Norwegian hospitals for general clinical tasks and used a questionnaire to evaluate this conclusion regarding the use of EMR systems among clinicians in the Norwegian hospitals.

Ellingsen & Monteiro (2003) argued that the EPRs in hospitals only marginally improved compared to the initial objectives [52].

At present, this is a wealth of knowledge in computer based database management. It is therefore desirable to use the existing knowledge in this field to design a sharp EPR system that could improve the program of a cost effective and efficient healthcare system.

2.4 Interoperability and Standardization of EPR

Published literatures reveals that there is a need for standardization of how information is represented and organized in Electronic Patient Records as well as interoperability standards that can allow healthcare systems to share EPRs. Winthereik (2003) and Berg (1999b) pointed out that electronic patient records (EPRs) are increasingly being used as an instrument to standardize healthcare patient records which is not achievable with the paper record [53, 54].

Bossen, (2006) indicated that the standardization term comprise EHRs structure, content and the way of exchanging them, which will assist and improve the connection between healthcare providers at distributed sectors, share of data between distributed EHRs, and support everyday medical work [55]. He described the electronic health records’ (EHR) standards and evaluated the results of testing a prototype electronic health record (EHR), which was based on a standard of EHRs called BEHR. This was developed by the National Board of Health in

Denmark. He concluded that the prototype needed more work in order to cover all the aspects required to achieve an absolute EHR standard.

Number of standards already exists to deal with the EHR architecture and interoperability functions, such as CEN EN 13606 EHRcom (CEN prEN 13606-1 2004) [56], the Health Level 7 Clinical Document Architecture (CDA) [57], the (ISO/TC215) Working Group1 [58], and openEHR [59]. (These standards will be covered with more details in chapter 3).

CEN/TC 251 is the technical committee on Health Informatics of the European Committee for Standardization while CEN ENV 13606 2000 is a message- based standard for the exchange of electronic healthcare records. At present, there is a working group to revise this standard to address interoperable EHRs. This consists of five parts. The first part (which has been published) holds basic information model for communication between EHRs. The second part holds a basic information model for symbolizing and connecting the model occasions. The third part will include models reflecting a diversity of clinical requirements. The fourth and fifth parts are the strategy for adapting the part 3 and 4 subsequently.

Eichelberg et al. (2005) pointed out that as well as integrating the Healthcare Enterprise (IHE), an industry initiative specified the Cross- Enterprise Document Sharing (XDS) integration profile for this purpose [60, 61].

They introduce a survey of seven known and important EHR standards (HL 7 CDA, CEN prEN13606, OpenEHR, DICOM, ISO/TC 215, IHE and Medical Mark up Language) in order to clarify the following points: the level of interoperability support, functionality, complementary and Market relevance. Ingenerf, et al. (2001) indicated that standardized medical vocabularies is another related issue which is the central in healthcare system’s architecture and there exists a number of nomenclatures (e.g. ICD9-10, SNOMED, UMLS, ASTM, Read codes (UK)). They revealed that the main challenge for integrating separate applications is the variety of medical vocabularies that currently coexist in different domains. Therefore, terminological standardization is needed to improve the interconnection between heterogeneous healthcare systems [62]. Akram et al., (2007) argued that although there are many programs has been introduced for accomplishing the interoperability, current EHRs are simply not outfitted with data items in order to share them between different healthcare organizations. They described sharing of patient healthcare data between healthcare location in the UK using aggregated and non-aggregated schema for extraction of patient data, which are stored in General Practitioners’ database. They revealed on the significance of database elements that stored at GP location to facilitate valuable data sharing [63].

There is a desire to create international standards through which Electronic Patient Record can be shared among different healthcare organizations nationally and internationally. Although there is strong desire to achieve a common standard for EHRs, the existence of several standards will move all the complexity and cost of margining EHRs.

2.5 Communication and Sharing EPRs

The most significant key feature of the EHR is the ability to share EPR information, which is the fundamental element of the healthcare system.

Berg (1999a) [20], and Walker et al. (2005) [64], pointed out that implementation of a standardized interoperable EHR system in order to accumulate and coordinate processes between all healthcare organizations in the United States could end with a net benefit of $77.8 billion per year once fully implemented.

Berg revealed that the roles of formal tools in medicine (including computerized patient records) are more than just 'transparent' or 'supporting' tools. He emphasized on the need for coordination processes due to the complexity of healthcare system. Walker et al., on the other hand, reviewed the interoperability of electronic healthcare information exchange between providers (hospitals and medical group practices) and independent laboratories, radiology centres, pharmacies, and other providers. The authors showed that it will cost a net value of $77.8 billion per year if the system has been fully implemented.

Schneider & Wagner (1993) argue that utilizing Electronic Patient Record in a secondary healthcare will support shared work via expanding the field of shared data. Using EPR will also supply clinicians with relevant information located at different locations over different times [65]. They were mainly concerned about the design of information objects to be exchanged than to the characteristics of the distributing system. They studied the use of information technology in twelve French hospitals; three cases focused on cooperative work and technology in a variety of settings. In these cases, the authors were concentrated on how the record system is designed and integrated. The Electronic Patient Record systems were integrated successfully in two cases. In the third case, the EPR was fragmented as each unit of the hospital developed its own database and record system that did not support data exchange between the units of the Hospital.

Schiff et al., (2003) indicated that fast and efficient sharing of Electronic Patient Record between disparate healthcare systems can increase patient safety and quality of healthcare. They claimed that better integration of clinical laboratory and pharmaceutical data will effectively manage clinical care for both inpatients and outpatients demands [66]. Unfortunately, the recent internal Department of Health document (NHS CRS consent/dissent: information sharing rules), revealed that the database will be unable to fulfil some of the NPfIT's expectation [67]. It will not be possible for clinicians working in one "instance" to access the Detailed Care Records (DCR) made by clinicians in another "instance", due to technical limitations. Liederman and Morefield, (2003) pointed out that web messaging (the process in facilitating communication between healthcare providers) can provide a stability of care [68]. They used web messaging system as a solution for Patient demand to have an electronic access to their provider. The result shows that an electronic communication between healthcare providers and their patients has been improved provided that clinicians respond in time.

However, Wagner, (2000) indicated that electronic health communication is crucial in sharing EPR systems, particularly, for patients with chronic diseases who routinely have different providers in various locations that must have a coordinate care plans [69]. He showed how skilled clinicians and educators who have both clinical skills and self management support skills can have a positive effect on chronically ill patients. On the other hand, the existence of a skilled and educated team may be of insignificant help when clinicians are unable to share care efficiently.

Chu S. J., (2006) perceived that in order to accomplish sharing of electronic patient data electronically, there is a need to integrate databases that have such data from different locations [70]. Akram et al., (2007) believed that by building component based software applications upon autonomous databases, sharing patient records will be possible without database integration [71]. Winthereik 2003 reported that the accumulation and coordination processes due to the use of EPR will positively affect the production of discharge letter as well as assisting GPs to code and make accounts in their clinic [72]. Hartswood et al. 2003 described variance between the actual task of EPR in integrating processes and the everyday healthcare services [73]. They claim that the benefits of EPR system can be provided if there is a clear vision of the work they are intended to support.

The tasks and roles of the multiplicity and heterogeneity of medical record have been explained by Geoffrey Bowker (1997) [74]. He demonstrated the achievement of the interaction and coordination between different locations.

Halamka et al., (2005), pointed out that the interoperability of healthcare systems between different U.S regions has been executed with restricted achievement due to a limited geographical area [75].

They showed that the healthcare system in the U.S is constructed in a heterogeneous and uncoordinated approach, which could make islands of patient information in the healthcare locations and lead to a waste of time and huge medical errors. Grimson et al. (2001) has identified an approach for sharing Electronic Patient Records over the internet. This method will provide an integrated view of EPRs which are created heterogeneously, and can be viewed by the clinicians electronically at any time [76]. Jung, B. (2000) presented an approach, which is being developed as part of a major EU (European Union) Health Telematics project, for sharing EPR between heterogeneous distributed systems [77].

2.6 Implementing EPR

Smith (2003) pointed out that in order to achieve an EPR and deliver high quality healthcare system, clear objectives have to be set out by the users themselves [78]. He highlighted the main subject that were involved in implementing an EPR system in a small healthcare clinic and concluded that selecting vendor and signing a contract is not enough to effectively implement an Electronic Patient Record system. It should focus on the work flow to hardware and software selection and training the staff. He added that the best way to start the implementation process is with precise goals in mind and a project implementation team in place.

Berg (1999b) presented the iterative approach as the most recommended approach for the development process, where any changes in technology requires a change in work practice (i.e. both evolve together), as well as a concurrency between analysis, design, implementation and evaluation stages [54].

Berg and Toussaint (2003) revealed that during the processes of design and implementation, it is essential to look at these processes as experimentation, political negotiation, and inventiveness, instead of trying to perform them centrally [79]. They first argue that an exhaustive modelling of work processes and data flows is the action that needs to be accomplished prior to the processes of developing EPRs. The second argument was in the EPR design: modelling should not be imagined as the essential first step, but rather as an involvement which establish accurate ICT improvement in the organizational progress. Andersen et al. (2002) pointed out that the various impediments and difficulties faced with the implementation and utilizing of the EPR system are more than expected [80].

Holbrook et al., (2003) indicated that the main factor is the deficiency of adequate funding [81]. They described the initiative of the COMPETE (computerization of medical practices for the enhancement of therapeutic efficacy) program, which evaluates the influence of EMRs on competence, excellence and secrecy matters for care. Their conclusions are that a precise and astringent process is needed in EMR choice.

Orfanidis et al. (2004), pointed at technological problems as another obstacle which may occur due to the use of images, sounds and videos, which expand significantly the size of the EPR database [82]. They discuss the kinds of difficulties for sustaining EHRs at national and international levels and divide their efforts into three parts. The first part was about recognizing and maintaining EHRs. The second concentrated on how the data quality can be guaranteed for EHRs. In the third part, they emphasized on certain impediment to the beginning of a Greek national EHR system. They concluded that the enhancement of EHR data quality and the problems that cannot be defeated are due to the existing restricted technology.

Hartswood et al. (2003) reviewed the obstacles caused by a disparity between the work of physicians and the EPR's view of the standard of healthcare systems. This disparity could be due to a lack of understanding of clinician work practices with the systems which are based on unrealistic assumptions [83].

Therefore the best way to eliminate such an obstacle is for the clinicians to be included in the implementation discussions of such system (Walsh, 2004; Darbyshire, 2004) and the agreement would be the key feature towards implementing the Electronic Patient Record [84, 85].

2.7 Summary

To date, there is no agreed definition for EPR or EHR that exist at the international level, but only a small number of official definitions are available at a national level. However, the definitions reviewed in this chapter have different peculiarities, such as very concise, very long or include diverse scopes, but they have more similarities than differences, which occasionally gives various shades of connotation in different countries and different health sectors.

Most of the literature shows that healthcare providers are aware of the benefits of sharing EPR using IT, and there is some confidence to step into this field. On the other hand, the heterogeneous natures of the IT systems' platforms as well as the various data models are the main barriers to share the EPRs that have been reviewed in this literature.

The implementation of Electronic Healthcare Records (EHCRs) is growing internationally, but the efficient implementation is yet to be achieved completely. The implementation faces several obstacles, such as standardization, funding, hardware provision, data point placement, database configuration and population, interface design and training which must be available before starting the implementation processes. Ethical and legal issues are one of the main obstacles that face implementation of the EHR which influences the privacy and security of patient's personal and medical information.

The correct Interoperability that can be used to increase the quality of healthcare services provided is when clinicians have access to the necessary EPRs' fragments and not about storing all the details of the 'cradle to grave' records. Thus, the main goal of healthcare providers is to have an immediate access to the most required EPR segment in the right form at the right time without any concerns about where the data is held and by whom.

Chapter 3

Interoperability Standards: the most requested element for the Electronic Healthcare Records significance

3.1 Introduction

Within the complexity of present healthcare systems, there is agreement that paper-based records can no longer reach the requirements of advanced health care system [86]. Computers have been used in healthcare organizations for decades to facilitate the integration and manipulation of patient's data and improve the clinical decision making process to be more efficient with respect to accuracy and convenience. The current understanding of what constitutes electronic health records has evolved as technology, system capabilities and healthcare information needs have grown.

In recent years, high percentage of nation's office clinicians frequently utilize computers to provides healthcare services, and that the speed of adoption is expected to grow as the technology expands. The introduction of electronic data accumulation, accessing and manipulation is significantly influencing the process of healthcare decision making. Information is significant if it is accessible as and when required. To improve the quality of services and to ensure consistency of healthcare delivery, various healthcare professionals are increasingly needed to improve data communication between their systems, which can be achieved by using Electronic Health Record system [87, 88].

The concept of electronic healthcare record has been around for about 30 years, and has incrementally evolved over these years. One of the significant initiatives set out in Healthcare organizations is the development of Electronic Health Records (EHR), which will inevitably replace the paper record at some point in the near future. Different patients records are created and stored at different healthcare locations due to an increasingly mobile society, such as patients relocate and changes their General Practitioners (GP) more frequently as well as many patients no longer have a single GP who provides their total care [89].

The EPR gives the ability to share patient records which facilitate healthcare professionals to advance the reliable and successful of knowledge-intensive health care delivery, avoid medical errors, improve quality, and enhance efficiency of the healthcare provided at the point of care. For instance, access to such factors like clinical laboratory test results or a list of recommended medications will assist healthcare providers in achieving enhanced clinical decisions based on medical history of the consumers.

Different titles are laid at the heart of the evolution of Electronic Healthcare Record such as accessibility, interoperability and standardization. It is anticipated to have a significant influence on healthcare organizations in the near future through enhancing communications between different healthcare institutes which involves high level of interoperability.

Interoperability concentrates on the necessity of healthcare information to be linked up so that information is available 24/7 from any healthcare organization. This communication will improve accessibility of the patient care record, so clinicians who require patient's personal or medical information are not restricted by the limitations of time or location, as they will have a reliable 24 hour access to relevant information that can be available from different places.

The barriers to the adoption of electronic healthcare records are formidable. The technical obstacles are relatively obvious; in addition there are organizational, financial, technological and political barriers. However, the structure of EHRs and the approaches required for exchanging patient information may differ significantly. Therefore, EHR structures, content and communication standards are essential to solve these obstacles in order to facilitate sharing medical data or medical records [90]. Also, clinical data can be enormously complicated because of the profusion of medical terminology and the complication in the pattern of the presented clinical information. Therefore, this information should be displayed in a standardized pattern to certify that these clinical terminologies are commonly comprehended and structured. Various EHR standards, defined by various initiatives that vary from nation to nation encompassing diverse matters of EHR standardization have been introduced.

The aim of this chapter is to overview the characteristics and significance of EHR with particular attention to the current situation within interoperability and standardization issues that needed to accommodates the accessing, storing and sharing processes of EPRs.

This chapter is structured as follows. Next section presents the evolution of EHR. Section 3.3 introduce and discuss the definitions and relationships between EHR and EPRs. Section 3.4 define and discuss the prerequisites of Interoperability and section 3.5 discuss the EHR standardization. Finally, section 3.6 concludes the chapter.

3.2 The Evolution of Electronic Health Records Service

The healthcare service delivery is as old as civilization itself. Archaeological findings give definite verifications of this truth and already Babylonians, Chinese, Egyptians and Indians confirm the term of healthcare as a publicly validated accountability [91].

The concept of a patient's healthcare information stored electronically instead of on paper has been around for several decades. However, healthcare organizations did not directly adopt the EHR. Many of the former systems are still not paperless, as healthcare professionals applied both an electronic and paper-based healthcare record systems.

Electronic Medical Record dates back to 1960, as healthcare system became more complex; patient's full history was not easily accessible to healthcare providers. The new efforts of pioneers, Lawrence Weed and Warner Slack, introduced the problem-oriented medical record and computerized patient record keeping that time [92].

The Problem-oriented Medical Information System (PROMIS) from the Medical Centre Hospital of Vermont prepared the healthcare record based on patient problem list using a SOAP format (subjective, objective, assessment, plan). Later on, time-oriented record keeping model was released via Rheumatism Association Medical Information System (ARAMIS) [93], in which clinical information was collected and displayed as a flow chart.

In 1970, the PROMIS was applied in a medical area in the Medical Center Hospital of Vermont for the first time [92]. In the following two decades, new thoughts and functionalities were appended to the electronic medical record system in order to improve the quality of healthcare provided.

Other systems, such as the Summary Time-Oriented Record (STOR) at University of California, the Regenstrief Medical Record System (RMRS) at Wishard Memorial Hospital in Indianapolis (which showed healthcare professionals warning messages of actions which may or may not be carried out), and The Medical Record at Duke University, were all released in years between 1970 and 1980 [91].

The term electronic health record (EHR) was first coined by the American Society for Testing and Materials (ASTM) and recently, in 1991, the IOM (Institute of Medicine) report defined the CPR (Computerized Patient Record: An Essential Technology for Health Care), calling for the elimination of paper-based record within ten years and applying an electronic record that exist in a system specifically considered to assist healthcare providers through accessibility of full and precise healthcare data, healthcare provider's alerts, clinical decision support system and other benefits [89, 94].

After 1991, a range of specialty healthcare records, such as HIV, diabetes cardiology healthcare records are applied in several healthcare organizations to handle consumer's treatment [95]. As computer technology rapidly developed the adaptability of EHR become much easier.

Currently, national strategies for electronic healthcare record service are growing, and moving towards stages of conceptualization, analysis, design, implementation, and testing, but, the development of national strategies is still in the early stages.

The main warnings to learn from the above review is that, despite significant indications to support approval of EHR, development has been slow to date and many healthcare organizations are still using a mixture of paper-based and electronic healthcare records.

3.3 Electronic Health Record versus Electronic Patient Record

As described earlier, in chapter 2, the concept of electronic healthcare record has been described by various names, based on the nation and the actual healthcare providing the care. These are Electronic Medical Record, Computerized medical record, Computerized Patient Record, Computer-based Patient Record and more recently the Electronic Patient Record and Electronic Health Record, which will be used throughout this Thesis. It is essential to be aware of that various definitions of EHR and EPR have been presumed over the past few decades in order to argue and analyze viewpoints of the Electronic Healthcare record. The Electronic Patient Record can mean many different things to different people at different countries. It is obvious that there is a need to determine explicitly what EPR means and how it is differentiated from EHR. The following discussion will clarify the confusion and agree on the ultimate definitions for EPR and EHR. EHR is mainly applied for setting up patient care records and evaluating the healthcare delivery. It comprises information concerning healthcare providers and consumers during episodes of care provided by different health care professionals from various healthcare organizations [96].

The definition of EPR and EHR provided by NHS (in section 2.2) shows that EPR is normally relates to the healthcare provided by acute care hospitals or specialist units. Even though there are differences between Electronic Health Records (EHR) and Electronic Patient Records (EPR), effectively, these terms describe systems that provide a "structured, digitized and secured accessible record." [97], except that EHR is a complete and lifelong record and it combines information about patient contacts with primary healthcare as well as subsets of information associated with the outcomes of periodic care held in EPRs. The relationship between EPR and EHR is illustrated in figure 3.1. It shows that whenever a healthcare consumer visits acute care hospital, mental healthcare, or has some other treatment from the GP or a community service, an EPR is created and kept. Therefore, different records about the treatment of the same person in various locations can be created. In each acute care hospital, there would be one EPR per patient and various departments would be able to check if and when they require any information about patient. It is clearly shows that the EHR record will be built from several EPRs created and stored at different healthcare locations.

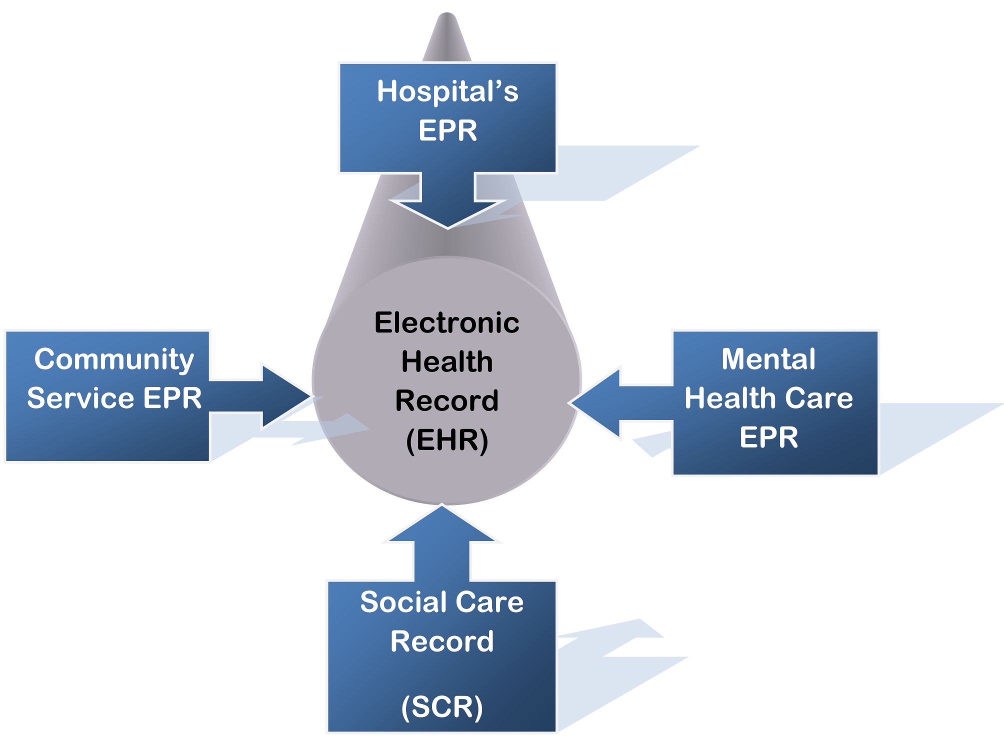

Figure 3.1: *Relationship between EPR and EHR*

However, the definition of EPR and EHR that has been provided by England NHS has no obvious variances to the definitions provided by ISO and also they have gained quite widespread prevalence even outside of the UK, therefore these definitions will be used throughout this Thesis, depending on the context in which these terms are utilized.

3.4 Interoperability

One of the main challenges in introducing patient healthcare records is the development and use of systems that advance communication and information sharing. Sharing information is an essential aspect of communicating with colleagues and patients about the delivery of care [98]. Medical errors caused by deficiency of healthcare information are categorized into different segments: a flop to have ability to access healthcare information, a flop to have reliable healthcare information and flop to apply healthcare information. The deficiency of instant access to patient healthcare information is the cause of one-fifth of medical errors [99]. Many other drawbacks occur from the deficiency of connectivity. Since healthcare professional regularly work autonomously, the deficiency in accessing vital healthcare information segments and shared knowledge can produce duplicate clinical tests to be arranged, consequential in extra cost as well as, danger, and pain. Similar trouble occurs for medications, which can differ with another to cause life- warning through medication conflicts. Connected and unconnected electronic systems would be coordinated and interoperable, meaning that healthcare information is accumulated and stored into an electronic holding place called data repository. All pertinent data would be shared between healthcare professionals in the same or in different organizations.

In the literature, various definitions have been introduced for the term Interoperability. In this Thesis, refer to the definition presented by Brown and Reynolds in year 2000 [100] “Interoperability with regard to a specific task is said to exist between two applications when one application can accept data (including data in the form of a service request) from the other and perform the task in an appropriate and satisfactory manner (as judged by the user of the receiving system) without the need for extra operator intervention”.

Several interoperability methods have been introduced for instance ODBC (Open Database Connectivity) data gateways, message queues and interface engines, software adapters, and Web services. The advantages of the interoperability system will cover both consumers and healthcare providers, which can be classified into improved expediency, privacy, access, and quality of healthcare services. Interoperability improves expediency by allowing healthcare providers to share patient’s clinical history, laboratory test results, and other significant information in an opportunity and accurate manner. Interoperability offers consumers with more privacy via preventing the not permitted users to access and tracking healthcare providers who view patient healthcare information. Interoperability system may reduce the time that consumers and providers should consume during filling out clinical application forms, which influence both cost and expediency. In the same way, interoperable system enhances stability of healthcare when service provided is conducted between multiple healthcare providers, specifically for consumers with chronic illness. Interoperable system assists consumers who travel between different regions and guarantee consistency of healthcare service provided.

Presenting interoperable EPRs will achieve high efficiency to the quality of patient care by facilitating the retrieval processing of clinical information located at various healthcare locations. Concisely, interoperable patient healthcare records improve the quality of healthcare provided.

3.4.1 Barriers to interoperable healthcare system

Implementing interoperable healthcare system may face various challenges:

Companies that deal with electronic health record systems have financial motivations to act against each other. However, by introducing EHR standards, pressure will increase on these companies to support their consumers connected systems quicker and simpler than ever before.

Other obstacle to achieve interoperable healthcare system is the huge cost needed to reestablish a complete system, includes a needs to updates, replacements, and changes in software, hardware, and procedures as standards and training are advanced.

However, standardization is the major step required for sharing and classifying healthcare information with respect to quality and proficiency way.

3.5 Standardization

Typically, electronic healthcare system consists of a variety of independent distributed healthcare locations, each with its own electronic based system, rather than a massive single mainframe. In order to reduce medical errors and labour costs which are caused by redundant data entry, there is a request to setup and improve connection among those systems.

The EHRs will be constructed and continuously updated from the contribution of one or many EPRs created and stored at different healthcare locations such as acute Hospitals, community services, Mental Health and Social Services.

The capability of EPRs is to create and store patient related information regarding facts such as clinical problems, diagnoses, patient healthcare history and others with information regarding clinical activities and their results, such as ECG, urine test or blood test taken by a specific clinician. This type of information needs to be exchanged among healthcare providers in a contemporary healthcare organization.

The main obstacle about introducing EHRs for local, national or at best international platform is the high number of diverse possessors, different standardized interfaces information systems such as (HL7, EDIFACT, DICOM, etc.), different content oriented standards such as (SNOMED, LOINC, ICD-10) or different hybrid approaches such as (CEN 13606, openEHR), which possibly needs to be integrated at present. Thus, there must be a common perception between participants for real connections to arise. Concisely, in order to make EHR interoperable and universally understood, there is a need to adhere to standards. Standards are the main factor for the implementation of any EHR as it will guarantee that the same interface, data element and approaches are used in the same way despite of the vendors.

Health informatics standardization falls into four categories:

1. The structure and content standard set up and provide clear descriptions to the data elements to be collected and included in the EHR system. This level also specifies the type, the width and the content of data to be collected in each data field. An example for this category is an American Society for Testing and Materials (ASTM) that provide E1384 standard for the content and structure of EHR.
2. The terminological standard defines common definitions for clinical terms to encourage consistent descriptions of an individual's condition in the health record. This standard is truly a challenging task as clinical terminology can even vary between clinicians working in the same organization. Examples for this category are SNOMED CT (Systematized Nomenclature of Medicine - Clinical Terms), CPT (Current Procedural Terminology), ICD-10 (International Classification of Diseases), etc.
3. Communication standard assist electronic data interchange (EDI) via establishing a format and sequence of data during electronic transmission process between two or more independent computer systems.
4. Security standard is to protect healthcare patient information from unofficial access, alteration or destruction. Different standard organizations are involved in this category such as ASTM and Health Level 7 (HL7).

To address the interoperability standards for EHR, there are several government agencies, voluntary groups, and healthcare related associations are engaged in presenting guidelines to support in producing standardization for EHR, such as: ISO/TC 215, CEN/TC251, Health Level 7 (HL7), openEHR, IHE, DICOM, ANSI, etc.

3.5.1 Health Level 7 (HL7)

Health Level 7 is a non-profit ANSI-accredited organization [101], founded in 1987 to provide standards for electronic exchange, integration, sharing, and retrieval of electronic healthcare information as well as financial and administrative information between autonomous healthcare organization systems, such as Hospital, General practitioner services, Community service, Mental health systems and others. The head quarters of HL7 is in the USA and meanwhile other nations like Argentina, Australia, Canada, Finland, Germany, India, Japan, Korea, Lithuania, New Zealand, Netherlands, UK and Taiwan are officially involved as affiliates.

The term HL7 arrives from "Health Level 7", which refers to the top level of the Open Systems Interconnection (OSI) layer protocol (i.e. application layer) for the health environment. It defines an essential standard for the communication of clinical orders, lab results, radiology reports, clinical observations and several other kinds of clinical data held in EHR. Currently, HL7 is used by almost all of the healthcare vendors and organizations, although a small number of healthcare organizations would now even think constructing a system not including HL7.

However, although HL7 is adaptable to many different systems, it takes a lot of work. When implementing an EHR, it is significant to know that each added system, will take extra time and cost. For each application that is linked, a set up of across reference list must be performed to map clinical codes from the transfer system to the matching codes in the implemented EHR system.

Different version has already been achieved such as HL7 and HL7 Version 2 (HL7 V2) specifications, which are extensively applied by various healthcare organizations as a messaging standard which facilitate different clinical applications to exchange importance medical and administrative data. The recent modification for HL7 (HL7 V3), is appropriate to various characteristics of clinical and administrative data in healthcare uses [102], as it covers specifications of abstract data types, reference information model (RIM V. 1.23), vocabulary area, and the additional XML Implementation Technology Specification (XMLITS) [103].

Reference Information Model (RIM) for version 3 of HL7 is basically based on sets of messages, each message managing a particular interaction requirement among healthcare teams.

It has been a great attempt to develop the RIM as an approach to assist the efficient development of message sets. However, RIM planned to offer a basic foundation approach for healthcare communication but, opposing to a lot of published knowledge, holds domain knowledge, healthcare procedure and workflow management concepts in one “terrific-model". It holds several subjective attributes which are very precise to special domains. For instance, attributes to hold the important data collected from a consumer during his/her admission and the two precise parts for protein and carbohydrate in the Diet class. This method is possible to cause a style that cannot climb up to the extensive variety of EPRs through all healthcare groups, or provide for the future growth of healthcare system and of clinical information.

Thus, RIM is not a firm model for sharing fragments or even whole EPRs among healthcare systems or teams. It also does not provide sufficient way for dynamic search engine for an important part of EPR.

Although, the HL7 organisation is huge and well supported globally; consequently it may establish a leading influence on the new invention of healthcare applications and their interactions interfaces.

Clinical Document Architecture (CDA) is an additional and more specialization of the structured document framework to accumulate the history of patient information, for instance: inpatient and outpatient clinical information, or emergency department clinical information.

3.5.2 DICOM

DICOM stands for Digital Imaging and Communications in Medicine, founded in 1983 by the American College of Radiologists (ACR) and the National Electronic Manufacturers' Association (NEMA). DICOM version 3 has been released in 1993. DICOM is the standard for creation, presentation, transmission and archiving of medical images such as digital X-rays, CT scans, MRIs and ultrasound as well as images from angiography, endoscopy, laparoscopy and microscopy [104]. DICOM provide the standard for the communication from a part of imaging tools to a software application as well as identifies the requirements measurement for a file that contains the digital images. Currently, there are 22 Working Groups belongs to DICOM, and it has working associations with ASTM Internet protocol TCP/IP, CENIISSS, JIARS(Japan Industries Association of Radiological Systems), HL7, ISOfI'C215 and ANSI-HlSBB.

3.5.3 International Standards Organization’s Technical Committee (ISO/TC 215)

ISO/TC 215 is an international standards body deals with Health Informatics, whose objective is to accomplish interoperability among independent healthcare systems. ISO/TC 215 is a recent standards body, which has developed a series of new standards and applied other international standards from CEN, HL7 and DICOM as the starting point for their standards. In the following, two standards from ISO will be briefly described, the ISO/TS 18308 and ISO/TR 18307, which are related to the interoperability of EHR.

3.5.3.1 ISO TR 18307

The ISO Technical Report “Health Informatics Interoperability and Compatibility in Messaging and Communication Standards Key Characteristics” illustrates a set of requirements needed for accomplishing interoperability and compatibility to interchange healthcare information among two or more application systems.
It indicates “the interoperability needs of the healthcare community for the subject of care, the healthcare professional, the healthcare provider organization, its business units and the integrated delivery network” [105].

3.5.3.2 ISO/TS 18308

The ISO Technical Specification TS 18308:2004 “Health Informatics Requirements for an Electronic Health Record Architecture” was introduced “to assemble and collate a set of clinical and technical requirements for an electronic health record architecture (EHRA) that supports using, sharing, and exchanging electronic health records across different health sectors, different countries, and different models of healthcare delivery” [106].

3.5.4 CEN13606

CEN TC 251 is the technical committee on Health Informatics of the European Committee for Standardization [107]. In 1999, CEN 13606 has published the four parts pre-standard named ENV 13606 involving in EHR Communications for European Standard [108, 109]. In 2001, CEN/TC 251 decided to review and update its 1999 pre-standard ENV13606 and agreed to the full European Standard EHR named openEHR archetype methodology, defined by the openEHR Foundation [110]. The consequence of this performance is in CEN prEN13606, which has been accepted by 48 countries in 2007 [111]. CEN EN13606 consists of five-parts as classified in prEN13606-1:2006. The five parts of the standard are as follows:

1. The reference model,
2. Archetype interchanges specification,
3. Reference archetypes and term lists,
4. Security features, and
5. Exchange models.

However, at present, only the reference model (EN 13606-1) is committed and parts 2 to 5 are still working drafts.

3.6 Summary

The significant Electronic Health Records are exceedingly growing and adopted by many nations to be shared among numerous healthcare professionals in an ever growing networked environment to achieve complete, fast and easy access processing with high level of confidentiality of patient's information. Interoperability subjects frequently become extremely technical, concentrating on how clinical information is created, stored, and shared between various systems.

To present a complete electronic health record, these systems must be connected, thus facilitating authorized healthcare providers to access required healthcare information.

Due to this expansion and prerequisite for successful deployment of appropriate EHR, relevant standards are essentially desired to enable EHR information to be shared whenever and wherever needed.

However, due to the increased global patient mobility, interoperability standards based on and supported by global agreements on sharing EHR can play a significant role towards improving healthcare safety, quality, efficiency and cost provided to consumers.

Chapter 4

The National Strategies for Electronic Health Record in Canada, Australia and England: General Status

4.1 Introduction

In several nations, superior effort to facilitate solutions to healthcare services, has been established as a key factor for introducing national Electronic Health Record (EHR) system based on a standardized organizational and technology infrastructure. The successful national strategies for EHR are assisted by various factors that must be in place in order to achieve the required electronic healthcare records such as, communications infrastructure, interoperable standards and implementation plans.

However, other aspects, such as cost, politics and extensive geographies may inhibit completion and supporting the agreement on the structure and continuing financial support of EHR projects. Generally, electronic health records are the most common fields that are staying at the top of the nations' priority lists around the world to develop an infrastructure for national health information, such as, Canada [112], Australia [113] England [114] and the United States [115].

To expand restrictions in overall knowledge and explore the factors that influence successful EHR program, this study presents the potential contribution of national strategies designed to play a part to a further understanding of EHR innovations in healthcare field via describing the current status of the selected countries, so that the knowledge acquired from these systems, their EHR programs and their answers to barriers may present useful guidelines for other countries to learn from.

Canada, Australia, and England were selected for an expediency reason, as they introduce a variety of national strategies for electronic health records at different levels. Essential notions exploited during this research are discussed here. These include national health information infrastructure, electronic health record, electronic patient record, healthcare storage and sharing healthcare records.

This chapter is structured as follows; the Canadian's national strategy is overviewed in the next section (4.2). In section 4.3, descriptions of the Australian's national strategy, section 4.4 for England's national strategy have been presented and section 4.5 concludes the chapter.

4.2 Canada

4.2.1 Infoway

Canada's healthcare system, since 1968, has been principally publicly supported.

The government of Canada has started the funding program for Canada Health Infoway in 2002 to develop the Electronic Health Records national strategy and the supporting national health information infrastructure.

Infoway is an autonomous non-profit corporation, responsible to the fourteen federal, provincial, and territorial governments to bring substantial benefits to Canadians by promoting and speeding up the development and adoption of electronic health information systems with matching standardization and communication techniques.

They recognized the spectacular advantages that flow from opportune access to current, accurate and extensive healthcare information.

For this reason, in September 2006, the first Ministers generally approved to support Canada's health IT structure and committed to developing EHRs and data standards to guarantee the harmonious of health information.

In year 2003, the First Ministers acknowledged the success of Infoway to date and expanded Infoway's mandate to include Telehealth. It was arranged that Infoway should get an extra $100 million for Telehealth and $500 million to speed up investments in EHR. In 2004, Infoway was funded with an addition $100 million to bring its total to $1.2 billion in order to support Public Health Surveillance [116].

The EHR supply patients in Canada by a protected and confidential lifetime record of healthcare history and continuum care within the health organization. The record will be accessed by healthcare providers and from different places at different times.

The EHR will contain summary information about healthcare encounters for each consumer. The EHR is not a data store and it is not one system but rather an interoperable network of peer-to-peer related info structures which facilitate exchanging clinical data across organizations [117].

4.2.2 EHR Solution (EHRS) Architecture

The main objective of Canada is to obtain Electronic Health Records covering 50% of Canada by 2009 and all of Canada by 2020 through the proposed national strategy which comprises a network of connected EHR solutions (EHRS), each covering a defined geography [118].

The development of Infoway's architecture blueprint of EHR is based on national and international greatest preparations that have been approved through massive consultations across Canada that assessed the following keys:

- Schemes of identifying the actors in a healthcare encounter.
- Mechanisms to make data semantically consistent and systems are more secure, private, portable, scalable and high performing.
- Approaches for the adoption of the IT systems by healthcare providers to be integrated using loosely coupled manned [119].

The Infoway Blueprint is a peer-to-peer network of interoperable EHR system organized across Canada, as showed in figure 4.1, which presents a vision of the EHR's elements and its communications.

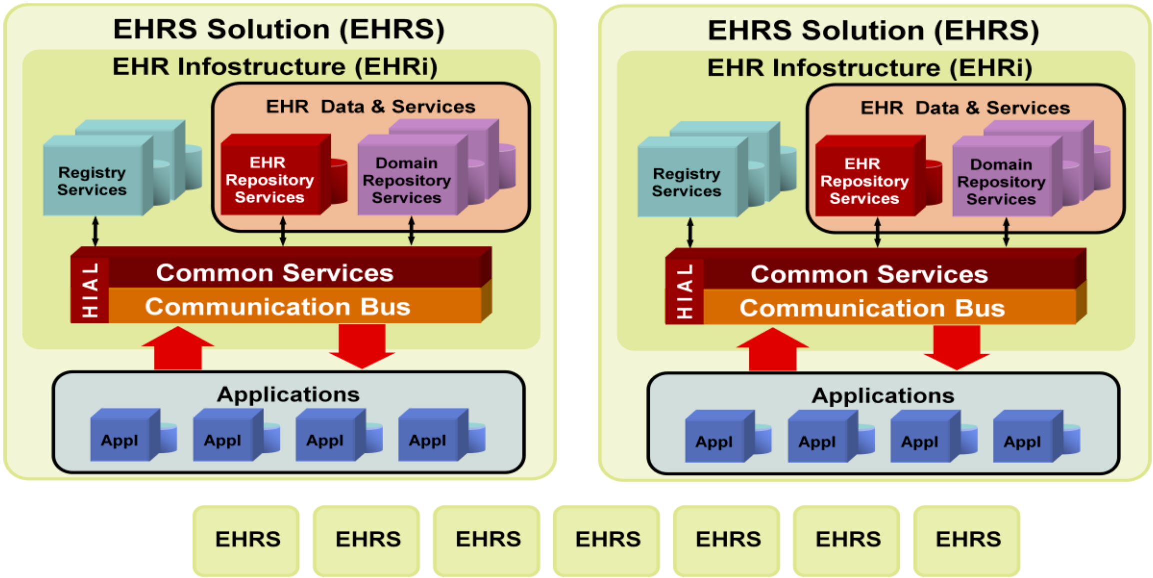

Figure 4.1: *EHR Solution: Distributed, Message-based, Peer-to-Peer Network of EHRS Systems. (Source: Canadian Perspective on an Interoperable EHR, Medinfo September 2004, Canada Health Infoway).*

It describes two EHRS that are interconnected with one another via services assembled in a layer called Health Information Access Layer (HIAL), which is a standard, common, and communication service to integrate applications across the continuum of care and healthcare delivery jurisdictions. HIAL identify elements of services, tasks, an information model and standards needed for sharing of EHR information and finishing of interoperability summaries between EHR services.

Another layer used in this blueprint is to create or use EHR content, which is allowed by HIAL for an abstraction layer for applications (EHRi).

The communicated EHRS across the nation used in this network presents the view of a peer-to-peer, distributed network of interoperable systems that could be available at local, regional or national level, in order to be used by particular healthcare organizations.

The communication with a given set of applications that cover a defined geography of points of care would be provided via EHRS. Therefore, authorized users who are connecting to any EHRS entry points, will get a secure access to all healthcare patient information existing across the network.

Each EHRS, contain an EHRi to store, maintain, and provide access to EHR information about consumers who have access to the healthcare system in the given jurisdiction.

By using EHRi, clinical data to share will received (pushed) from operational systems used in healthcare organizations into EHR or provide EHR data back (pulled) to the provider's application at the same operational systems.

A grouping of both the EHR repository (contains information healthcare encounters of each person) and the domain repository (such as drugs or medication profiles, laboratory test results and diagnosis images.) systems are situated at the centre of the EHRi which required to have a patient-centric, lifetime, federated data for a consumer.

The second component of EHRi is the registry services that provide identification resolution services which are needed to be used for identifying the setting of any transaction.

4.3 Australia

Australia, with a population of around 20 million has total health sector expenditure of $66.6 billion in 2001/2002 (Australian Dollar), representing 9.3% of the GDP [120].

The national Australian Healthcare strategy for electronic health records was prepared in the HealthConnect Business architecture, which included the constructing of a national health information network and a sequence of patient event summaries would form the core of the electronic health records, which would be stored in a federated HealthConnect record system to be utilized by healthcare organizations and in the National Data Store for secondary applications [121].

Medicare Benefit Scheme (Medicare) provide citizens and residents an access to healthcare by offering financial support for medical services such as general practitioner's (GP), public hospital accommodation and treatment as well as some specialist, pathology and diagnostic imaging services.

4.3.1 HealthConnect

In Australia, since the late 1990s, the e-health agenda has been managed at a national level. HealthConnect is the biggest Australia EHR service project at the national level, aimed to enhance the delivery of healthcare, to supply high quality of clinical care and to enhance patient safety and health outcomes.

It involves the collection, storage and sharing of patient clinical information in summary layout through a secure network using precise security protection.

During 2005, national Australian strategy for electronic health records has been changed to be shared between HealthConnect Program Office and the National E-Health Transition Authority (NEHTA).

The HealthConnect program has changed from managing the HealthConnect electronic trials and designing a national EHR architecture to ‘‘ensur[ing] coordinated activity between all areas of the health care sector, underpinned by the mandatory application of specifications, standards, and infrastructure developed by the NEHTA’’. The role of NEHTA's is ‘‘to develop better ways of electronically collecting and securely exchanging health information’’ and ‘‘to establish the fundamental standards necessary to progress e-health” [122].

In 2000, Australia's National Electronic Health Records Taskforce presented a recommendation to create a national health information network, which formed the basis for the development of HealthConnect in 2001 [123].

HealthConnect is at this time moving ahead through three main stages [124].

> **Stage 1:** A research and development to test the feasibility and value of the HealthConnect concept was carried out during 2001/2003. MediConnect (an electronic medication record system), which was under development as a separate project from HealthConnect, was to concentrate on reducing the

incidence of adverse drug events by enhancing consumer and healthcare professional's access to fulfilled medication information.

Stage 2: A continuation of research and development was carried out during years 2003-2005, with an importance on get ready to implement national HealthConnect, at the same time work was continued on architectural design, system and data components.

Stage 3: This stage, which has been moving forward during 2004/2008, started with a transfer in the HealthConnect project from research and development to actual implementation on a national level.

4.3.2 Architecture of HealthConnect

The components of HealthConnect model are a series of event summaries, which produced according to defined metadata covering format, data items and allowable code sets and contain key information about specific healthcare events, such as, allergies, observations, test orders and results, diagnoses, medications and referrals, and EHR lists which will be extracted automatically from the event summaries.

Therefore it is not a full healthcare record and it does not eliminates provider's healthcare records or clinical information systems, but providers will persist in preserving their own patient healthcare records except they may choose to integrate information segments from HealthConnect into their own records.

Authorized healthcare professional would access data from the stored event summaries via a series of predefined HealthConnect views.

Each HealthConnect electronic health record would be stored in two locations: a HealthConnect Record System (HRS) and the National Data Store.

HRS is responsible for performing the processing of HealthConnect event summaries, and query transactions that maintain the primary HealthConnect repository [6]. In order to share information between HealthConnect users, each HRS cooperates with HealthConnect to enable user applications via a common HealthConnect message handling and transport system [124].

The ‘‘federated model’’ of Health Record Systems would enable healthcare provider and consumer access to the event summaries (the operating environment of HealthConnect is illustrated in figure 4.2), while National Data Store would preserve archival copies of EHRs.

Healthcare professional and in order to deliver healthcare services, there are two ways to interact with HealthConnect, the first through a clinical information system and the second by using a Web browser via a provider access portal by handling a provider front-end application. Another access portal will be prepared for the healthcare consumer in order to use a Web browser to access HealthConnect by handling a consumer front-end application.

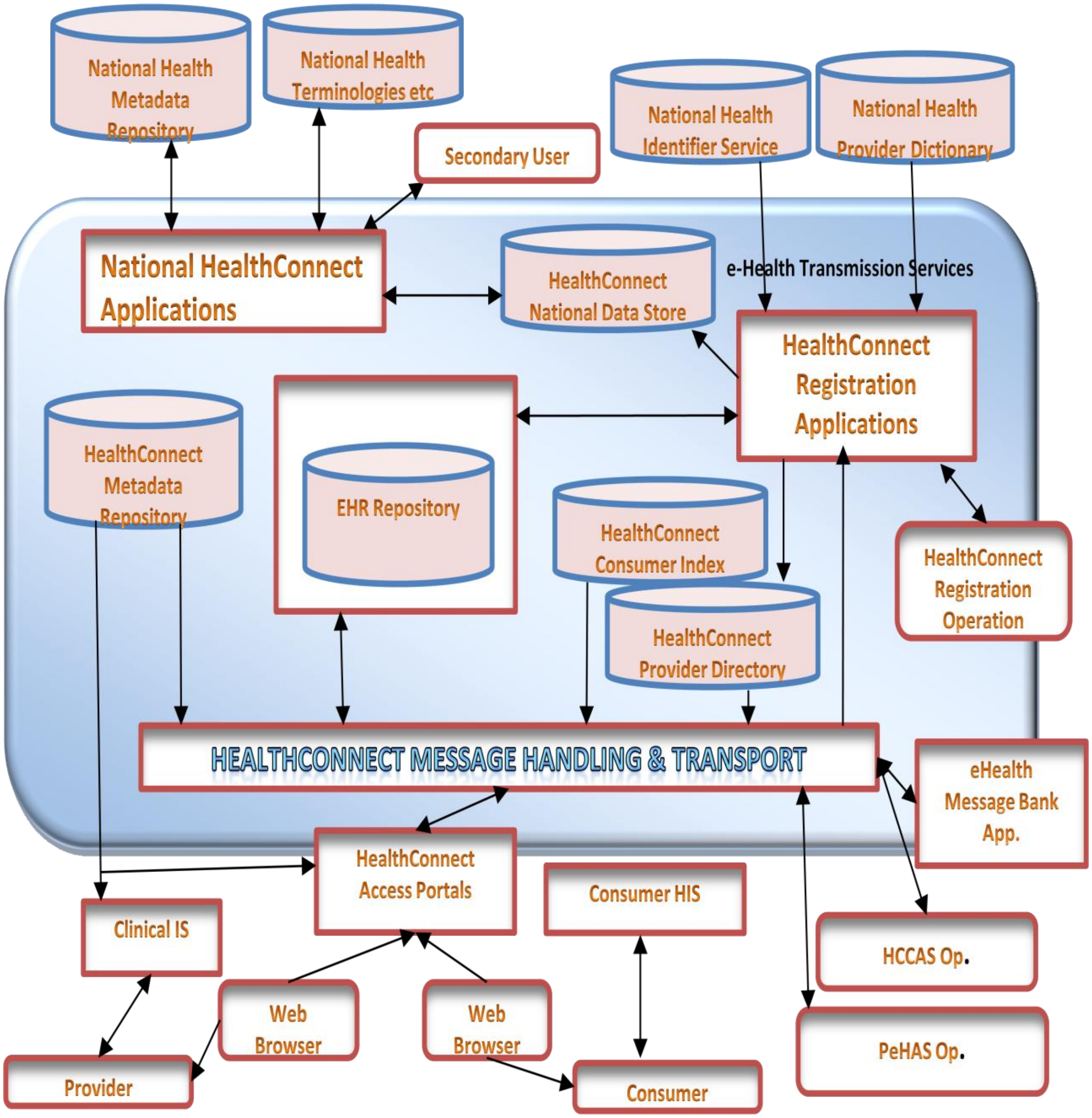

Figure 4.2: *HealthConnect systems overview.*
(Source: HealthConnect Business Architecture, V1.9 Commonwealth of Australia.).

4.4 England

England's may be an exclusive amongst countries with healthcare system due to the National Health Service (NHS), established in 1948, which went through significant restructuring through introducing a national strategy for electronic health records. This started with the publication of Information for Health: An Information Strategy for the Modern NHS 1998–2005, A National Strategy for Local Implementation in 1998 [126].

The Department of Health (DoH) created the structure for the EHR program through its agency, NHS Connecting for Health, which was established as a new NHS executive agency following the closure of the NHS Information Authority (NHSIA) in March 2005 with the main task of delivering the National Programme for Information Technology (NPfIT).

England will be divided into five different geographical areas, called "clusters", (Figure 4.3).

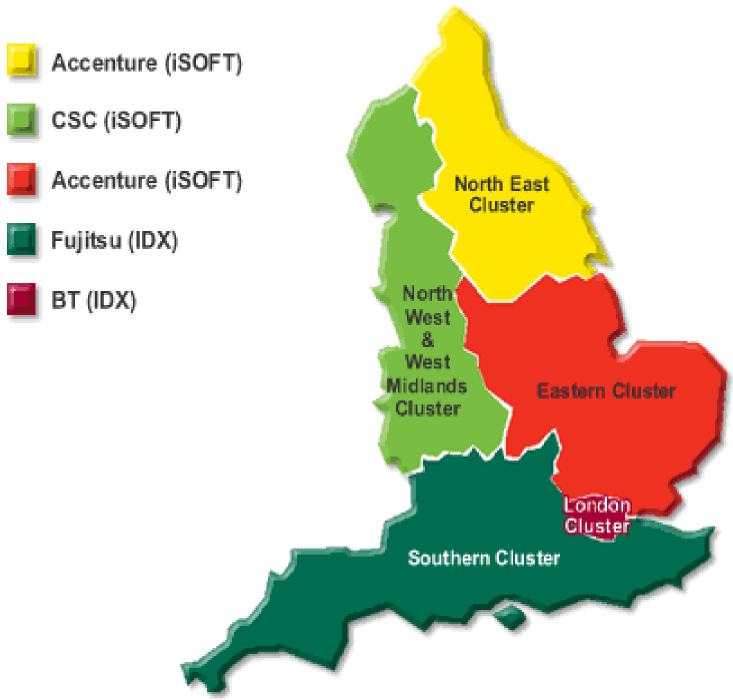

Figure 4.3: *The service providers and cluster for England.*
(Source: NHS Connecting for Health)

Each cluster has being assigned to distinct IT suppliers, and there will be one database assigned for each cluster which can be divided into two or may be more portions called "instances" [127]. The schedule for implementing and integration of health and social care systems of electronic health records is anticipated to be archived in 2010 [128].

4.4.1 National Program for Information Technology (NPfIT)

The NHS CfH presenting the NPfIT remains to be a crucial organization for providing guidance and observing progress of policy development across all five clusters (showed in figure 4.3) [129]. One of the main roles of the NPfIT is to introduce an integrated system called the NHS Care Records Service. Other services will also be supplied by the Program, such as electronic transmission of prescriptions, an email and directory service for all NHS staff (NHSmail), computer accessible X-rays (Picture Archiving Communications Systems), a capability for patients to book outpatient appointments electronically (Choose & Book) and a broadband network (N3).

4.4.1.1 NCRS (National Care Record Service)

The existing EHR project for England, The National Care Record Service (NCRS), allows authorized healthcare professionals access to a patient's Health Care Record 24 hours a day, seven days a week. Patients will also be able to have an access to their own health records online through a service called HealthSpace.
The NHS CRS will connect England's 30,000 GPs and 300 acute, community and mental health NHS trusts in a single national system called "Spine". The program started implementation by a national process during 2003, which led to bestow of contracts in December 2003 to one National Application Service Provider (NASP) and five Local Service Providers (LSP), (Figure 4.4).

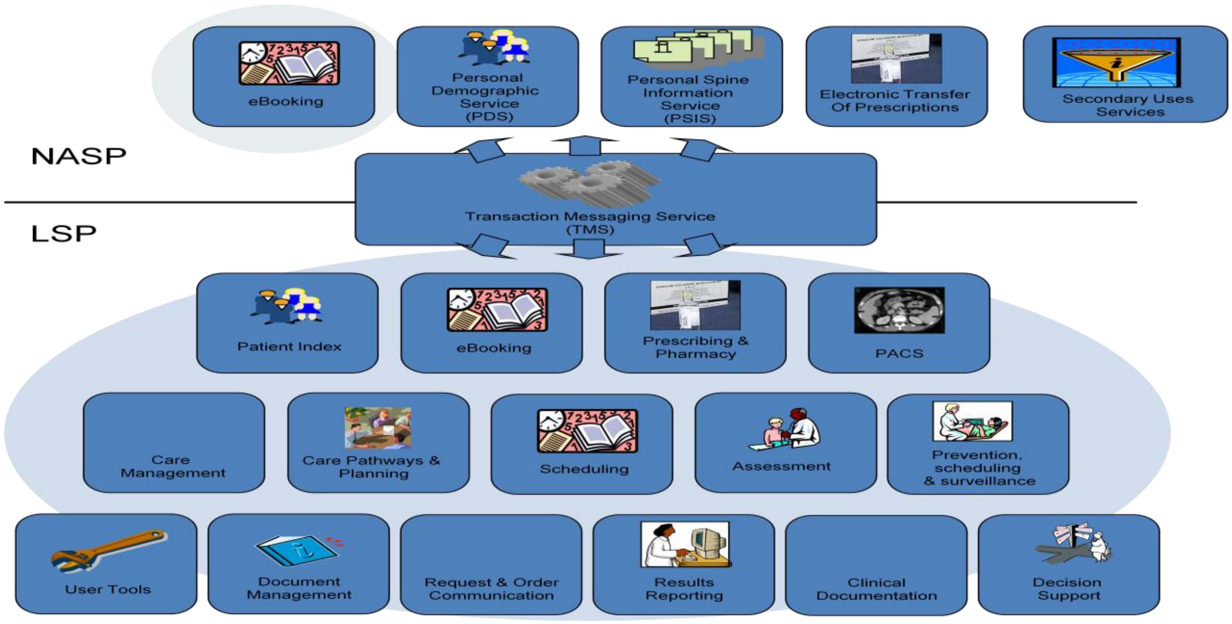

Figure 4.4: *NCRS (One NASP and five LSP). (Source: NHS Connecting for Health)*

Figure 4.4 describes how the NCRS will increase the quality and efficiency of healthcare communications within and across a diversity of institutions such as primary and secondary care. Implementation of electronic patient records is taking place locally in England's five geographical clusters. For each England cluster, there is one Local Service Provider (LSP), which is responsible for developing electronic patient records in each cluster, supplying IT systems and services in the five regional clusters in England to be connecting to the Spine [130]. The Electronic Health Record (which consist of vital information that will be automatically uploaded), together with the locally created Electronic Patient Records, comprise the NHS Care Record (formerly called Integrated Care Record): ''...a cradle-to-grave NHS Care Record for each patient, which will transcend traditional care organizations' boundaries'' [131].

National Application Service Provider (NASP) is responsible for purchasing and implementing IT systems which are common to all NHS users nationally (Figure 4.5) [132].

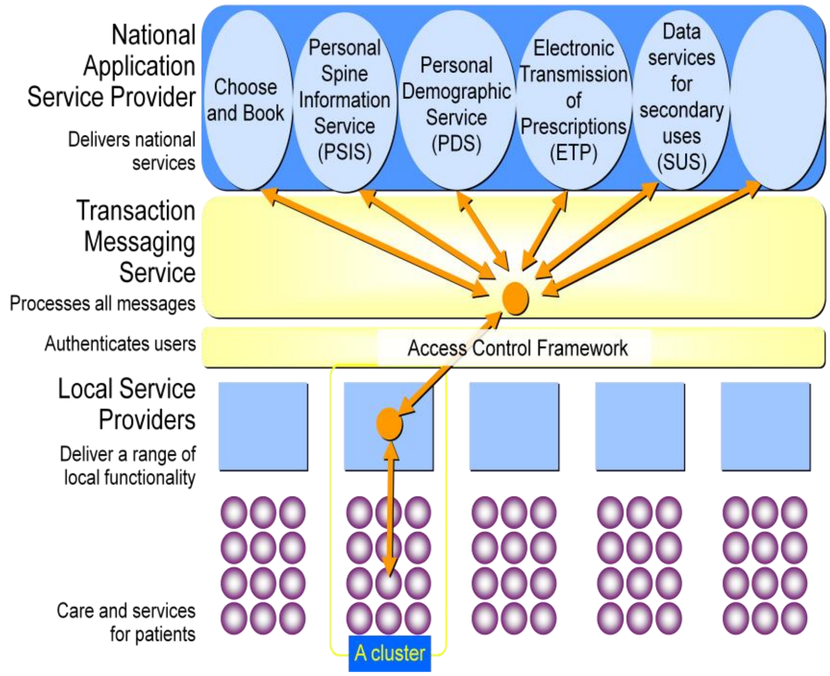

Figure 4.5: *The NHS NCRS.*
(Source NHS Connecting for Health)

NCRS based on two components. The first is Detailed Care Record to be used inside local healthcare where the patient care is supplied. Detailed Care Record (such as pathology test results, drugs prescribed or hospital discharge notification) is to facilitate clinicians to improve the quality of diagnoses processes through order tests and prescribe drugs. The other component is the national Summary Care Record which will be stored on a national database known as 'the Spine', aiming that important information on a patient can be accessed 24 hours a day, seven days a week.

4.4.1.1.1 EHR Storage (Spine)

The SPINE, the heart of the NHS Care Records Service, is the national huge central database containing vital information (summary patient records) about every patient's healthcare [133].

The NHS spine is creating an electronic record for all England's 50 million plus patients, to be feed by critical information from sources, such as GP systems and hospital patient administration systems, from the end of 2004, (Figure 4.6).

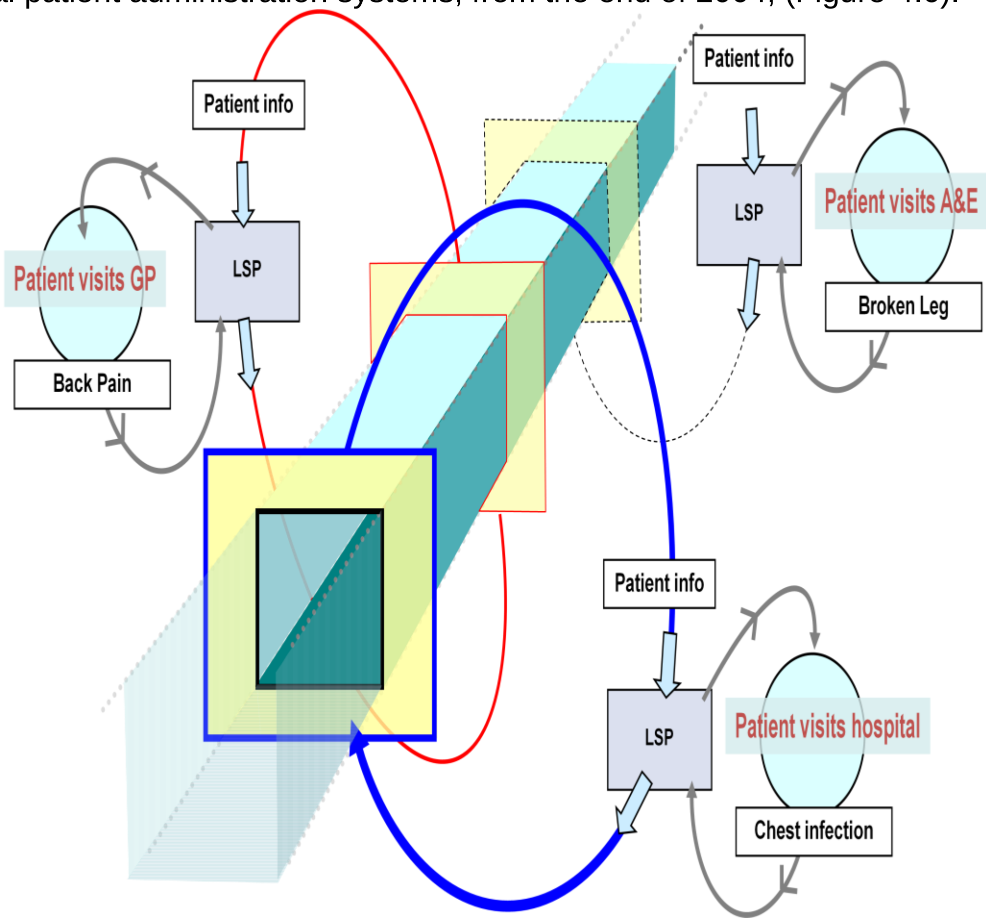

Figure 4.6: *The Spine – clinical events through time.*
(Source: NHS Connecting for Health)

Authorized healthcare professionals can access patient's healthcare Summary Care Record, forming the core of the NHS Care Records Service, e.g. NHS number, date of birth, name and address, allergies, adverse drug reactions and major treatments [134]. Patients will be able to access the NHS spine themselves through 'MyhealthSpace' on the internet, which arranged should be available in the mid of 2005. All patients' NHS Detailed Care Record will be stored at the locally, where most healthcares are administered.

4.4.1.2 Choose and Book

Choose and Book is a national electronic referral service, aims to improve the process of coordination of patient activities. It offers patients an option to choose the hospital or clinic, date and time for their first outpatient appointment and book their appointment by telephone or over the 24 hrs, 7 days a week online service using the internet at a time more convenient to them.

4.4.1.3 ETP (Electronic Transmission of Prescription)

This program aims to improve the quality of primary care service through facilitate GPs role to issue prescriptions faster by transferred electronically to the chemist or pharmacist chosen by the patient and it will be more appropriate for patients to collect their medicines.

4.4.1.4 NHSmail

NHSmail program is providing email and directory service for all NHS staff by NHS Connecting for Health. It gives NHS staff the ability with authorized access to healthcare data to safely and securely exchange patient restricted information between NHSmail users.

4.4.1.5 N3 (New National Network) for the NHS

The New National Network for the NHS (N3) project aims to provide network service and fast broadband connectivity to link England's NHS organizations for enabling data to be exchanged reliably and securely. N3 is the heart of NPfIT, as it would be difficult to supply other components of the NPfIT that need higher bandwidth than the previous networks NHSnet and N2 gave.

4.4.1.6 Picture Archiving and Communications Systems (PACS)

PACS project was introduced to improve the quality and efficiency of diagnosis and treatment procedures by providing organized access to digital images into England's NHS organizations. It captures stores, delivers and shows clinical digital images such as electronic x-rays or scans.

4.5 Summary

There is no strategy that has yet been achieved in completely deploying an EHR on a national basis. However, Canada, Australia and England have accomplished significant improvement in many elements that can be shared in common such as allowing consumers access their own health care records, the selection and implementation of interoperable standards for sharing and managing EHR, and development of patient data security.

However, the national strategies for EHR provided by any nation are considering the healthcare, political, and market system presented by that nation. These strategies are mainly based on two components, the first is technical and standard issues regarding sharing EHR, and the second is the political evaluations.

The strategies for Canada, Australia, and England were reviewed and showed that all develop national strategies for electronic health records have an advanced EHR programs. National strategies are growing, and moving towards stages of conceptualization, analysis, design, implementation, and testing, but, the development of national strategies is in the early stages.

The main warning to learn from the above review is that, despite significant indications to support approval of EHR, development has been slow to date. Apart from England's NPfIT, the growth of those healthcare strategies is in slow stapes; although the implementation of the NPfIT's strategy is moving in protraction steps. Finally, the main drawbacks of judging the success of national strategies for electronic health records are the lack of existing evidence base, misalignment of financial encouragement, lack of an obvious business case for taking up an EHR and for interoperability between EHR solutions and deficiency in measuring and developing EHR standardization.

Chapter 5

The Influence of adopting Detailed Healthcare Record on improving the quality of healthcare diagnosis and decision making process

5.1 Introduction

Personal information is increasingly collected and stored on computers. This will provide a possibility to exchange the vital segments of the stored data with those who require having access to it more easily than can be done with paper-based records systems. Increasing amount and complexity of unused clinical information is one of the main challenges that healthcare organizations face during the processes of gathering, viewing and sharing patient data, especially, when the IT support is not available.

However, this information can provide a powerful tool for change as it is a fundamental and crucial element in the delivery of healthcare quality services that meet the needs and expectations of service users. Years ago, various national strategies for electronic healthcare records including the national health information infrastructure elements related to EHRs and the storage of EHRs have perceived the significance of health information technology for dropping healthcare costs and for improving health care quality and efficiency. As clinical errors becoming apparent, the main challenges facing clinicians is to provide safe and effective healthcare services as these errors lead to a huge cost, afflictions, enduring injuries, and even death [135]. The significant action for avoiding these errors is by identifying them, as the errors if not be perceived, it cannot be managed [136]. Medical errors caused by deficiency of healthcare information are categorized into different segments: the inability to access, have reliable and/or to apply healthcare information. The current quality of healthcare system is evolving fast and dictates a new demand regarding eased and direct access to detailed, available and managed EPR segments as it has not been as successful as in other industries. Personal details about the consumer, different types of medications prescribed at different times, medical tests and other therapies should be accessible by healthcare providers at the point of care as any deficiency of all of the essential information about consumers are possibly the main cause to misdiagnose or mistreat [137]. Detailed patient records are needed to demonstrate competence, simplify and improve medical decision making, the quality of care, the cost of care, the education and credentialing of providers, the development of medical knowledge itself and to justify use of healthcare resources [138, 139, 140]. This chapter describe the main role of detailed healthcare record to improve quality and efficiency of medical diagnosis and preventing errors during decision-making process. This research also discusses the results of the survey carried out for this purpose in order to investigate the impact of deficiency or perfection of detailed patient record in clinical decision-making process. The remainder of this chapter is organized as follows. Section 5.2 and 5.3 discusses the research methods and their results. Section 5.4 describes the theory of Medical diagnosis and errors occur during decision making process. Section 5.5, explains the deficiency in using Detailed Patient Record and how it can be presented in different approaches. Finally, section 5.6 concludes the chapter.

5.2 Methodology

The research methodology of this study was accomplished in two phases which have been explained in sections 1.7.1 and 1.7.2.

5.3 Results

Based on the collected survey, it was concluded that there is a demands for giving an ability to healthcare professional to access full detailed patient record efficiently in order to provide high quality healthcare service.

The survey showed that out of 130 questionnaires dispatched, a total of 120 individual physicians responded to the questionnaires. An overall response rate of 92% (120 of 130) was achieved (see Figure 5.1). 82% (98 of 120) of the responses indicate that detailed Patient Record (DPR) must be adopted as a first choice for healthcare professional to be shared using well designed healthcare system in order to improve the quality of medical diagnosis and avoid clinical decision making errors. Around 8% (10 of 120) of the responses state that Summarized Patient Record (SPR) is enough information for clinician to achieve proper diagnosis and detailed patient records are needed very rarely. Around 6% (7 of 120) of the responses showed that working with paper-based record is the better way for indicating high quality of medical diagnosis. Two questionnaires were sent back uncompleted and an additional three were returned back due to the changes in the physician's addresses.

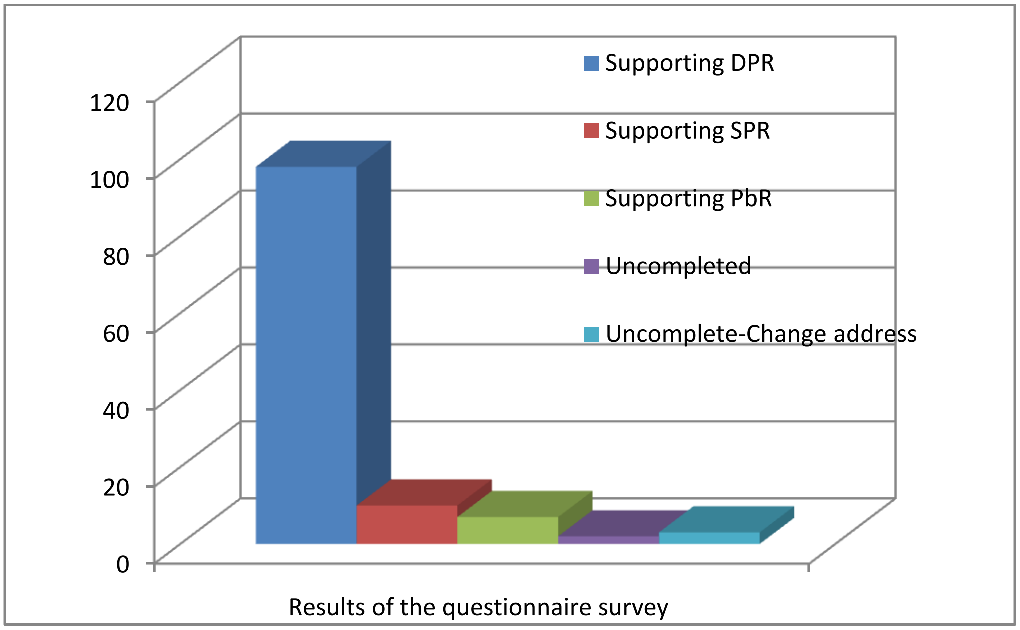

Figure 5.1: *Adopting DPR questionnaires survey*

A considerable body of literatures and the survey responses confirmed that people identified the benefits of wider sharing of Detailed Patient Record using information technology, and the certainty of moving into this field.

The outcomes of the survey used in this research, characterized increasing demands for adopting detailed healthcare records in healthcare organizations as fundamental element for enhancing the quality and efficiency, avoiding clinical decision- making errors, and increasing patients confidence in healthcare system. The physician's perspective illustrates that the sharing of greater and more detailed healthcare information between healthcare professionals from various locations has the ability to enhance extensively the care provided to patients.

By presenting advanced storage management to the detailed patient record segments, healthcare professionals can share a comprehensive, fully compliant Electronic Health Record storage solution, as a consequence will speed up and improve the quality of medical diagnosis and avoid errors during clinical decision-making processes.

5.4 Theory of Medical diagnosis and errors during decision making process

Clinical diagnoses and decision making process about healthcare service have always been completed on the basis of consumer's healthcare information.

Electronic Health Record in general and electronic patient records in particular plays an important role in healthcare decision making, due to the fact that the data which make up the healthcare records are the main source which is needed in healthcare decision-making process. Different models have been recommended for diagnostic process in clinical practice. Four key strategies for medical diagnosis have been described by Sackett [141]. The first is Pattern Recognition; which uses instant identification of a disease after one aspect at the patient. Hypothetico-deductive is the second strategy; during which some form of test is carried out to inspect hypothesis diagnosis. The third strategy that he revealed is the algorithm strategy and the final one is the 'complete history' strategy.

In 1999 Institute of Medicine (IOM) informed "To Err Is Human" that the affect of medical errors bring about more than one million injuries and between 44,000 and 98,000 deaths annually in hospitalized patients [142]. Also, British Medical Journal, through their editor, Dr. Richard Smith, is calling for a rethink of healthcare systems. He spoke to BBC Radio and said: "Probably 20-30,000 people a year in Britain die of medical errors but then of course many more will be injured and suffer other consequences." [143] In Canada, the Canadian Institute for Health Information's annual report comments that treatment errors are the reason for nearly 700 deaths in Canada each year [144].

Medical errors are more familiar in US hospitals, which has recently received extensive attention. American Hospital Association CDER, in 2004, presents different causes to the medical errors; incomplete patient information was the main reason [145]. For instance, an Emergency Department is a multiplex and dynamic location, where clinical decisions are achieved under time pressure and with deficient healthcare information, have been considered encouraging to medical-decision errors [146]. Even in some healthcare areas, where merely very basic clinical information is being shared, there is still a requirement for sharing Detailed Patient Record in order to improve the quality of care provided. However, detailed health record plays the core point during the diagnosis session due to the fact that medical diagnosis in more than 70% of cases is based on the patient's history alone [147]. In order to avoiding medical errors, medical decisions should be accurate, efficient and based on integrated, completed and updated detailed patient record [148]. Proper clinical diagnosis requires detailed healthcare record currently placed in EHR at various locations. Therefore, the consequence of abstracting Electronic Health Record is a barrier to improving diagnosis and avoiding medical error provided at point of care.

5.5 Different Models for accessing Detailed Patient Record

Consumers are typically receiving healthcare services from different providers at different locations. Sharing of healthcare information facilitates healthcare professional from different locations to offer more efficient healthcare service to the patients, which consequences in cost reduction for social insurance institutions.

National strategies for electronic health records are more or less new but all of them are evolving. However, Detailed Patient Record can be viewed as part of EHR as fitting into one of three general models defined below:

5.5.1 Centralized Single Repository

This model is demonstrated by the NHS National Programme for Information Technology (NPfIT). This approach described as centralized single repository of healthcare patient record that contains information such as demographics, medical conditions and allergies. The required healthcare information is uploaded to this national repository, ‘Spine’, (Summarized Care Record Service) using HL7 v3 messages from various standardized EHR applications allocated across all healthcare organizations such as primary care, secondary care, mental health service, etc. This approach shows that only the Summary Care Record (SCR) will be a national system but the richest and the most detailed information about consumers is kept locally. Unfortunately, NHS NPfIT shows an incomplete and ambiguity regarding accessing and sharing detailed information [149].

In Dec. 2005, an internal document “NHS CRS consent/dissent: information sharing rules” created by NHS Connecting for Health, the agents of Department of Health, exposes that although the proposed NPfIT would allow healthcare providers across England access to detailed care records where appropriate, it will not be ‘feasible’ to access detailed records, even from within the same cluster [148].

In other word, the healthcare providers working in one “instance” are unable to access the detailed care records created by healthcare providers in another "instance". For example, clinicians in North West cluster are incapable to shared detailed patient records created in North East cluster. The difficulty arrives for patients who reside nearby the boundaries between clusters. They will find that their healthcare providers in their "cluster" are incapable to access a detailed care record even with the other clinicians in the local Hospital if it is in the neighbouring "cluster" (see figure 5.2).

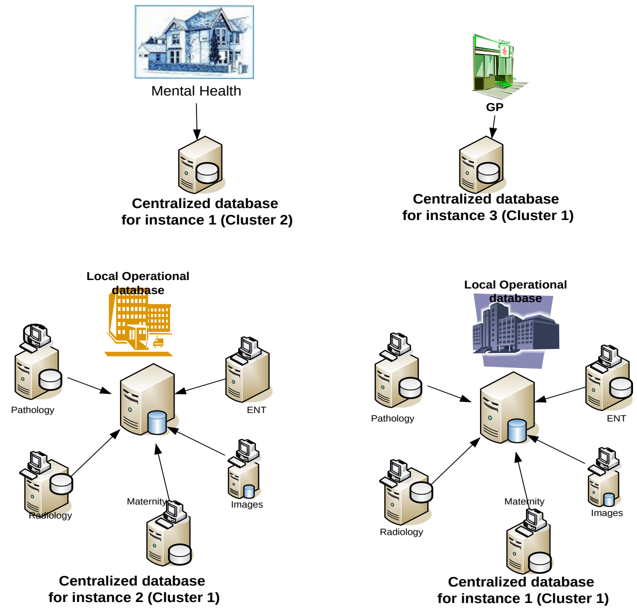

Figure 5.2: *RDBMS at different instances*

A spokesperson for CfH confirmed the document and she added: "It has always been the intention that detailed care records will not be accessible outside the local area."

5.5.2 Centralized various Repositories

This approach is being considered by several national strategies for electronic health records. This approach is based on various central healthcare patient record repositories created by different healthcare organizations and connected to new or existing applications through a standardized and certified messaging. The care setting is responsible for sending and receiving the standard messages. Several developments of national strategies for electronic health records, such as Sweden, Germany and France are considering this approach.

5.5.3 Distributed Data Repositories

This approach, which is considered by some countries such as, Austria, Denmark, Netherlands and Scotland, presents an option of peer-to-peer networking model. It allows any EHR system to be connected with another system through a web browser.

5.6 Summary

Due to the increasing complexity of healthcare information, healthcare trusts need solutions and services for knowledge creation and discovery, decision support, patient management, quality, disease management in order to meet their strategic goals.

Sharing of healthcare records from various repositories through integrated healthcare system, results a massive storage of detailed patient record's database, which will be explained in more details next chapter. With this massive repository, clinicians need an efficient and reliable access to detailed patient record, which can be archived by developing an advanced storage and data management environment.

The outcomes of the questionnaires survey as well as the literature reviews used in this research indicated that sharing of detailed healthcare records enables clinicians to provide more efficient care to the patients who can receive healthcare services from different providers. Healthcare organizations require a system which provides more efficient and accessible method of a complete healthcare reporting so that it could helps clinicians to access to the more required segments of electronic patient records at different levels, increase analyst productivity, and gain more visibility and control over the costs and quality of healthcare system operations.

Chapter 6

Storing, Searching and Viewing Electronic Patient Record's Segments based on Centralized Single Repository

6.1 Introduction

Healthcare is an important constituent of modern societies, representing a large percentage of gross domestic products (GDP), and sustaining a high political profile and a strong public interest [150]. However, due to a growing need for improved healthcare services, which is complex and growing more, to organize and deliver the high quality that paper-based records cannot support especially with an increasingly complex data entry.

Healthcare systems throughout the world are not only increasing in number but in size, complexity and the variety of services presented, therefore there is a increasing need for qualified management of Healthcare information.

With this complexity of information, healthcare trusts need solutions and services for knowledge creation and discovery, decision support, patient management, quality, disease management in order to meet their strategic goals.

In order to improve Healthcare Record Service, clinicians need an efficient and reliable access to patient record, which can be archived by developing an advanced storage and data management environment.

To facilitate OLAP process for clinical decision making, the OLTP data should be stored in a data warehouse model, which need to be well-structured for searching aggregates of large, with predefine searches in mind.

This chapter propose a conceptual approach system which takes full advantages of IT within healthcare environment by creating an information infrastructure that enables fast, rapid, secure, private, and complete communication among different types (levels) of data to meet the needs of patient care and provide an efficient access to healthcare records to improve the quality and safety, and strengthen the efforts of patients and providers.

The proposed approach is web-based system architecture uses an OLTP for storing the Electronic Patient Record locally for daily operations and OLAP for mining the data stored in **centralized data warehouse storage**.

Therefore, there are two different demands of data; the first is satisfying an online transactional processing and the second is satisfying a request for an online report and analysis on healthcare records.

The approach aims to improve managing the flow of information throughout the healthcare environment and helps in accessing high quality of data and uses that data for producing patient reports for clinicians in order to manage the secure and efficient delivery of complex and knowledge-intensive healthcare and improve clinical decision making process; then collect more data to evaluate the results of those decisions.

As healthcare clinicians need help analyzing clinical and when making qualified clinical decisions [151,152], OLAP is the technique which is used in this system to integrate the data resources and analytical powers to create the ability to evolve its data into meaningful performance indicators for healthcare decisions with greater impact and results. Data inside data warehouse will then be rolled up to populate data marts that will service OLAP in each of the healthcare areas [153].

The aims of this approach is to improve the capabilities for multipurpose healthcare systems to facilitate healthcare record management needs in order to gain a better comprehension of the range of care provided, from diagnosis through final treatment and comparative analysis by integrating and unifying information into one database system.

The remainder of this chapter is organized as follows. Section 6.2 discusses the architecture that has four main stages required to build the proposed system tiers. Section 6.3 lists the main benefits of the proposed system. Finally, section 6.4 concludes the chapter.

6.2 The system architecture

Healthcare Record Service is contained within a variety of On-Line Transaction Processing (OLTP) systems, which is organized for efficient storage and updating of data. Keep large amounts of data in OLTPs can tie down computer resources and slow down processing.

Normal relational databases store data in two-dimensional tables and analytical queries against them are normally very slow, therefore it would be a time consuming process for an eligible clinician to obtain a persuasive Healthcare Record such as the following query: What are the most medications received by this patient from acute care within a specific location at a specific time period?

Database schema design choices are made on the basis of whether the system is to be used for transaction processing (OLTP) or for reporting, analysis, or decision support (OLAP) [154].

Sharing of healthcare records through integrated healthcare system enables clinicians to provide more efficient care to the patients who can receive healthcare services from different providers.

The proposed system approach provide more efficient and accessible method of reporting so that it could helps clinicians to access different types of health records at different levels, increase analyst productivity, and gain more visibility and control over the costs and quality of healthcare system operations.

Two demands made upon the data simultaneously: one user interface is satisfying a transactional processing status and the eligible clinicians interface is satisfying a request for an online multidimensional healthcare record service processing.

As illustrated in figure 6.1, the architecture of the proposed system creates a data warehouse: cohesive data model that defines the central data repository for healthcare record by integrating records from across healthcare trusts (instance databases). The system extract, cleanse, transform and load the source data and to periodically refresh the existing data in the Warehouse.

However, the process of making data available through OLAP applications using the proposed system typically goes through four major development initiatives:

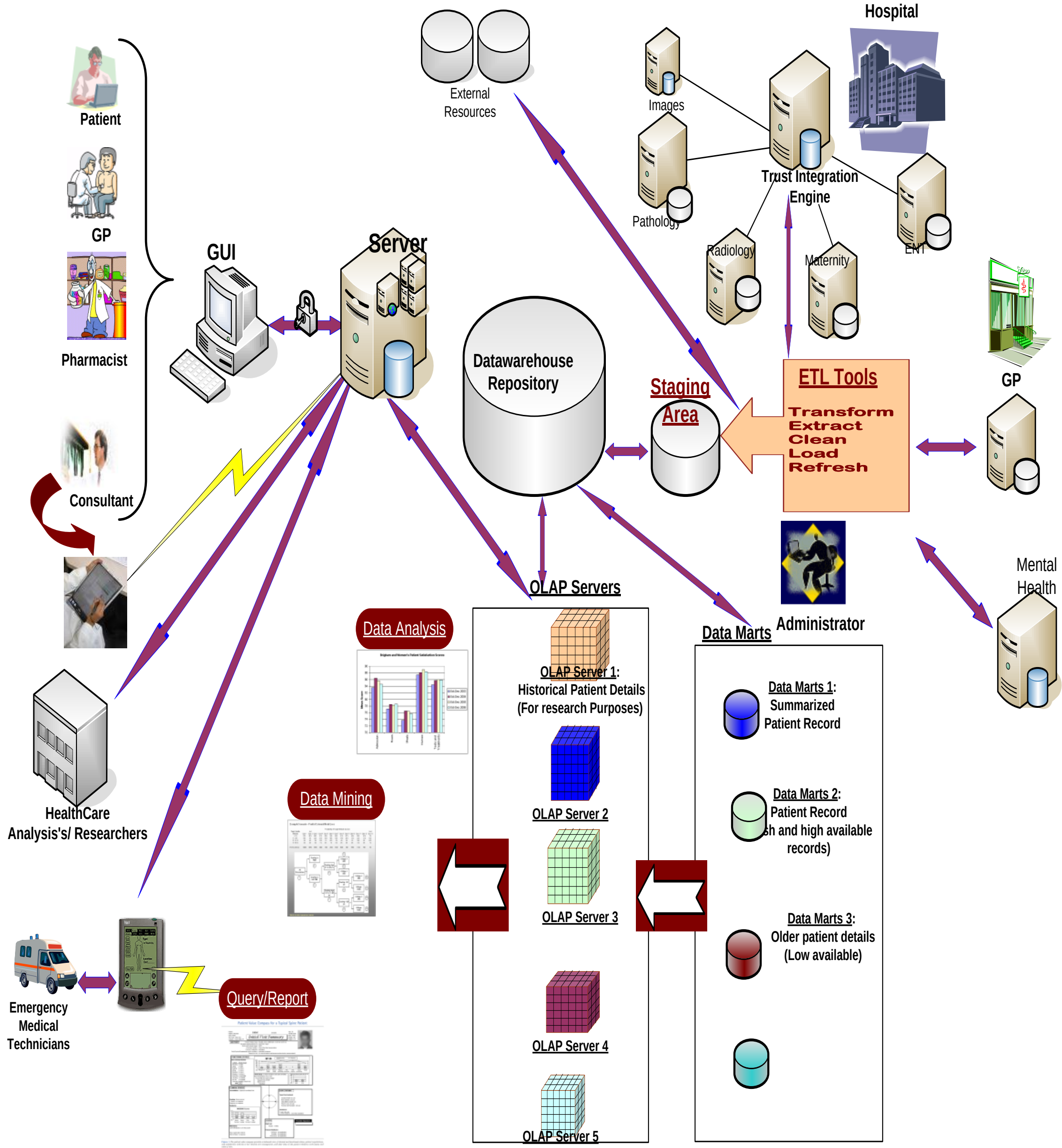

Figure 6.1: *The conceptual design of the proposed system approach.*

6.2.1 OLTP system

On the usage front, OLTP systems at each local connect high number of concurrent clinicians through web interfaces to the instance database system (regional database(s)). The applications consistency, recoverability, and maximum transaction throughput are required from the database.

6.2.2 Data Warehouse

Healthcare organizations have been developing their local information systems independently and as various types of patient records and medical decisions must be made over large, statistically significant data patterns; Healthcare system needs to join their heterogeneous patient records into a single data warehouse, which becomes the foundation of the knowledge discovery system.

Data Warehousing is an important strategy to integrate heterogeneous data sources [155], because on-line Transaction Processing (OLTP) and On-Line analytical Processing (OLAP) could not coexist efficiently in the same database environment.

Data warehousing are more prevalent in the healthcare industry because of the large quantities and complexity of data stored in various systems at medical institutions and the number of medical decisions made based on the data [156, 157].

As illustrated in figure 6.1, data warehouse uses a multi-tier architecture that includes:

- **Extraction, Transformation, and Loading (ETL) Tier**: Millions of healthcare record rows from various sources need to be loaded. The system needed to enhance ETL must be capable to cut the time required to load and transform its data. Therefore the proposed hybrid system became interested in Microsoft SQL Server 2005 as it provides a completely new enterprise extraction, transformation, and loading (ETL) platform called SQL Server Integration Services (SSIS).

- **Staging Area Tier**: is a place where data is processed before entering the warehouse. SQL Server Integration Services is used to import healthcare record into staging tables, where it is used to format, clean, and validate the information, before moving it into the data warehouse.

- **Data Warehouse Tier:** Table and Index Partitioning feature of SQL Server 2005 will be used to allow indexes and tables to be partitioned across multiple file groups.
  The main data warehouse tiers (ETL, staging, and data warehouse) are hosted on SQL Server 2005 running on Microsoft Windows Server™ 2003 Enterprise Edition operating system, part of Microsoft Windows Server System integrated server software.

6.2.3 A Specialized Data Marts

Data mart is a split of a data warehouse and each one is designed for a particular subject area. Each one of these special-purpose data marts are just one segment of the data warehouse which give faster response to targeted questions. Typical examples of data marts are ENT Dept., Maternity Dept., Radiology Dept, etc.

6.2.4 OLAP Cubes

A typical OLAP service usually starts from one or more specifically designed data marts, which integrates the complex issues of healthcare data structures into a multidimensional database (MDDB) cubes structure, accessed through the Internet, analyzed, using the appropriate middleware and presents the easy-to-understand dimensional information views to clinicians while empowering them to explore their data in a very instinctive way.

During this stage data is conceptually viewed as cubes, which consist of quantitative values (measures), and descriptive categories (dimensions), which allow clinicians to slice and dice or drill down to more detailed levels or roll up to higher levels to meet clinicians required data.

Reporting services is supported by SQL Server 2005, which gives clinicians the ability to combine information from data warehouse in a way that helps to gain a better view through patient's medical history to see not what is happening to a specific medical patient case, but what is causing it.

6.3 Main challenges of the centralised system

The general concept of data warehouse within healthcare system architecture has been proposed by a few numbers of national strategies for electronic health records such as HealthConnect (Australian) [158], Infoway (Canada) [159], and NHS Care Record Service (England) [160].

These projects face a deficiency in sharing segments of detailed healthcare record.

However, centralized approach has many disadvantages that influence healthcare professionals to choose other models. The main disadvantages are:

1. As one central system achieving all the demanded procedures, apparently this model will be slow as well as if the CPU goes down, the whole system will terminate, for instance, if the central node of this approach fails to connect with multiple healthcare organizations due to server or network failure caused mass destruction or any other reason.
2. The creation of nationally accessible system rather than groups of smaller distributed systems would increase the risk of security breaks.
3. When healthcare patient information sources belong to different organizations, it is very difficult to keep the warehouse data up to date.
4. Various healthcare organizations, each with different RDBMS, data models and different standards, will make it difficult to integrate EPRs into centralized repository.
5. Creating new massive data warehouse requires huge time and high cost to build the relevant size of database.

6.4 Summary

In order to improve the quality and efficiency of healthcare organizations, fast and easier access control to healthcare records and to introduce best practices are required. This approach builds a suitable solution for integration and gets benefit of high volumes of complex healthcare data through congregate and use of both OLTP and OLAP systems in order to create and capacitate the integration of heterogeneous healthcare data source into a centralized data warehouse.

The Data Warehouse utilize and support creation of multifarious kind of reports that facilitate clinicians to maximize the views of different measurements of Patient Care Records in order to make the right diagnosis, as well as support medical decision-making process.

This approach is a significant step towards consolidating the interoperability and derives the most valuable and high quality care record reports in healthcare sector, which results in a better quality of care for patients, the clinicians, healthcare surveillance, researching and the administrating. On the other hand this approach faces real challenges such as security, complexity and wasting in time and cost. Therefore, the federated system model (SVSEPRS) will be revealed in the following chapters.

Chapter 7

SVSEPRS model: Requirements, Architecture Design and Implementation

7.1 Introduction

The EHR comprise one or many EPRs that are accumulated at different healthcare locations. This distribution is due to the greater mobility of the population, as every patient visit medical centre, medical information are produced and stored in his/her EPR on local database storage, which consequences in a patient's clinical information that will be located in a variety of locations that has no connection between them.

Typically, a healthcare professional, before providing care to individuals, need to know when and which patient groups (e.g. diagnoses, laboratory test results) received what kinds of medical services and in which order (e.g. radiation therapy or surgical operations), and results.

One of the main ambitions that healthcare providers' aiming to accomplish is to reduce medical errors, through improving the healthcare management. This is done by using dynamic searches to select and view vital and accurate information from the comprehensive scattered EPRs.

The contents of patient healthcare information is normally large, diverse and of variable quality. Various types of information in the patient records have different application for different kinds of users.

Obtaining the most required and vital EPR fragment which is harmonious with the daily operational work is a challenging target for several of healthcare providers. This case implied a system with scalable searching ability.

Sharing patient healthcare information electronically can speed up clinical communication, reduce the number of errors, and assist doctors in diagnosis and treatment. The Internet as an essential facilitating tool for sharing and communication data can be utilised at any healthcare organisation.

Java tool provide the essential improvements to the design and deployment of healthcare applications over internet. It simplifies the complexity related to developing software and deployed over various distinct platforms through writing once, run anywhere. Thus, EPR segments can be viewed from any Web browser to provide clinical information to healthcare providers who may need this information to improve the quality and efficiency of healthcare services provided.

Many healthcare information systems approaches are proposed and different migration projects have being done mainly based on two typical architectures: Client/Server (C/S) architecture and peer-to-peer (P2P) architecture.

In the previous chapter the centralized approach using massive single data warehouse has been used to facilitate the process of accessing detailed and complete health records. This is done among different types (levels) of data to meet the needs of patient care and provide an efficient access to healthcare records.

However, with centralised approach, local healthcare organisations are isolated from each other. They interact only with a centralised massive single service that coordinates their queries.

This chapter present the requirements, design and architecture towards building the SVSEPRS system model. This model is a Client server, Web and Java based collaborative system model with suitable open architecture for successful collaboration among several dispersed healthcare system organisations.

A prototype has been built to support the execution of the model by establishing a multidimensional data query and open access over scattered healthcare systems using client-server searching scheme.

The proposed model will facilitate and support each participant healthcare providers to utilize the provided link at their portals for searching and viewing EPRs segment created and stored at other healthcare institutes.

As a result, progress towards putting the right patient healthcare information in the hands of eligible healthcare providers, whenever they need and from wherever location will be achieved.

7.2 Requirement Analysis

This section presents the requirements of the proposed SVSEPRS information architecture. The following requirements should consider the functional requirements of a distributed system providing ubiquitous access to vital segments of patient health records. In addition, it will satisfy the user needs in terms of system functionality, scalability, reliability, accessibility and simplicity.

7.2.1Target users

As already explained in the previous chapters, the target audience of the SVSEPRS are healthcare providers. The design approach should provide a first study of how to enhance the search using multidimensional query process of EPRs. This is created and stored at various locations for healthcare providers to provide the enhanced clinical decision making process.

7.2.2 System Requirements

In order for the proposed SVSEPRS system model to be effectively installed and operated, the following requirements for minimum hardware and software server-side and client-side should be met.

Note that it should be added on a devoted web server that is situated on the same LAN as the database server.

7.2.2.1 Web Server(s) Side Requirements

- 2 GB RAM
- Operating systems: Microsoft Windows 2000 Server, or Windows Server 2003
- Apache Tomcat 5.5
- Server-side Scripting Language: Java 2 Enterprise Edition (J2EE)
- 700MB drive space for software and additional space is required for content.
- Internet Explorer 5.5 or higher.

7.2.2.2 Database Server

The requirements for the Database server are as follows:

- Operating System: UNIX 2004 or Windows Server 2003

- Database: MySQL 5.0 or Oracle 10g
  "EMR requires about 2MB of data per patient on average. For 1 million patients, you're talking about 2TB of storage." says John Lightfoot, CTO at EMR technology vendor Orion Health Inc [161]. The database server should actually accumulate the outlined EPRs only, which could be no more than 10% of the total record stored at local site. Therefore for each patient, there is a need for about 200 KB and for 1 million (200 * 1000000) may need around 200GB.

7.2.2.3 Client Side Requirements

- Windows 2000 Service or Windows XP Professional Service
- 1024 x 768 monitor resolution
- HTTP or HTTPS access to SVSEPRS server(s)
- Internet Explorer 5.5 or higher

7.2.2.4 System Main Functions

Before discussing the functional and non-functional requirements of the SVSEPRS in details, the main functions of the proposed system are categorised into two main parts, locally and centrally.
In the local part, healthcare providers and receptionists at a participant healthcare organisation should accomplish the following tasks:

Receptionists:

- Book an appointment for patients
- Cancel patients' appointment

Healthcare Providers:
The following tasks are just a few segments that are created and stored locally by the clinician in order to demonstrate the contribution of this project. However, the local tasks can be categorized as follows:

- View Booked Appointments
- Add Patient's Chief complaints and clinical observations
- Clinical lab test
- Confirm final diagnosis

For each created EPR; vital fields from those segments will be dispatched to the database server at centralised SVSEPRS.
The second part of the proposed system model, which is the key contribution of this research is the centralised web-based SVSEPRS.
The main tasks archived by the main users of this system are highlighted as follows:
SVSEPRS Administrators:
The following functions can only be accomplished by the administrator.

- Add new Healthcare organisation
- Add new Healthcare providers (based on the previous point)

Healthcare Providers using SVSEPRS system: The following tasks can only be achieved by the clinicians when logged in to the system:

- Search and view chief complaints and medical observation segments

- Search and view patient laboratory test segment
- Search and view diagnosis segment

Login and Validation: All users of local healthcare systems and central web based SVSEPRS system should login using their username and password. The system will then validate the user's details in order to ensure the successful login.

7.2.3 Functional Requirements

The main functional requirements of the proposed model are presented as follows:
The Searching and Viewing Segments of Electronic Patient Record Service (SVSEPRS) service is proposed to enable healthcare providers to search for and view patient's healthcare record information segments from scattered healthcare systems (feeders). This process does not involve other procedures such as deletion, edition or creation of such data on feeder systems as those processes are performed locally (on feeder's systems).
The access to view EPR segments does not necessarily imply that the recipient will utilise another constant store as the requested information will more commonly be for transient viewing only.
The core of SVSEPRS is the Centralized Multidimensional Searching Map (CMDSM), which are a well structured multidimensional search engine containing essential health records segments, the registered healthcare users and a mapping to the feeder systems that contain detailed parts of the EHR for each consumer.
The following are the local (embedded inside local healthcare organisation) functional requirements for the proposed system:

1- **Receptionist Perspectives: book and/or cancelling an appointments:**
   After registering a patient, the receptionist should be able to book an available appointment for the patient with the clinician at a suitable time.
   In order to book appointments, the receptionist needs the following details:
   - The clinician number
   - Patient's name
   - Patient's date of birth
   - Appointment date
   - Appointment time

2- **Healthcare providers perspectives:**
   - ✓ **View booked appointments**: This function shows the clinician all the booked appointments that are not attended yet.
   - ✓ **Add patient's Chief-Complaints and clinical observations**: This function requires the following data to be entered:
     - ▪ Patient's id
     - ▪ First Chief-Complain
     - ▪ Second Chief-Complain
     - ▪ Third Chief-Complain

    - Observation name
    - Observation type
    - Observation value
- ✓ **Propose medical lab test:** This function may be required to be selected by the clinician for clarification and right diagnosis.
- ✓ **Final diagnosis:** The clinicians should insert the final diagnosis that has been reached based on the above procedures. This function requires the following details:
    - Patient's id
    - Diagnosis name (based on ICD/10):

The second component of the proposed model is the centralized SVSEPRS which is the key contribution of this project and contains the following functions:

1- **Administrator Perspectives: Add new Healthcare organisation:** In order to share EPR segments with other healthcare providers, their organisation must register to join the SVSEPRS and provide the required details such as organisation's name, address, main website IP-address.

2- **Administrator Perspectives: Add new healthcare providers:** details about healthcare providers from already registered healthcare organisations must be provided and stored in the centralised database server. The admin will supervise the process of creating a new username and password for each of the participant's healthcare provider which is to be used at each time he/she need to login to the centralised system.

3- **Healthcare provider's perspectives:** The participant healthcare providers can search for the following EPRs segments using CMDSM:
   - ✓ **Search and view patient's chief-complaints and medical observation segments**
   - ✓ **Search and view patient's laboratory test segment**
   - ✓ **Search and view patient's diagnosis**

   The CMDSM that can be used by healthcare providers is to roll up or drill down the brief patient information stored at the centralized database server. The required data in these search engines are:
   - Patient id
   - Date: From
   - Date: To
   - Location

The results of this search process are a list of outlined EPR segments, each with its links to the source of detailed EPR stored at the local healthcare organisation.

The system should validate any data inserted by the receptionist or by healthcare providers and issue an appropriate error message if one of the following errors has occurred:

- One or more of the required fields have not been filled out.
- The entered unique data is already exists in the database.
- Date inserted is not in the correct format

If the required field has been added successfully, the system should issue a message confirming that and provides the user with the option to precede to another function or return to the main page.

7.2.4 Non-functional Requirements

Non-functional requirements do not explicitly concern the functions of the system but it is expected to meet the constraint or restriction that must be considered during the design of the proposed model.

1- **Architecture perspectives**

The system work as client-server architecture that operates in a Windows environment with a combined database approach (federated and centralised). Therefore, the functionality of the proposed system must be provided from any workstation within the network.

2- Usability and Reliability perspectives

The proposed system must work as three tier web-based applications and any user that is proficient in using a web browser who has used services at a portal like www.yahoo.com, should be able to access SVSEPRS.

Thus, the participants on the SVSEPRS should be able to use the system without much training.

To improve the reliability and robustness of the system, validation processes should be incorporated into the system where required to prevent the system from malfunctioning. This mainly involves validating user's input data. The web server of the proposed model should be based on clustering network architecture which is used to improve the stability and reliability of the system. Finally, the system should provide full functionality from any internet-enabled computer.

3- User Interfaces Design

All system interfaces should have two important principles to improve the usability of any web-based application. These principles are consistency and simplicity. This can mainly be achieved by creating graphical user interfaces that adopt a simple and consistent layout.

4- Supportability

SVSEPRS supportability includes:

- Adaptability: The proposed model is a platform-independent development framework, and the server use Java Servlet. Hence, SVSEPRS should be able to change platform configurations easily.

- Maintainability: The system should be upgradeable to the latest standard in the web portal and services implementation, without any degradation in performance.

5- Security requirements

Since patient's healthcare information is very sensitive, it is important to provide a security mechanism to the SVSEPRS. Thus, participant healthcare providers must be logged on to the system with a secure username and password mechanisms. The system should provide high security against hacking. This can be done using a secure type of database. The web server should be secure and the best way to develop a secure web server is to use J2EE especially servlets. The servlets as a java byte-code classes will provide high security for two reasons:

- Since it is not possible to read the byte-code classes without JVM, hence, any business logic written using byte-code will be secure.
- The Java byte-code classes are residing on the server side, where other securities will be applied, such as server authentications and routing and hardware firewalls.

The design of the proposed system must enable local healthcare organisation to conform to national authorization and instructions on the protection of patient's healthcare information.

Authentication methods should be utilized as an accurate method to recognize and to validate the eligibility to access or of a request for an electronic patient record viewing.

The service of the proposed system must ensure that the sharing of patient records among systems should comply with request and authentication processes between both the contributor and the recipient access level to guarantee that the requested segments of EPR is viewed by the eligible healthcare providers only.

7.3 Overview of the SVSEPRS Architecture

Healthcare organizations have been developing their own local information systems autonomously and as large number of patient records and medical decisions must be made over large, statistically significant data patterns; Healthcare system needs to share their heterogeneous patient records between each other without using centralized single massive data warehouse repository.

The system architecture that is about to be illustrated does not concentrate on the network communication nor contents standardization of the EHR. As important as they may be, the system rather attempts to provide a search mechanism, open access and view segments of EPRs that has been already created and stored at local healthcare systems using centralised web based system. As such, the federated and centralised approaches were chosen, based on a set of previously available local systems.

In order to improve the collaborative process between various healthcare organisations, three tiers web-based client server system architecture called

SRVEPRS have been designed and developed, which separates the web tier (middle tier) and the database tier from the client-side tier (the browser) to enhance healthcare providers sharing vital EPR segments.

This will result in business logic and database encapsulation, which means any changes in the database or in the business logic do not need to make changes in the client-side code.

The SVSEPRS contain a multidimensional search engine over the Internet which shares virtually the vital segments of EPRs between different participating healthcare organizations through redefined links but not physically moved, copied or edited.

The high level conceptual design, illuminated in Figure 7.1, shows the universality, simplicity and flexibility of the model that can be quickly and easily accessible over the Internet from any local Health facility throughout the organization seamlessly and with minimum effort.

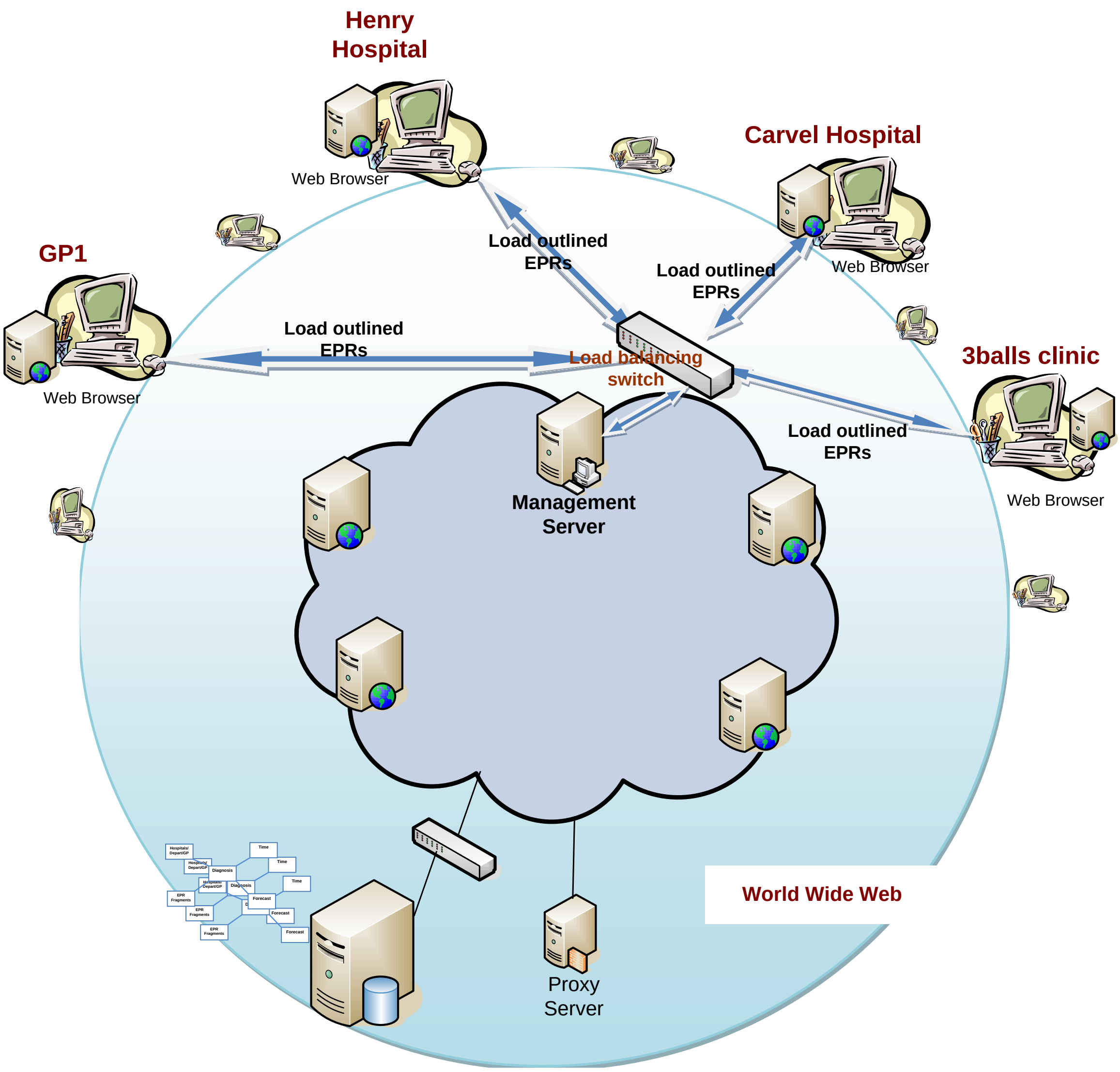

Figure 7.1: *High levels SVSEPRS conceptual design*

The accomplishment of sharing vital segments of EPRs depends on the aptitude to provide access to the scattered EPRs that belong to each EHR and not to integrate them in one single repository.

Typically, the proposed approach requires keeping the several participants' local healthcare system autonomous. However, the centralised web based system will be required to put in place the capability that will corroborate continuity of care.

This approach will be able to offer consistent, fast and authorized online access for healthcare providers to search for and view EPR segments that is physically created and stored at various healthcare information systems within the boundaries of the SVSEPRS system.

7.3.1 Java 2 Platform Enterprise Edition (J2EE) for developing multi tiered architecture

N-tier J2EE architecture (Java 2 Platform, Enterprise Edition) [162] that has been used for several applications due to its essential features such as an object oriented language was chosen to implement the proposed SVSEPRS system.

J2EE was used to clarify the development process of enterprise applications; therefore, any software used to manage the business activities of healthcare environment can be accessed by the healthcare providers through the internet.

As well as the above advantages, J2EE satisfies vital requirements that can empower the system such as platform autonomy, reusability, modularity and providing simple and combined pattern for the use of scattered applications by a component based application model.

J2EE is a set of several servers' side technologies that jointly produce the core of effective enterprise applications.

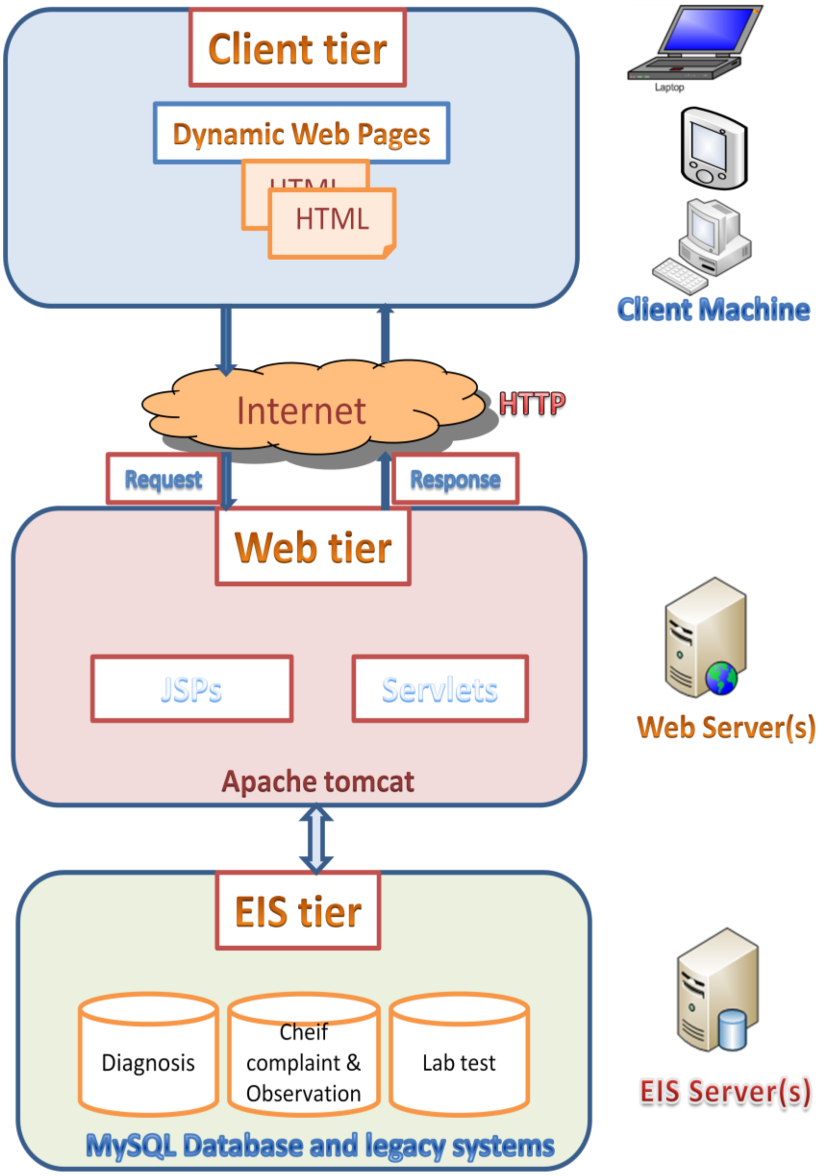

Figure 7.2: *SVSEPRS, three tiers client server model*

The SVSEPRS model has 3 tiers architecture. As shown in Fig 7.2, the architecture comprises the following tier components:

1- Client tier component using application client runs on the client machine.
2- Web-tier component runs on the Java EE server.
3- Data management tier runs on the EIS server.

The web tier component implements the logic tier application, which is the heart of the coordinating function of the system. It receives the requests from the clients, access the database and sends out the results. Although the business tier controls the logic of the application, the web tier offers an instrument to permit clients to connect with the application using web browser.

Building application server based on J2EE will provide enhanced management of the complete system architecture. This is because J2EE supply a mechanisms called containers, which helps the developers by freeing them from some low level configuration and data transaction management tasks.

Some examples of J2EE containers which have been used in our proposed system are JDBC (Java Data Base Connectivity), servlets, and JSP (Java Server Pages). The SVSEPRS system components are arranged over these containers.

The web server applications are implemented by object-oriented J2EE language, which offers scalability, maintainability, reliability, tolerance and quick response to a high number of clients. This is due to its high qualities compared to other systems based on some interpreter languages such as CGI or PHP that must examine each line in a code each time the program is executed.

Therefore, the use of J2EE in this project will meet the requirements that have been stated before: Security, independency, the requirements for client-server system, etc.

Also, J2EE was adapted by numerous healthcare organisations inside or outside UK, which means a strengthened understanding of J2EE has been obtainable. Consequently, J2EE is a sufficient tool for the architecture of the SVSEPRS system.

7.3.2 Description and general SVSEPRS components

The WEB-based SVSEPRS system architecture is composed of Apache WEB Server and the Tomcat JSP-Servlet container and a MySQL relational database to present server applications.

Figure 7.3 shows the architectural components that are necessary to the proposed model:

1- User interface component
2- Access control (Authorizing login) component
3- CMDSM searching component
4- CMDSM viewing component residing at the middle layer for managing the required EPR segment to be accessed and virtually viewed;
5- Database component

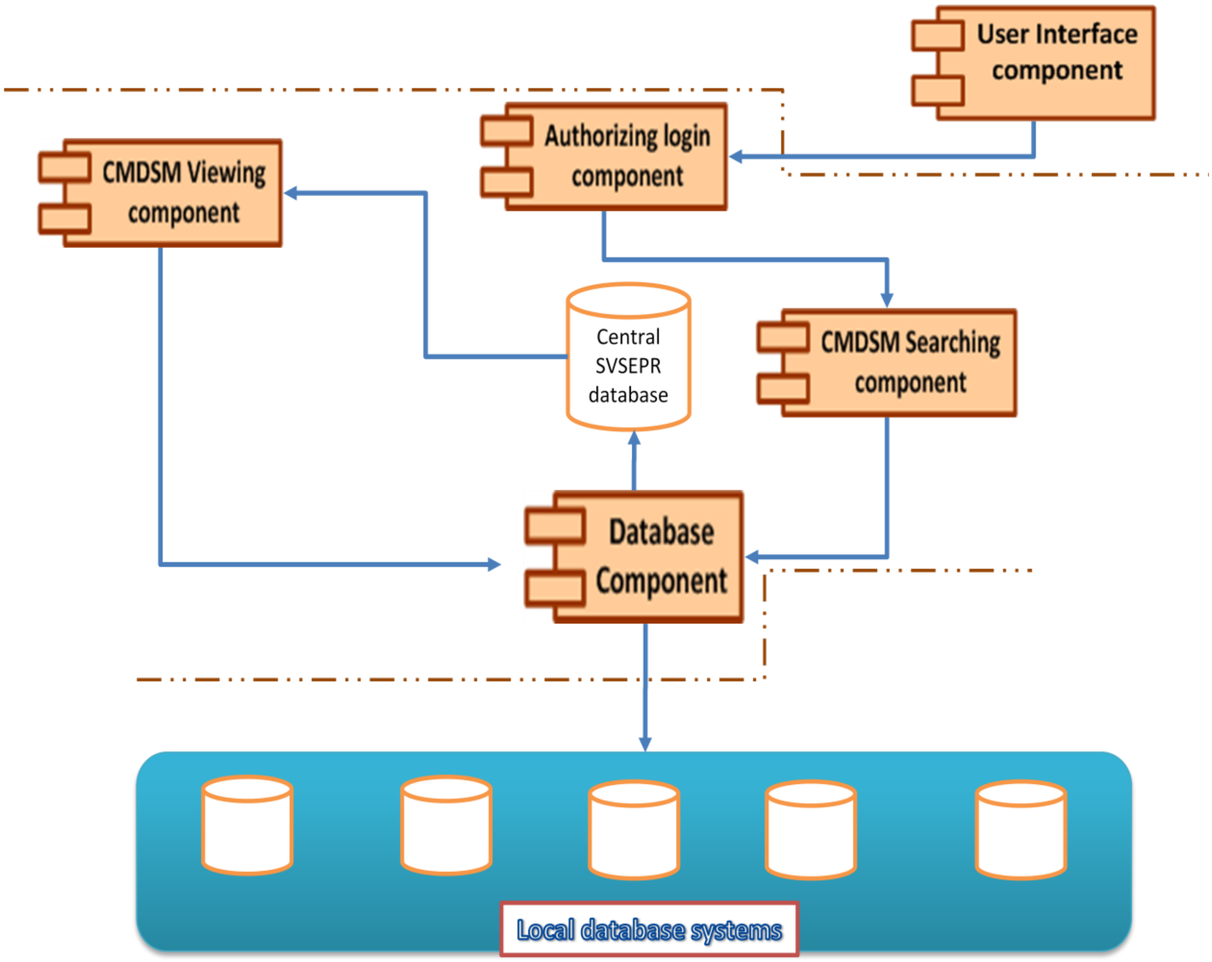

Figure 7.3: *The overall architectural components of SVSEPRS*

In the following sections, the components are described according to the order mentioned above will be shown.

7.3.3 User interface and Access Control components

The client tier is the interface for users to communicate with the system.
All participating local healthcare organisation system sites have a standardised user interface, which contains a link to the central SVSEPRS (Figure 7.1).
Through a secure IT infrastructure, patient health information can be shared between all authorized clinicians in the healthcare community [163].
SVSEPRS has a centralized authorization service that enables the participating organizations to have full control over their own healthcare participants. The healthcare professionals can access the system from their personal workstations using a web browser to define their information needs within a ’user interface (UI) Component’. Thus, the healthcare provider is not needed to acquire, install, or maintain any particular software or hardware. This means that the end users only need a personal computer with access to the World Wide Web and a user account to login to the central SVSEPRS web server.

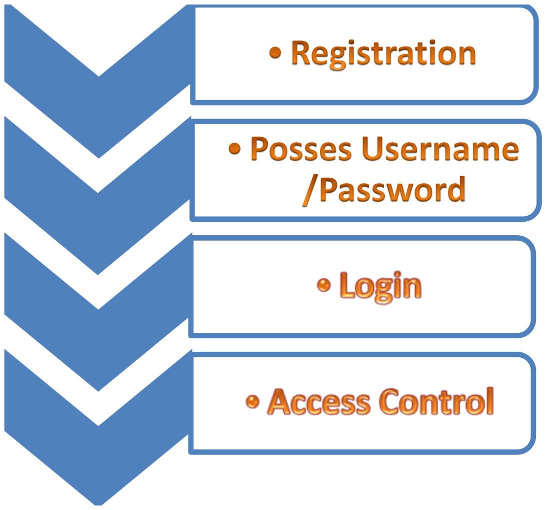

Figure 7.4: *End users authorisation main steps*

The proposed system provides an easy setup of regional, national or even international (future work) registries.
Each participant of the SVSEPRS system must be registered in order to be eligible for using any of the system services, and subsequently, to possess a unique username and password (Figure 7.4).
By completing the registration process, healthcare providers with the required credentials will become legitimate users of the services provided, so he/she can start to login to the system.
During the logon phase, healthcare provider access is validated through the centralised web server and end users should get only the permitted functions based on his/her roles.
The roles are granted permissions and rights that are stated by “permit” and “reject” policy. Each policy expresses the following data:
1) The type of policy by which the end users will be permitted or rejected access;
2) The source and type of clinical information that this policy applies.

The designation of policy implies the existence of an administrator at the SVSEPRS service level who is accountable for the supervision process of correlating participant healthcare providers with roles. The administrator can supervise on the process of creating and/or removing users and roles, and correlating users with roles. This procedure, in spite of its simplicity, has established powerful security, adequate for the most frequent scenarios.

7.3.4 Database components

Data management tier or sometimes called EIS-tier (Enterprise Information System) is to store and retrieve the data handled by the application system.
Electronic Patient Records usually consist of a combination of text and coded entries to demonstrate things like personal data, encounters, medical history, medical finding, discharge, transfer, conditions, diagnoses and procedures, medications and treatments.

After a medical session, certain fields of new EPR encounter, that would be useful for later selection and multidimensional searching process will be automatically appended by the participant (local) healthcare system and stored at the appropriate tables in the central database component. This is done only when permission has been given by the patient to opt-in the sharing of his/her selected valuable EPR fields.
This process of dispatching these fields is repeated for each time an EPR was created and stored locally (Figure 7.5).

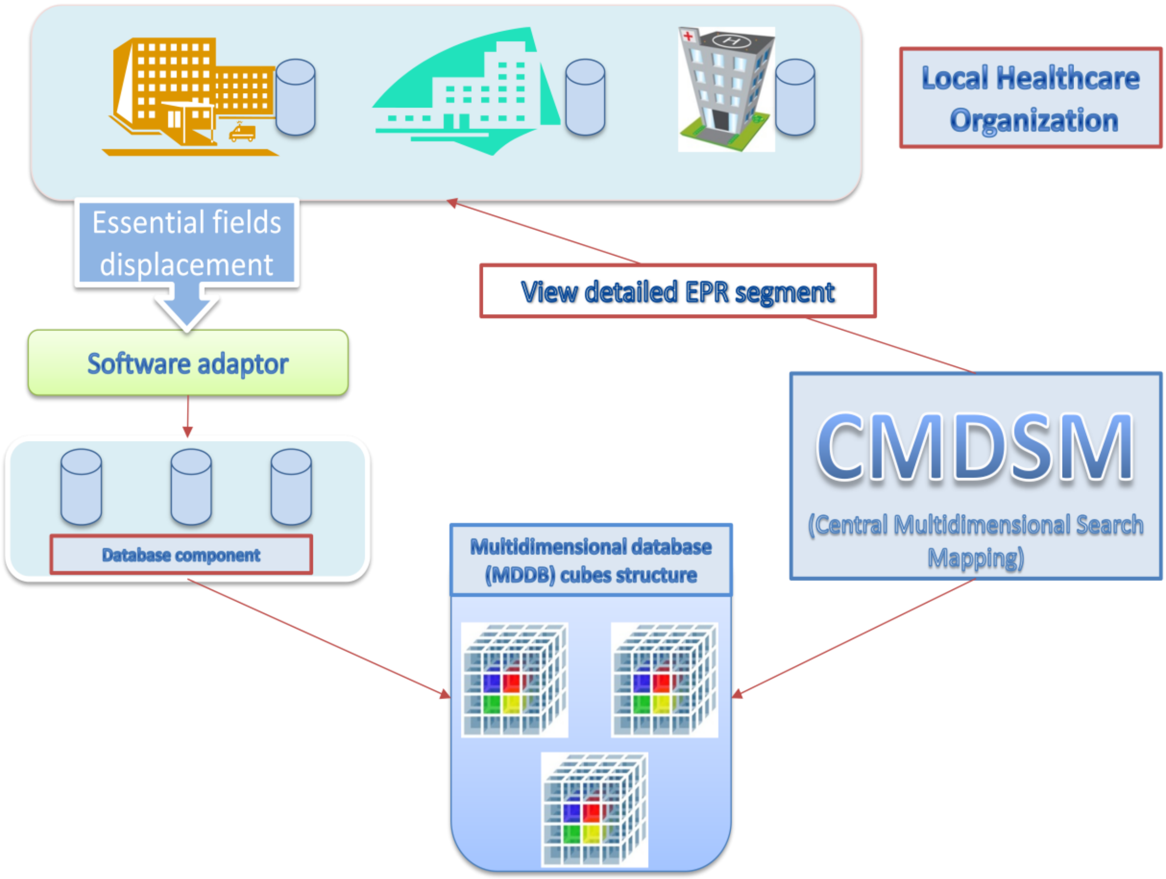

Figure 7.5: *Schemata architecture for database and CMDSM components*

Some EPR segments use clinical texts which may contain a large numbers of ambiguous phrases and terms. A technique needs to be used by the participant's institutions to constrict the documentation of medical texts to a limited and controlled number of terms.
Those terms are used by clinicians during the stage of CMDSM as measures to perform slice and dice processes.
Therefore, controlled vocabularies may offer an opportunity to improve the quality of selecting and viewing long text fields as valuable fragments are required by clinicians.
This ensures that all registered clinical trusts have agreed to use the same vocabulary, and that the words in this vocabulary (dimensions and measures) have the same meaning.

Special adapter software should be installed locally into each of the participant healthcare systems through which essential fields are fed into the appropriate web storage and the full EPR record will continue to be stored locally.
The database component comprise different storage, each belong to different EPR segment. The dispatched essential fields must contain the identification of a patient and only essential patient information of the contents of the particular patient record, thus, multidimensional search processes will be based on patient's ID groups. The quality of the dispatched fields will be validated at the point of data entry in order to check that local healthcare system cannot dispatch incomplete, unacceptable or incompatible data sets. Otherwise an error message indicating the type of the error is displayed and the essential EPR information will not be dispatched before the error is corrected and justification standards are met.
This function will assure that only accurate, integrative, valid and competent essential data sets are dispatched without any need for backward-looking data correction.

7.3.5 Centralised Multidimensional Searching Map (CMDSM)

EPRs data are located in a RDBMS which is enough to run simple queries, but running complex and special designed queries is difficult. Although it may be able to accomplish this kind of queries except that the user needs to correctly design them and collect the results which is a time consuming process.
Complex queries can be achieved using Online Analytical Processing (OLAP) system, by way of using data warehousing, to access and share valuable and variety of EPRs fields to detect disease trends through the process of evaluation and monitoring stored data. This can lead to ascertaining of trends that would improve and speed up the understanding of disease progression.
Many healthcare systems have made significant investments in data warehousing architecture to maximize the value of their Electronic Health Records [164].
One of the main challenges that face this architecture is when creation of a nationally accessible system, rather than groups of smaller distributed systems, would increase the risk of security breaches.
It is often impractical to use data warehousing, especially if the data sources belong to different organizations and it is very difficult to keep the warehouse data up to date.
Multidimensional data models intended for OLAP can handle the duplication of healthcare services by allowing detailed access to high number of detailed EPRs created and stored at different locations to view a more comprehensive picture and promote advances in the diagnosis and treatment of illnesses.
SVSEPRS uses an endowed and well structured multidimensional search engine CMDSM, which defines different common facts and dimensions (e.g. Chief-complain, lab-result and diagnosis).
It is located on the main server helping clinicians to navigate through all the available EPRs dimensions, searching for specific EPRs fragments using Drill up, roll down, slice and dice processes. Within each selected location a

specially tailored detailed EPR segment will be requested in order to handle issues displaying the information in details manner (see figure 7.5).
The participant healthcare professionals have assured, 24/7 navigation through CMDSM and performing the processes of drill-down and roll up the dimensions hierarchy to view the valuable and needed critical EPRs' fragment, from anywhere to finalize the query forms. This will be run using the attached links to the sources of the EPRs fragments. CMDSM therefore, will facilitate the process of searching for the vital and valuable EPRs' field stored at many different local institutions.

7.3.6 CMDSM searching component using OLAP cubes

The healthcare providers, by using CMDSM, identify the required vital EPR segment and by using attached links will access the corresponding local healthcare system to virtually view the detailed EPR stored at this location.
Multidimensional data model, has taken over from the relational model which lies at the core of *On-Line Analytical Processing* (OLAP) systems, in which data is viewed as specifying points in multidimensional space to analyze and manipulate data. It classifies data as being either *facts* with associated *measures* or as being *dimensions* which describes the fact tables.
Dimensions are used for selecting and aggregating data at the level of detail and the significant characteristic of multidimensional data model is to apply hierarchical dimensions to present many of contexts for the facts [165].
A typical OLAP service usually starts from one or more specifically designed data storage, which integrates the complex issues of EPR segment structures into a multidimensional database (MDDB) cubes structure. This is accessed through the Internet, analyzed, using the appropriate middleware and presents the easy-to-understand dimensional information views to clinicians while empowering them to explore their data in a very instinctive way.
Authorized healthcare providers can have open access into the SVSEPRS web server using the web browser to get the CMDSM which gives the users the ability to navigate through the OLAP cubes.
During this stage data is conceptually viewed as cubes, which consist of quantitative values (measures), and descriptive categories (dimensions), which allow clinicians to slice and dice or drill down to more detailed levels or roll up to higher levels to meet clinicians required data.
OLAP "cubes" empower the healthcare providers by allowing them to interact with the stored outlined healthcare record fields through actions like "drilling" or "slicing and dicing".

7.3.7 CMDSM viewing component

CMDSM search component will result with zero, one or more outlined EPR segments, and each record associated with a link to request permission from the system of the source site of this record to view the details of this segment record.
Regular information of errors in internet security causes an impression that internet technologies are not appropriate tools for sharing highly sensitive

healthcare information. Thus, deploying such a system must include functions at the local healthcare organisation to authenticate and control access for any query to their local database.

All queries to view EPR segment generated by local healthcare requester via central SVSEPRS servers are transmitted to a particular local healthcare feeder.

Therefore, local access control must check the eligibility of any request query to whether the requester has the necessary permissions or not.

Also, in order to improve the quality, efficiency and usability of patient's healthcare information, facilitating the process of accessing EPR's segment require major healthcare organizational obligation at the early stages. In this context, patient's healthcare information should be reachable without any perceptible healthcare organizational limitations. However, for security purposes, the local system will not give permission to view their own EPRs before verifying the eligibility of users who are generating and requesting this query. This process is performed by checking the existence and eligibility of the user's URL. This is achieved through checking the file that stores the URLs of all participant users. Hence, all generated query requests are tagged with a user identifier for audit-trailing purposes and sent back to the central SVSEPRS server for verification. If the user has received an enabling permission then he/she will only be able to access and view virtually the required EPR segment.

Therefore, the request to view detailed EPR will take seconds for this checking process. Also, for the best practice security policy suggested by SVSEPRS the local healthcare system should audit and verify the level of the generated query to define whether access is enabled or disabled.

After obtaining permission and by click on the view key button, queries can then be transferred to the selected local database system and results to the requested query can then be viewed virtually.

The CMDSM viewing component displays a read-only view and structured in a user-friendly manners.

7.4 The architecture of clustering web server

The achievement of a web server system is a significant task in many internet related companies.

High number of clients may open access to the web server within a very short time which may produce network overcrowding and increase in reply time [166].

For the healthcare environment, this long delay in response time is harmful and would frustrate healthcare provider's interest in contact with the web server and they may quit browsing the web site, especially when the time of the encounter is very limited. Using a single web server can only control a restricted number of requests and cannot increase with demand, which as a consequence may become a single point of failure with high number of requests.

Cluster web server can be a principal architecture in developing influential web based system, especially when the number of clinicians using the system is grows numerously [167].

Figure 7.6, shows the proposed cluster web server for the SVSEPRS system, which consists of a load balancing switch, which is used for appending requests generated by end users to several web servers for processing procedures [166,167,168]. The web-switch obtains http requests from end users, and chooses a server from the web server pool for further processing.

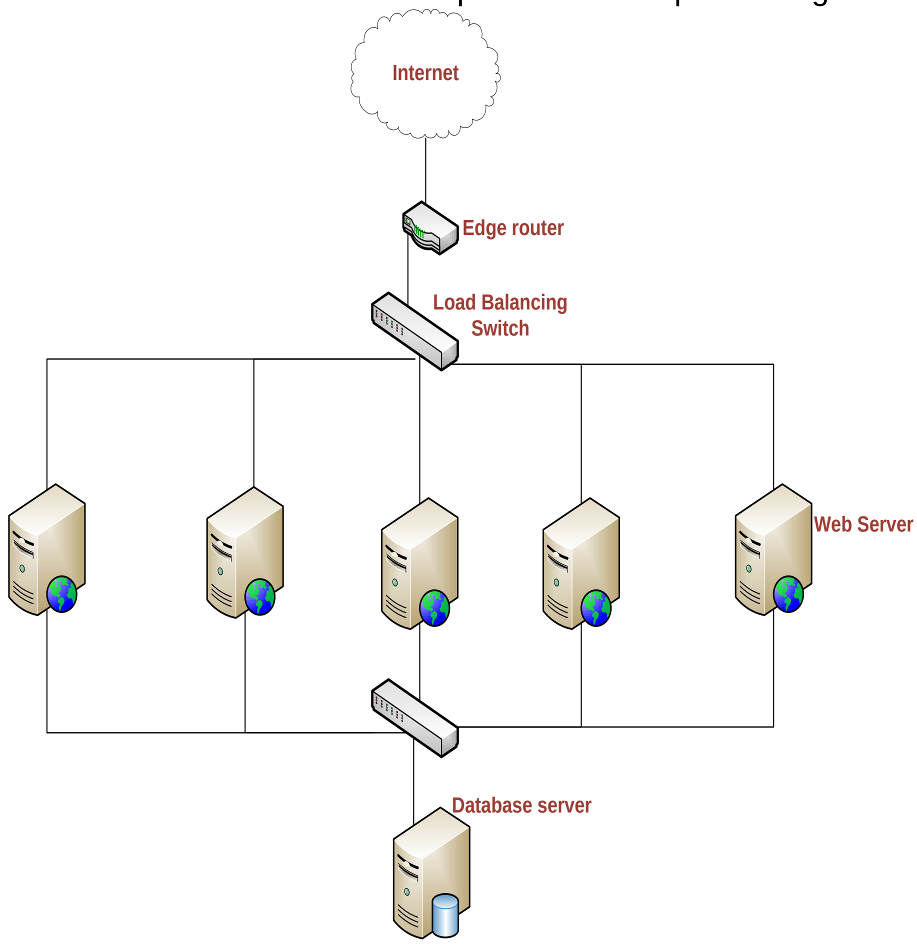

Figure 7.6: *Clustering web servers for SVSEPRS system model*

The entire web servers of the above clustering architecture can be located together in the same physical place. The routers handle arriving traffic to a web-switch which sends off these requests between the web servers.

It is fundamental to apply an appropriate dispatching algorithm to consider the servers' loads. Load balancing algorithms and the admission controls (which are implemented in the web-switch) are particularly important but it is not involved in this thesis and it will be left for future work.

However, it can be done by spreading the received loads of requests between the web servers. A web-switch is based on two main elements, a dispatcher and a distributor. The dispatcher is to identify which web server would receive a collected request, while the distributor achieves a mechanism for spreading the clients' requests to a particular web server [168].

7.5 UML (Unified Modelling Language)

7.5.1 Use Case Diagrams

A use-case illustrates a sequence of actions that supply something of assessable value to the users.

The Electronic Patient Record's segment is regarded here as being accessed through a SVSEPRS system. Users may wish to request certain EPR segment and to view those that exist in the local healthcare organisations of a given patient. Figure 7.7 illustrate the main Use Case Diagram for SVSEPRS system:

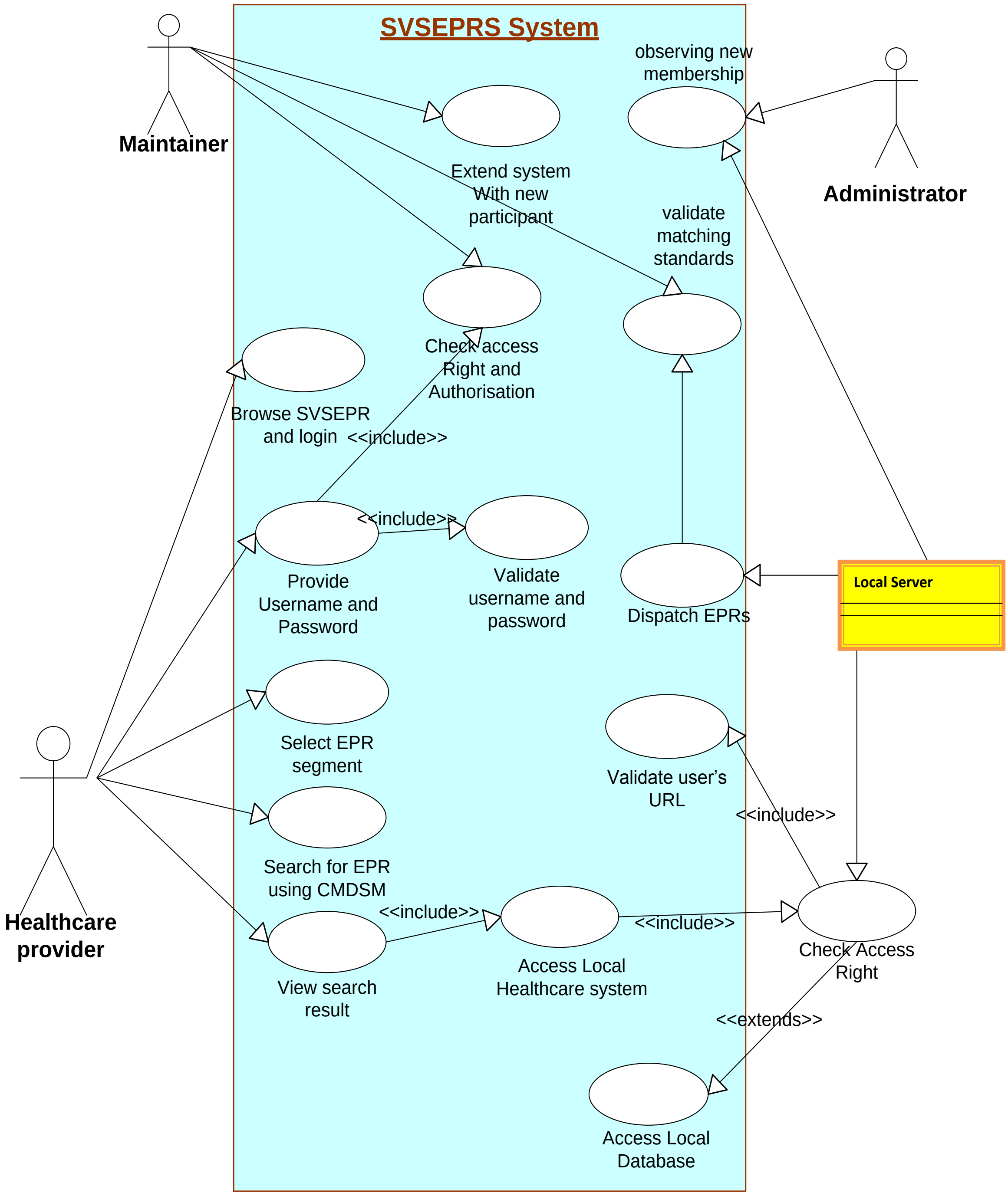

Figure 7.7: *SVSEPRS system level use case diagram*

The key actors acknowledged to be connected with the SVSEPRS service are:
1) The healthcare providers who require the SVSEPRS service to be able to offer role-based, secure access to reliable, patient healthcare information whenever and from wherever they need it;
2) The Maintainer who is responsible for the preservation, extra development, and enhancement with new system characters whenever it requires;
3) The Administrator is responsible for observing new membership system generation through a regular report that indicates the new participant names, roles and health institutes.

7.5.2 Sequence Diagram

The following sequence diagram scenario (Figure 7.8) illustrates the likely principal interactions between the requester of healthcare provider, located at specific healthcare location, the SVSEPRS system components and the feeder local healthcare system to view EPR diagnosis segment.

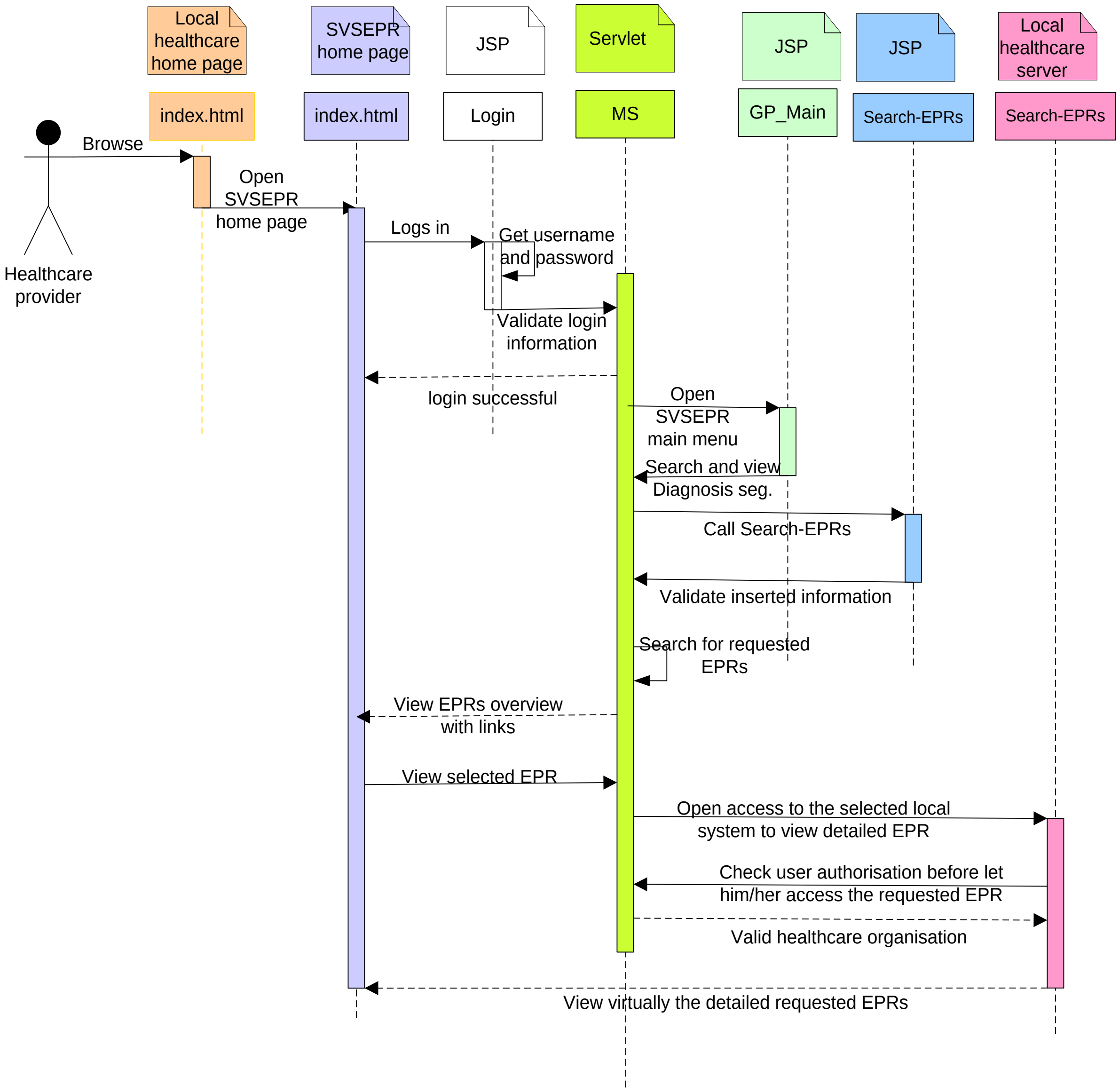

Figure 7.8: *Login and searching using SVSEPRS to view diagnosis segment*

7.5.3 Class Diagram

A class diagram of the proposed SVSEPRS system illustrates the classes that comprise this approach and the static connection between them.
However, UML diagrams are not the place to declare all variables. Such declarations are already done in the source code.
As it shows in the following class diagram (figure 7.9), all Servlets are a subclass of HTTPServlet and that it relies on the definition of the PrintWriter class in some way. However, we omitted the Optimalclass of HTTPServlet, and also omitted HTTPServletRequest and HTTPServletResponse. An object of the HTTPServletClass was explicitly used by these methods.

7.5.3.1 Relationships:

The following relationships are used in this class diagram:

- **Dependency:** All servlets used in this system are depends in some way on the definition of PrintWriter class.
- **Generalisation:** All Servlets are extends HttpServlet, which means **HttpServlet** is a generalisation of our Servlets (i.e. some methods are inherited from Optimalclass).
- **Association:**
  - MS may have one or more HH, CH and GP.

The name CH, HH, GP and MS are short names of the Carvel Hospital, Henry Hospital, 3balls clinic (used as example of healthcare locations) and Multidimensional Searching used by SVSEPRS system model subsequently.

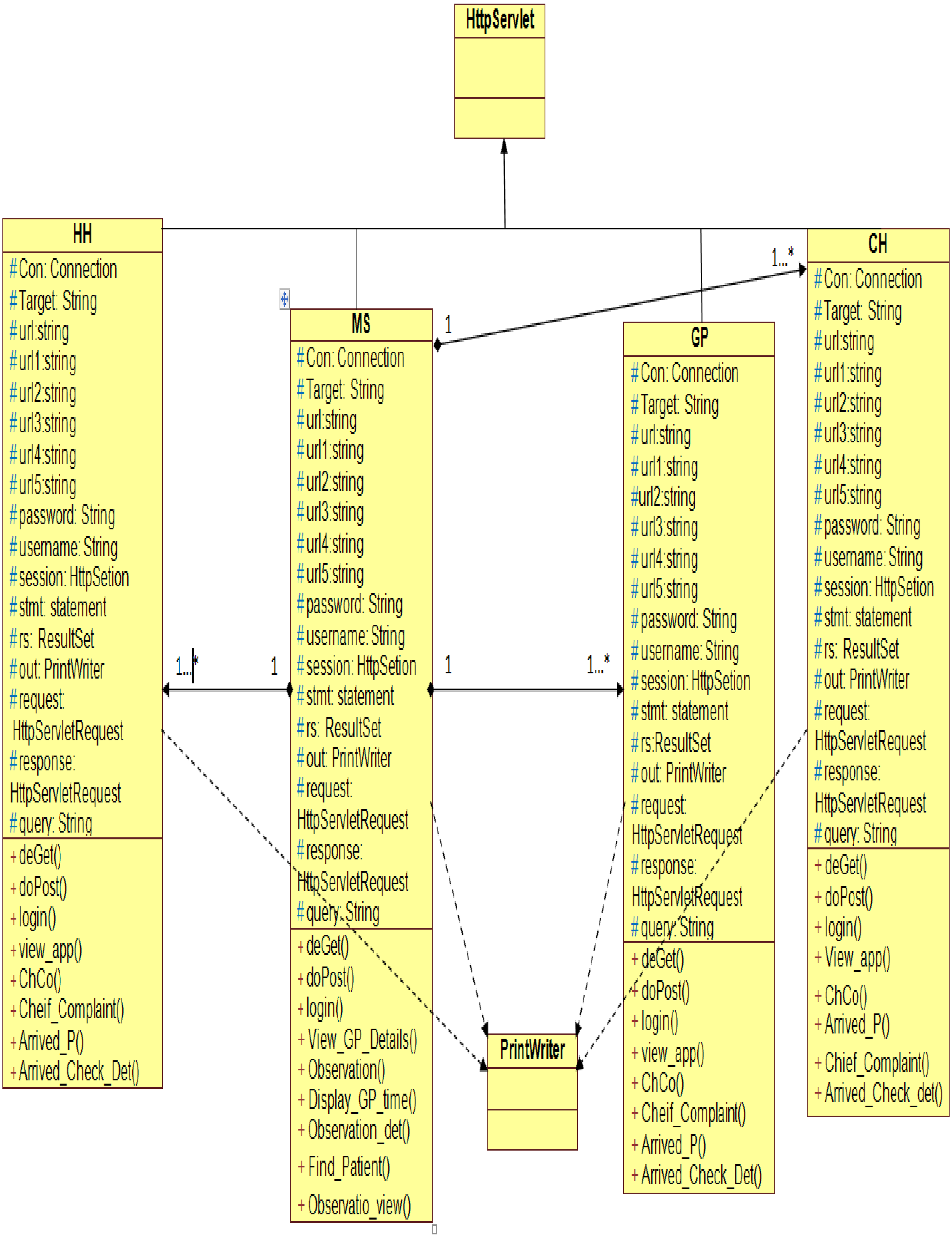

Figure 7.9: *SVSEPRS class diagram*

7.6 Implementation of the SVSEPRS

In the previous steps we presented the requirements, design and architecture of the proposed model, which gave a broad picture of the system and all the necessary parts. In this section, the implementation of the system will be described.

It has already been discussed how the system would operate in the previous steps, but in this component one needs to decide what user interface is requested, how to manage the data and what middleware technologies are needed.

This section, introduces a first prototype of the proposed system model (SVSEPRS).

Java was selected as the software tool for the implementation process due to its exceptional characteristics such as Open Source and non-commercial software.

The implementation of the Interface, web server, and database layers in the current SVSEPRS system is realized by a traditional client-server model.

In the next section, Java Servlets, Java Server Pages (JSP) and HTML files needed to build the client-side interfaces and the server-side web tier are illustrated.

Figure 7.10 illustrates the main servlets, JSPs and HTML files that have been used to implement the model and the cooperation between them.

Figure 7.10: *Servlets, JSPs and HTML used for SVSEPRS system implementation*

7.6.1 Interface layer

The interfaces layer is built with HTML (Hypertext Markup Language) and JSP (JavaServer Pages) and includes menu, push-button, and drop-list, which facilitates and enriches the user interface and provide more control and interaction on the user interface.

Three local healthcare systems and one main central SVSEPRS web site have been designed for three distinct healthcare organisations. Each one of these local home pages are supplied with a hyperlink to enable clinicians to open access to the centralised SVSEPRS home page.

Figure 7.11 shows the home page of one of the local healthcare organisation (Carvel Hospital).

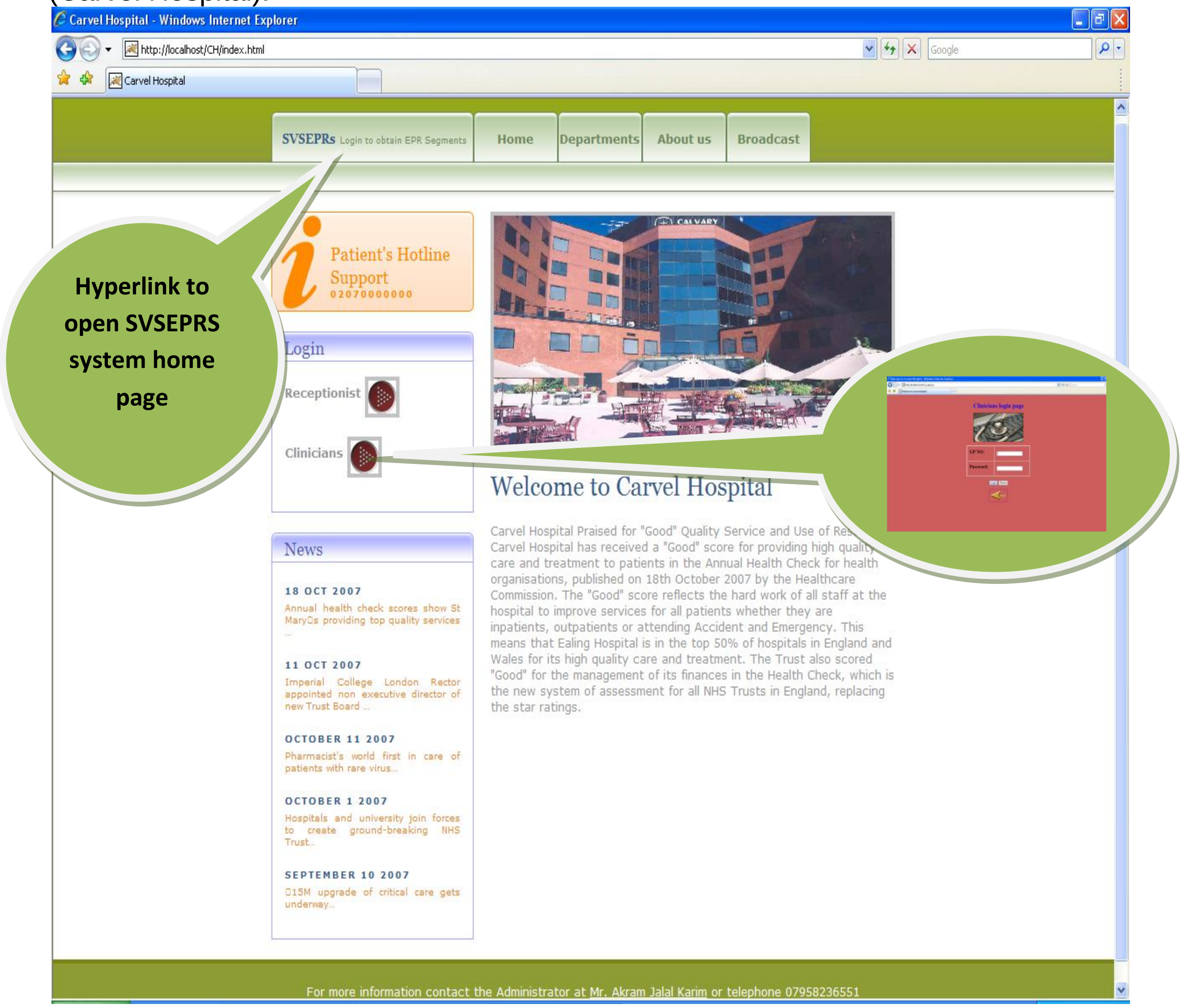

Figure 7.11: *The home page of one of the local healthcare organisation (Carvel Hospital)*

Each healthcare provider begins a session by running a standard web browser to open their local home page. As a result, an HTML page is generated with the appropriate text fields, JPEG images and hyperlinks for moving between pages. Using local sites, clinicians can create and store EPRs locally during each clinical session.

Each local healthcare home page contains a button to generate and view the SVSEPRS system home page for healthcare providers to search for and view the most required EPRs that are created and stored at different healthcare organisations.

Figure 7.12 shows the SVSEPRS system home page.

The home page is based on two main buttons, the registration and login. The staff of unregistered healthcare organisations are unable to login to the system, thus, they should first start the registration process by filling up the registration form and listing all their own clinicians who want to use the SVSEPRS system. The SVSEPRS then will generate a username and password for each one of the supplied names to allow them to login to the system.

Figure 7.12: *The home page of the SVSEPRS*

For both sites (local healthcare and SVSEPRS), the authentication process will start after pressing the login button, which will generate a JSP submenu for the login process. After a successful authentication; a main menu for each user will be displayed.

7.6.2 Web server layer

The local healthcare and SVSEPRS web servers have been implemented using Java servlets which is a high performance plug-in that runs a Java Virtual Machine (JVM) and Java Server Pages (JSPs) running through the Apache Jakarta Tomcat servlet engine. The servlets are implemented and compiled inside the Web server. Servlets are assured protocol and a platform-independent server written in the Java language. They offer a system model services constructed using the request-response theory.

Servlets are the heart of the SVSEPRS system implementation which handles incoming requests from healthcare providers and provides correct responses by using Java Class called HttpServlet which exchanges SVSEPRS GET and POST protocol operations with the browser client.

Inside Class HttpServlet, the method doGet implements the HTTP GET operation, and the method doPost implements the HTTP POST operation.

For instance, when the healthcare provider opens access to SVSEPRS, the browser will invoke a servlet via identifying the name of the servlet in the provided URL, which will execute the doGet method.

However, when the healthcare provider enters username and password for the login process, the doPost method will be executed.

The web browser and the web server communicate with each other using the HTTP protocol (Figure 7.13). Even though all SVSEPRS servlets are written in Java, the participating healthcare organisation system applications can be developed in any other language as Java will be able to communicate with other systems written in any other language.

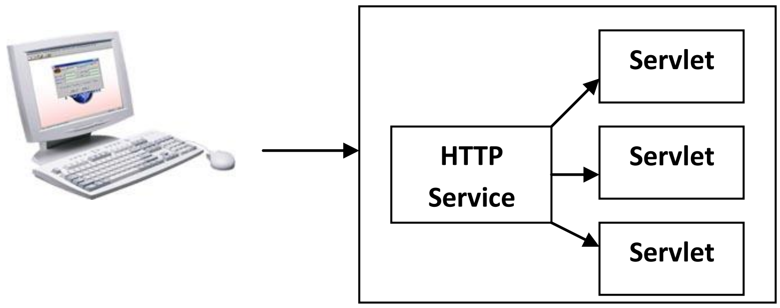

Figure 7.13: *Http protocol for communication process.*

By building the servlets in the SVSEPRS web server, they can in turn be clients to other services. For instance, servlets can use SQL to open access with an application's relational databases management system such as MySQL, Oracle, DB2, etc.

By specifying the exact, patient identification, time period and the organisation‘s identification number, SVSEPRS will facilitate clinician needs to know “what” patient healthcare information exists and “where” and “when” it has been created before the clinician can access it (see Figure 7.14).

Figure 7.14: *CMDSM of the SVSEPRS system model*

SVSEPRS system uses five servlets to hold the rules and business logic for the different user types. Three implement and manage three different local healthcare organisations, (i.e. Carver Hospital, Henry Hospital and 3balls clinic). The forth implement the local booking appointment process which is called Patient_CH. The fifth implement the CMDSM which is called MS.
In the following, a brief description to local healthcare and the SVSEPRS servlets and their methods are presented.

7.6.2.1 Patient_CH.java

This servlet deals with all functionalities and services that are related to the booking appointments at Carvel Hospital, which contains the following methods:

Method name	Brief explanation
Init()	Initialize the servlet. This is called once the servlet is loaded.
doGet()	Performs the HTTP GET operations
doPost()	Performs the HTTP Post operations
login()	Verifying the receptionist login information
View_GP_Details	Used to call: **View_GP_det.jsp** file.
Display_GP_time()	This method is used to select and book a convenient clinical appointment. The method starts by getting three parameters; checks them to ensure they are not empty. The first function in this method is to check whether the patient has already booked this appointment (date and time) with a selected clinician. If the patient has not yet attended the already booked appointment with a clinician, he/she cannot book another appointment with the same clinician even at a different time. The patient cannot even book an appointment with a clinician at a specific time if that clinician has another booked appointment at that time. If none of the above cases had been chosen, the appointment will be booked successfully.

Table 7.1: *Main methods used by Patient_CH Servlet*

7.6.2.2 CH.java

This servlet deals with all functionalities and services that is related to the Carvel Hospital services, which contains the following functions:

Method name	Brief explanation
Init()	Initialize the servlet. This is called once the servlet is loaded.
DoGet()	Performs the HTTP GET operations
DoPost()	Performs the HTTP Post operations
login()	Verifying the clinicians login information
Arrived_P()	Used to call: **Arrived_GP.jsp** file.
ChCo()	Used to call: **CheifObser.jsp** file.
View_app	This method lists all unattended booked appointments with the clinicians. Note that the clinician number will be captured using the session mechanism.
Arrived_Check_Det()	This Servlet gets the inserted diagnosis parameters locally. Update and dispatch key sets fields from local to the central SVSEPRS cube 1.
Chief_Complaint()	This Servlet gets the inserted chief complaint parameters locally. Update and dispatch key set fields from local to the central SVSEPRS cube 2.

Table 7.2: *Main methods used by CH Servlet*

7.6.2.3 MS.java

This servlet is the core of the SVSEPRS which contains several methods that deals with all functionalities and services of the proposed system.

The functionalities of this servlet are briefly explained in the following table:

Method name	Brief explanation
Init()	Initialize the servlet. This is called once the servlet is loaded.
doGet()	Performs the HTTP GET operations
doPost()	Performs the HTTP Post operations
login()	Verifying the username and password of clinicians login to the SVSEPRS system
SetURL()	This method gets the parameter URL and stores it into a session to be used latter and call index.html file.
Svs_regform()	This method starts by getting the URL and clinical name parameters during the registration process and stores them in the central database. Any local healthcare feeder will use this table to verify eligibility by checking weather the URL of the requester already exists and registered or not, before giving him/her permission to view the required EPR.
View_GP_Details()	Used to call: Search_EPRs.jsp file.
Observation()	Used to call: Search_EPRs1.jsp file.
Display_GP_time()	The method starts by getting parameters which are entered by Search_EPRs.jsp. It then searches the diagnosis cube and stores the results (app_No and URL) in two arrays and pass them to the Find_Patient servlet method.
Find_Patient()	It starts by getting the passed parameters and search the selected local healthcare systems for the virtual viewing of the diagnosis segment.
Observation_det()	The class starts by getting parameters which are entered by Search_EPRs1.jsp. Then searches the chief complaint and observation cube and store the results (app_No and URL) in two arrays and pass them in to the Observation_view servlet method.

Observation_view()	It starts by getting the passed parameters and searches the selected local healthcare system for virtual viewing patient complaints and observation segment.

Table 7.3: *Main methods used by MS Servlet*

7.6.3 Database layer

The efficiency of the database layer is dealt with by a MySQL5 DBMS with a database having tables and relations matching to the connection model of the local healthcare systems.

MySQL is the familiar and most admired open source database management system.

As MySQL tool supports java database connectivity (JDBC), the cooperation between Java language and MySQL will be more efficient and there will be no requirements for the use of particular statements to access the RDBMS.

The database layer provides a basic set of methods for storing, retrieving and querying objects from the database.

A distinctive data model for multidimensional data query, which is the core of this layer, is the star schema. The star schema includes basic table structure reducing joins complexity and speeding up the execution of queries [169]. It is applied for the logical design of multidimensional data cube table structures and holds complex queries known as on-line analytical processing (OLAP).

As figure 7.15 and 7.16 shows, the star schemas belong to two EPR segments, Diagnosis and chief-complain. The *fact table*, which is the table at the centre of the structure, containing quantitative measures of transactional nature (such as diagnosis name, diagnosis type, chief complain1) is linked with multiple dimensional tables.

Dimension tables comprise single primary key and several attributes that are useful for comparing the facts. These dimensions usually comprise a time, group and location.

7.6.3.1 Indexes searching algorithm

When patient healthcare information in data warehouse is appended directly in the form of Star Schema is often adopted for the process of management and organization.

Currently, some methods for improving the performance of OLAP query processing based on relational structure have been improved to speed up the process of data searching [170].

Data Warehouses are used to accumulate huge amounts of outlined patient information. This information is often used for OLAP. Quick response time is the significant issue for clinical decision making process. There are many methods of enhancing the performance of a data warehouse. Bitmap index is the algorithm used to enhance the searching process for multidimensional data cubes.

Currently, indexing is the optimal algorithm used for enhancing the speed of searching process without adding extra hardware [171].

The centralised web database of SVSEPRS may contain millions of rows of outlined EPR segment; a search for a specific row would take a long time.

Bitmap indexing is an algorithm used for search the EPRs stored in the multidimensional data warehouse. It was first introduced and implemented in the Model 204 DBMS [172].

The idea is to record values for sparse columns as a sequence of bits, one for each possible value. For example, a gender value is either 10 or 01; a 1 in the first position denote male and 1 in the second position denote female. If the gender values have been considered for all rows in the Patient table, we can treat this as a collection of two bit vectors. The collection of bit vectors for a column is called a bitmap index for that column.

Thus, bitmap index consists of B (total number of different values of the indexed attribute) bitmap vectors each of which is formed to denote each individual value of the indexed attribute. For example, a bit i in a bitmap vector, representing value x, is set to 1 if the record i in the indexed table contains x.

If B=15, Bitmap Index on this attribute is the collection of 15 bitmap vectors, says {R0,Ri,...RI4}, one for each distinct value of the attribute A. To run a search query, the bitmap vectors of the values specified in the predicate condition are read into memory. If there are more than one bitmap vectors read, a Boolean operation will be performed on them before accessing data [172].

Bitmap indexes present two main advantages over conventional hash and tree indexes. First they allow the use of efficient bit operations to answer queries. Second, bitmap indexes can be much more compact than the traditional B+ tree index and are very amenable to the use of compression techniques.

However, B-tree and a hash table are still needed to map values of the corresponding vector.

This algorithm which is adapted to work with hash indexes as well as B+ tree indexes will speed up the process of searching is extremely improved and this algorithm showed that it is highly efficient.

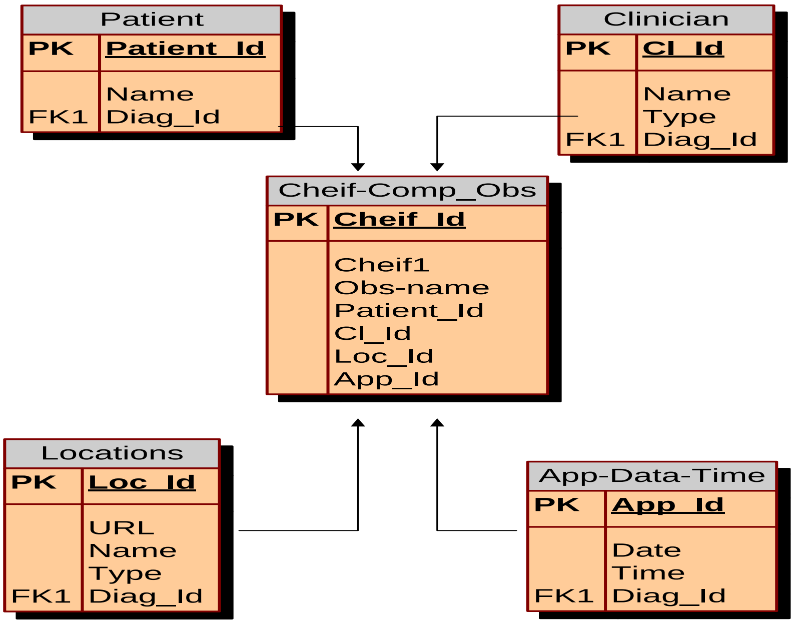

Figure 7.15: *Chief-Complaint and Observation segment star schema*

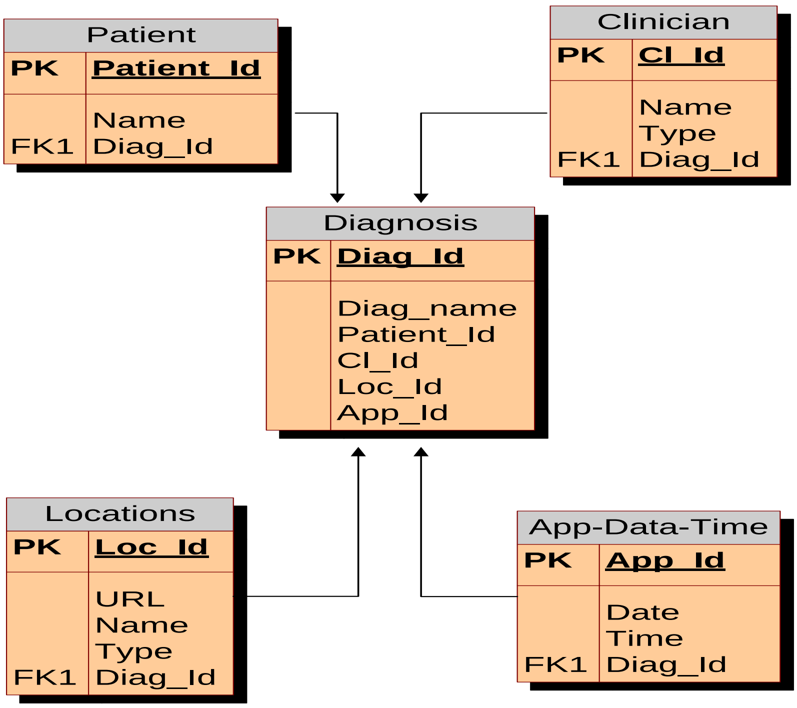

Figure 7.16: *Diagnosis segment star schema*

7.7 Verification of SVSEPRS model using the concept of Induction theory

Several thoughts in mathematics and computer science are obviously proved using inductive theory.
Mathematical induction is an extremely powerful technique that can be applied to verify properties about unlimited (or very large) data types [173].
This section illustrates how the concept of mathematical induction can be applied in a practical way to prove that the total time required to request a specific EPR from a particular healthcare organization's database $\mathbf{t}^*_{\mathbf{total}(\mathbf{n})}$ using the proposed SVSEPRS model is less than(faster) the time needed to get the same EPR using an ordinary (broadcasting) model $\mathbf{t}_{\mathbf{total}(\mathbf{n})}$.

7.7.1 Induction principle

Proof by induction implies statements which depend on the natural numbers, n = 1, 2, 3, etc. These natural numbers indicates the number of database location which needs to be queried by our models to access electronic patient records in order to find the more scalable model.
It uses summation notation ∑, which denotes a sum over its argument for each natural number i from the lowest value, here i = 1, to the maximum value, here i = n.

Let P (n) be the statement which involves a natural number n, then P (n) is true for all n if:

1- P (1) is true
2- P (k) is true
3- P (k+1) is true
4- $\Longrightarrow$ P (n) for all natural numbers n.

Therefore, proving the trueness of the following statements:

$$t^*_{total}(1) \leq t_{total}(1)$$
$$t^*_{total}(2) \leq t_{total}(2)$$
$$t^*_{total}(3) \leq t_{total}(3)$$
$$t^*_{total}(n) \leq t_{total}(n)$$

will conclude that the proposed model (SVSEPRS) is faster in querying for a specific record stored at specific location than the broadcasting model.

7.7.2 Broadcasting database queries Vs. SVSEPRS model

Scenario 1**: for n=1, proving that** $t^{*}_{total\,(1)} \leq t_{total\,(1)}$

If only one local database (e.g. Db1) that belongs to a particular healthcare organization which needs to be queried using the broadcasting model to access some records belonging to a particular patient, then the time needed to access this database will be explained in this section:

Db1 = { db|db Є Db1, db{Table1, Table2, …. $Table_n$ }}

Db1.Table1= {tb|tb Є Table1, tb{Record1, Record2, …$Record_n$}}

Db1.Table2= {tb|tb Є Table2, tb{Record1, Record2, … $Record_n$}}

∴ Db1.$Table_n$={dbtb|dbtb Є Db1.$Table_n$, dbtb {Record1, Record2, … $Record_n$ }}

Where Db1.$Table_n$ is the total tables belong to Db1.

If Db= {Db1.$Table_n$} →time needed for querying records stored at Db1 is:

$$t_1 = \sum_{i=1}^{nDb1.Table_n} (\delta t_i)$$

Where, ***nDb1.Table$_n$*** is the total number of records stored in all tables of Db1.

$$\therefore t_{total} = t_1$$

Where, t_{total} is the total time required to search this database for a specific query using a broadcasting model.

Scenario 2: **for n=2, proving** $t^{*}_{total\,(2)} \leq t_{total\,(2)}$

In this scenario, two databases (Db1 and Db2) that belong to different healthcare organizations are queried directly using an ordinary system (broadcasting model) in order to collect some EPRs that have been created and stored locally. The time needed to access these records in these databases is showing here:

Db1 = {db|db Є Db1, db {$Table1_1$, $Table2_1$, …. $Table_{n1}$}}

Db1.Table1= {tb|tb Є $Table1_1$, tb{$Record1_{1-1}$, $Record2_{1-1}$, …$Record_{n-1-1}$}}

Db1.Table2= {tb|tb Є Table2, tb{$Record1_{2-1}$, $Record2_{2-1}$, … $Record_{n-2-1}$ }}

Db1.$Table_n$={dbtb|dbtb Є Db1.$Table_n$, dbtb {$Record1_{n-1}$, $Record2_{n-1}$, … $Record_{n-n-1}$ }}

Db2 = {db|db Є Db2, db{$Table1_2$, $Table2_2$, …. $Table_{n2}$ }}

Db2.Table1= {tb|tb Є Table1, tb{$Record1_{1-2}$, $Record2_{1-2}$, …$Record_{n-1-2}$}}

Db2.Table2= {tb|tb Є Table2, tb{$Record1_{2-2}$, $Record2_{2-2}$, … $Record_{n-2-2}$ }}

Db2.$Table_n$= {dbtb|dbtb Є Db2.$Table_n$, dbtb {$Record1_{n-2}$, $Record2_{n-2}$, … $Record_{n-n-2}$ }}

If Db= {Db1.$Table_n$, Db2.$Table_n$} →time needed for querying each of these two databases is:

$$t_1 = \sum_{i=1}^{nDb\,1.Table_n} (\delta t_i)$$

$$t_2 = \sum_{i=1}^{nDb\,2.Table_n} (\delta t_i)$$

Where, t_1 and t_2 are the times needed to query and search the whole records of the whole tables placed in $Db1$ and$Db2$ respectively.

$\boldsymbol{nDb1.Table_n}$ and $\boldsymbol{nDb2.Table_n}$ refers to the maximum number of records of maximum tables in Db1 and Db2 respectively.

$$\therefore t_{total} = t_1 + t_2$$

$$t_{total} = \sum_{i=1}^{nDb\,1.Table_n} (\delta t_i) + \sum_{i=1}^{nDb\,2.Table_n} (\delta t_i)$$

$\boldsymbol{t_{total}}$ is the total time needed to search the whole records of the whole tables placed at database1 and database2 (i.e. the databases of two healthcare clinics).

Db_c= $Db1.Table_n$ ∩ $Db2.Table_n$
= { dbtb|dbtb Є $Db1.Table_n$ & dbtb Є $Db2.Table_n$}

Db_c refer to the records which are common in both databases.
This occurs when a patient visits two health locations and at each one an EPR was created and stored.

As $t_{total} = t_1 + t_2$

By using decompose:
$t_1 = t_1' + t_c$
Where t_1' is the time of the query needed to search the records of the tables in Db1 which are **not in common** with Db2.
While t_c is the time of the query needed to search the records of the tables in Db1 which are **in common** with the other database (i.e. Db_2).

$t_2 = t_2' + t_c$

$$\boldsymbol{t_{total} = t_1' + t_2' + 2t_c}$$

Db_s= $Db_1.Table_n$ ∪ $Db_2.Table_n$ ∩ $Db_c.Table_n$
= {dbtb|dbtb Є $Db_1.Table_n$ *or* dbtb Є $Db_2.Table_n$ *and* dbtb Є $Db_c.Table_n$}

$$t^{*}_{total} = (\sum_{i=1}^{nDb1.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc.Table_n} (\delta t_i)) + (\sum_{i=1}^{nDb2.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc.Table_n} (\delta t_i)) + \sum_{i=1}^{nDbc.Table_n} (\delta t_i)$$

$$t^{*}_{total} = \sum_{i=1}^{nDb1.Table_n} (\delta t_i) + \sum_{i=1}^{nDb2.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc.Table_n} (\delta t_i)$$

<u>Scenario 3:</u> for n=3, proving $t^{*}_{total\,(3)} \leq t_{total\,(3)}$

Three databases are used in this scenario which are belongs to different healthcare organizations. Assuming that these databases are queried directly using an ordinary system (broadcasting models) in order to access records that are created and stored locally for a particular patient. The time needed to search Db1, Db2 and Db3 are as follows:

As mentioned earlier:

$Db1.Table_n$= {dbtb|dbtb Є $Db1.Table_n$, dbtb {$Record1_{n-1}$, $Record2_{n-1}$, … $Record_{n-n-1}$ }}

$Db2.Table_n$= {dbtb|dbtb Є $Db2.Table_n$, dbtb {$Record1_{n-2}$, $Record2_{n-2}$, … $Record_{n-n-2}$ }}

The third database can be defined as:

Db3 = {db|db Є Db3, db {$Table1_3$, $Table2_3$, …. $Table_{n3}$}}

Db3.Table1= {tb|tb Є $Table1_3$, tb {$Record1_{1-3}$, $Record2_{1-3}$, …$Record_{n-1-3}$}}

Db3.Table2= {tb|tb Є Table2, tb {$Record1_{2-3}$, $Record2_{2-3}$, … $Record_{n-2-3}$}}

$Db3.Table_n$={dbtb|dbtb Є $Db3.Table_n$, dbtb {$Record1_{n-3}$, $Record2_{n-3}$, … $Record_{n-n-3}$ }}

If Db= {$Db1.Table_n$, $Db2.Table_n$, $Db3.Table_n$ } →time needed to search tables stored at these databases is:

$$t_1 = \sum_{i=1}^{nDb1.Table_n} (\delta t_i)$$

$$t_2 = \sum_{i=1}^{nDb2.Table_n} (\delta t_i)$$

$$t_3 = \sum_{i=1}^{nDb3.Table_n} (\delta t_i)$$

Where, $t_{1,}$ t_2 and t_3 are the time needed for searching the whole records of the whole tables placed in $Db1, Db2$ and $Db3$ respectivly.

$\boldsymbol{nDb3.Table_n}$ is the maximum number of records of all tables in Db3.

$$\therefore t_{total} = t_1 + t_2 + t_3$$

$$t_{total} = \sum_{i=1}^{nDb\,1.Table_n} (\delta t_i) + \sum_{i=1}^{nDb\,2.Table_n} (\delta t_i) + \sum_{i=1}^{nDb\,3.Table_n} (\delta t_i)$$

$\boldsymbol{t_{total}}$ is the total time needed to search the whole records of the whole tables placed at database 1, 2 and 3 using broadcasting model.

Db_c= $Db1.Table_n \cap Db2.Table_n \cap Db3.Table_n$
= { dbtb | dbtb ∈ $Db1.Table_n$ & dbtb ∈ $Db2.Table_n$ & dbtb ∈ $Db3.Table_n$ }

Db_c refers to the records which are common in all the databases.
This occurs when a patient visits three health locations and at each one an EPR is created and stored locally.

As $t_{total} = t_1 + t_2 + t_3$

By using decompose:

$$t_1 = t_1' + t_c + t_{c1,2} + t_{c1,3}$$
$$t_2 = t_2' + t_c + t_{c2,3} + t_{c1,2}$$
$$t_3 = t_3' + t_c + t_{c2,3} + t_{c1,3}$$

Where, t_1' is the time of the query needed to search the records of the tables which are not in common with other databases.
While t_c is the time of the query needed to search the records of the tables which are in common with the other databases.

$$t_{total} = (t_1' + t_2' + t_3') + 3t_c + 2t_{c1,2} + 2t_{c1,3} + 2t_{c2,3}$$

For scenario 3:

$$\boldsymbol{t^{*}_{total}} = \left(\sum_{i=1}^{nDb\,1.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,1,2.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,1,3.Table_n} (\delta t_i) \right) + \left(\sum_{i=1}^{nDb\,2.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,1,2.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,2,3.Table_n} (\delta t_i) \right) + \left(\sum_{i=1}^{nDb\,3.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,1,3.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,2,3.Table_n} (\delta t_i) \right) + \sum_{i=1}^{nDbc\,.Table_n} (\delta t_i) + \sum_{i=1}^{nDbc\,1,2.Table_n} (\delta t_i) + \sum_{i=1}^{nDbc\,1,3.Table_n} (\delta t_i) + \sum_{i=1}^{nDbc\,2,3.Table_n} (\delta t_i)$$

$$\boldsymbol{t^{*}_{total}} = \sum_{i=1}^{nDb\,1.Table_n} (\delta t_i) + \sum_{i=1}^{nDb\,2.Table_n} (\delta t_i) + \sum_{i=1}^{nDb\,3.Table_n} (\delta t_i) - 2\sum_{i=1}^{nDbc\,.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,1,2.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,1,3.Table_n} (\delta t_i) - \sum_{i=1}^{nDbc\,2,3.Table_n} (\delta t_i)$$

$$\therefore \boldsymbol{t^{*}_{total} \leq t_{total}}$$

SVSEPRS facilitates searching and viewing a selective EPRs fragments on clinicians' needs among scattered Healthcare organizations over the Internet is simulated mathematically as follows:

For scenario 2:

$$\boldsymbol{t^{*}_{total}} = t_1 + t_2 - t_c$$

$$t_{total} = t_1' + t_2' + 2t_c$$

$$\therefore \boldsymbol{t^{*}_{total} \leq t_{total}}$$

<u>Scenario 4</u>: for n=k, proving $\boldsymbol{t^{*}_{total\,(k)} \leq t_{total\,(k)}}$

$$\boldsymbol{t_{total} = t1 + t2 + t3 + \cdots + tk}$$

$$t_{total} = \sum_{i=1}^{nDb\,1.Table_n} (\delta t_i) + \sum_{i=1}^{nDb\,2.Table_n} (\delta t_i) + \sum_{i=1}^{nDb\,3.Table_n} (\delta t_i) + \cdots + \sum_{i=1}^{nDbk\,.Table_n} (\delta t_i)$$

But By using decompose:

$$t_1 = t_1' + t_c + t_{c1,2} + t_{c1,2,3} + \cdots + t_{c1,2,3,\ldots,k} + \cdots$$
$$t_2 = t_2' + t_c + t_{c2,1} + t_{c2,1,3} + \cdots + t_{c2,1,3,\ldots,k} + \cdots$$
.
.
.
$$t_k = t_k' + t_c + t_{ck,1} + t_{ck,1,2} + \cdots + t_{ck,1,2,\ldots,k-1} + \cdots$$

Where, t_1' is the time of the query needed to search the records of the tables which are not in common with other databases.
While t_c is the time of the query needed to search the records of the tables which are in common with the other databases.

$$t_{total} = (t_1' + t_2' + \cdots + t_k') + kt_c + 2t_{c1,2} + 2t_{c1,3} + 2t_{c2,3} + \cdots$$

$$\begin{aligned} t^*_{total} = (& \sum_{i=1}^{nDb\,1.Table_n} (\delta t_i) \\ & + \sum_{i=1}^{nDb\,2.Table_n} (\delta t_i) + \cdots + \sum_{i=1}^{nDbn\,.Table_n} (\delta t_i)) - 2k \sum_{i=1}^{nDbc\,.Table_n} (\delta t_i) - (2k \\ & - 1) \sum_{i=1}^{nDbc\,1,\ldots.n-1.Table_n} (\delta t_i) \\ & - (2k-1) \sum_{i=1}^{nDbc\,2,\ldots.,k-1.Table_n} (\delta t_i) - (2k-1) \sum_{i=1}^{nDbc\,1,\ldots,k-1.Table_n} (\delta t_i) \\ & - (2k-1) \sum_{i=1}^{nDbc\,2,\ldots,k-1.Table_n} (\delta t_i) - \cdots - 2 \sum_{i=1}^{nDb\,1,2.Table_n} (\delta t_i) \\ & - 2 \sum_{i=1}^{nDb\,1,3.Table_n} (\delta t_i) - 2 \sum_{i=1}^{nDbc\,1,4.Table_n} (\delta t_i) - \cdots - 2 \sum_{i=1}^{nDbc\,1,k.Table_n} (\delta t_i) \\ & - 2 \sum_{i=1}^{nDbc\,2,3.Tab\,le_n} (\delta t_i) - 2 \sum_{i=1}^{nDbc\,2,4.Table_n} (\delta t_i) - \cdots - 2 \sum_{i=1}^{nDbc\,2,k.Table_n} (\delta t_i) - \ldots \end{aligned}$$

$$\therefore \boldsymbol{t^*_{total}} \leq \boldsymbol{t_{total}}$$

<u>Scenario 5:</u> for n=k+1, proving $\mathbf{t^*_{total\,(k+1)}} \leq \mathbf{t_{total\,(k+1)}}$

$$\boldsymbol{t_{total} = t1 + t2 + t3 + \cdots + tk + 1}$$

$$t_{total} = \sum_{i=1}^{nDb\,1.Table_n} (\delta t_i) + \sum_{i=1}^{nDb\,2.Table_n} (\delta t_i) + \sum_{i=1}^{nDb\,3.Table_n} (\delta t_i) + \cdots + \sum_{i=1}^{nDbk\,+1.Table_n} (\delta t_i)$$

By using decomposition:

$$t_1 = t_1' + t_c + t_{c1,2} + t_{c1,2,3} + \cdots + t_{c1,2,3,\ldots,k+1} + \cdots$$
$$t_2 = t_2' + t_c + t_{c2,1} + t_{c2,1,3} + \cdots + t_{c2,1,3,\ldots,k+1} + \cdots$$

.

.

.

$$t_{k+1} = t_{k+1}' + t_c + t_{ck+1,1} + t_{ck+1,1,2} + \cdots + t_{ck+1,1,2,\ldots,k} + \cdots$$

Where, t_1' is the time of the query needed to search the records of the tables which are not in common with other databases.
While t_c is the time of the query needed to search the records of the tables which are in common with the other databases.

$$t_{total} = (t_1' + t_2' + \cdots + t_{k+1}') + (k+1)t_c + 2t_{c1,2} + 2t_{c1,3} + 2t_{c2,3} + \cdots$$

$$\begin{aligned} \boldsymbol{t^*_{total}} = (& \sum_{i=1}^{nDb\,1.Table_n} (\delta t_i) \\ & + \sum_{i=1}^{nDb\,2.Table_n} (\delta t_i) + \cdots + \sum_{i=1}^{nDbn\,.Table_n} (\delta t_i)) - 2(k+1) \sum_{i=1}^{nDbc\,.Table_n} (\delta t_i) - (2k \\ & + 1) \sum_{i=1}^{nDbc\,1,\ldots.n-1.Table_n} (\delta t_i) \\ & - (2k+1) \sum_{i=1}^{nDbc\,2,\ldots.,k.Table_n} (\delta t_i) - (2k+1) \sum_{i=1}^{nDbc\,1,\ldots,k.Table_n} (\delta t_i) \\ & - (2k+1) \sum_{i=1}^{nDbc\,2,\ldots,k-1.Table_n} (\delta t_i) - \cdots - 2 \sum_{i=1}^{nDb\,1,2.Table_n} (\delta t_i) \\ & - 2 \sum_{i=1}^{nDb\,1,3.Table_n} (\delta t_i) - 2 \sum_{i=1}^{nDbc\,1,4.Table_n} (\delta t_i) - \cdots - 2 \sum_{i=1}^{nDbc\,1,k+1.Table_n} (\delta t_i) \\ & - 2 \sum_{i=1}^{nDbc\,2,3.Table_n} (\delta t_i) - 2 \sum_{i=1}^{nDbc\,2,4.Table_n} (\delta t_i) - \cdots - 2 \sum_{i=1}^{nDbc\,2,k+1.Table_n} (\delta t_i) - \ \ldots \end{aligned}$$

$$\therefore \boldsymbol{t^*_{total} \leq t_{total}}$$

And $\boldsymbol{t^*_{total} \leq t_{total}\ for\ n} \ldots$

7.8 Summary

In this chapter, the requirements, design, architecture, and implementation processes of the proposed SVSEPRS are described as a federated system with a client-server multidimensional search engine.

Each local healthcare organisation creates and stores its own EPRs and the standard contents must be in compliance with a central server which maintains outlined EPR information dispatched by local systems. This can be used for searching, mapping, and viewing (using stored links pointing) EPR segments that are stored at various healthcare locations (feeder local system).

Each local server(s) has pointers to the central server(s) which can be used to dispatch the basic and essential EPR fields of information soon after creating it and storing it locally.

Using CMDSM, the core of the SVSEPRS, the system offers the participating healthcare professionals the opportunity to search on the more beneficial and relevant EPR segment for medical diagnosis or decision making which are stored at different OLAP cubes using the process of rolls up and drill down.

Using the most up-to-date Java technologies such as JSP and Servlets, this web based client server model allows participants healthcare providers and researchers to share a vital EPR segments using not just normal work station, but also for remote machine control such as PDAs. Thus, adoption of servlet technology allows the SVSEPRS service to activate in a scalable, reliable and robust manner as well as increasing the availability of the service.

Finally, this model is compared with a model that does not use client server (e.g. broadcasting peer-to-peer model) using the mathematical induction theory. The results conclude that the proposed model (SVSEPRS) is faster in querying for a particular record stored at a specific location than the broadcasting model.

Chapter 8

Performance evaluation

8.1 Introduction

The discussion on EHR infrastructure that can be seen as centralization or decentralization of various healthcare systems which is not always obvious has flourished for more than a decade and is carried on.

Review of EHR system in various countries throughout the world shows significant variations in the way healthcare systems are structured. Some nations prefer to use decentralization and others are structuring their system using the centralized approach [174]. In Europe, for instance, Norway abandoned the decentralization approach, where healthcare system has in recent times been switched to a recentralized approach while England and through the world's most expensive IT project in the public sector (NPfIT) has structured their system based on the centralized approach [175].

The proposed model introduced in this thesis encompasses mainly a number of requirements and clinical information for representing EPRs which are created locally for implementing an SVSEPRS system, as explained in Chapter 7.

This information is obtained based on the research carried out by the author and supplemented by previous work in this area, and associated areas of health informatics.

The development of the model took place after frequent meetings and discussions with healthcare professionals from different institutions. Also, discussions took place which consulted a number of academic professionals in healthcare from inside and outside Brunel University as well as gathering information by attending relevant conferences of sharing EPR segments among different healthcare organisations.

Our design of this module is to build an extremely scalable infrastructure for accomplishing web applications on extensively spread set of healthcare locations.

In healthcare application fields, where the performance issue needs to be essential, typically, developers concentrate on corroborating several performance values such as scalability, latency and reliability**.**

This chapter describes the evaluation of the model performance in the light of the results shown.

8.2 Local healthcare organisations' model performance

The presented results are based on a three hypothetical healthcare organisations to measure the performance of the proposed system.

1- Henry Hospital
2- 3balls Surgery
3- Carvel Hospital

A brief explanation of how the local healthcare organisations create, store and share EPR segments between each other using the proposed model is given below:

Assume that a patient arrives at the Carvel Hospital with a specific illness.

Once has completed the admission procedure, the healthcare provider, after login to the local system successfully, will check patient's chief complains and clinical observation to create and store the ***first EPR segment*.**

During this stage, the clinician starts giving diagnostic hypothesis, which may require some clinical examinations such as lab tests, X-Ray, ECG test, etc to confirm it. These requests will be sent to the relevant department. The nurse may assist in archiving this duty by transferring the blood or urine samples to the laboratory or take the patient directly to the relevant department.

Healthcare professionals from other departments, and in order to achieve one or more of the above clinical examinations, need to login to their own main menu to see all the tasks need for this patient.

Wherever the patient is moved inside the Hospital, clinicians can create and insert clinical test results using a desktop, tablet, or pocket PC, to generate the ***second EPR segment***.

When the healthcare provider accumulates the clinical examination results, analyze it, and either authorizes the final diagnosis or suggests another diagnostic hypothesis and asks for further clinical examinations. Determining the final diagnosis will create and store the ***third EPR segment***. When the final diagnosis is confirmed, the clinician may set the proper therapy to be the ***fourth segment of this EPR***.

For each local EPR segment created and stored during the process, the local system dispatches the key sets (outlined segment) to the relevant storage at the SVSEPRS web database using the expanded tasks that have been added to each local system for this purpose.

During the discharge stage, the SVSEPRS can generate a discharge letter from all EPR segments for other clinicians such as General Practitioner, Consultants from other healthcare organisations, etc.

From the above scenario, it is clear that this model deals with two different databases, the local healthcare storage, which contains the complete and detailed EPR and the centralised web database storages that contains the outlined EPR segments on which the CMDSM is based (sections 7.3.5 and 7.3.6). Now, let us assume that the same patient visits other SVSEPRS's participant healthcare institutions such as the Henry Hospital. When this participant healthcare provider needs to view this particular patient's EPR segment; first, he/she starts by opening the **SVSEPRS home page,** using the attached link (see figure 7.11), to login and confirm the authorisation, which means unauthorized accesses will be refused. After a successful login, clicking on a specific EPR segment's key for viewing purposes will display the CMDSM home page (see figure 7.14). The Multidimensional query searching the centralised web database, based on specific patient ID, limited for a period of time and at a particular location. The query results will display a list of **outlined EPR segments**, each with an attached key button that is needed to view the detailed segment from local healthcare RDBMS (see figure 8.2).

Clicking on the view button that belongs to a particular segment of the selected EPR will generate and dispatch a query to the selected healthcare location. However, for security reasons, each local RDBMS and before giving permission to view a particular EPR segment, will check the validity of the requester's URL through inspecting the healthcare registration table. This table is stored in the web database tier, which contains the details of each participant healthcare location. If the requester is a valid SVSEPRS user, then a virtual view of the requested EPR segment will be displayed.

8.3 Experiment evaluation based on implementation of system model

To evaluate the performance results of the web-based SVSEPRS system model, it is compared with the P2P approach that generates a query based on a broadcasting request to all healthcare organisations. This query will pass a request to each correspondent RDBMS system to view all EPRs belonging to a particular patient, which was created and stored at specific local healthcare system.

For example if a diabetic patient needs to visit different departments regularly; he/she may be under a diabetologist, an ophthalmologist, nephrologists, a dietician, a wheelchair clinic, their GP and a District Nurse.

Therefore, with the broadcasting approach, the query results in all patients' EPRs. Thus for patients aged over 80 or 90 years old who are suffering from chronic diseases, hundreds or even more of EPRs will be displayed at once.

8.3.1 Experimental results of SVSEPRS Query response time

The main focus of these experiments is to investigate the performance of the SVSEPRS model. In order to effectively optimize the model with the best quality and performance, it is necessary to calculate the query and response time of the proposed model and compared with the performance of the broadcasting model.

The query response time is described as the time started at the beginning of query execution and ended at the end of query execution. System.currentTimeMillis() is java function which has been used for capturing transaction times.

However, the results can vary based on the platform used. This function was run on a machine with the following conditions:

- Pentium® 4
- 3.60 GHz Processor, 1.00 GB of RAM
- Microsoft Windows XP Professional
- JVM version 1.6.0_06

Figure 8.1, shows the average query response times for broadcasting and SVSEPRS models, in which, the broadcasting query runs over varying number of EPRs that are created and stored at scattered healthcare locations. This is done while SVSEPRS model runs this query over outlined EPRs which have been dispatched by local systems to the relevant SVSEPRS web database storage. It is obvious that the average query response time for SVSEPRS is noted to be much lower than that for the broadcasting model.

This is because, for each of the query processes, the number of healthcare organisations nodes in P2P broadcasting model is much larger than the number of nodes that needs to be searched in the proposed SVSEPRS model.
Thus, the query process using the SVSEPRS model needs a lower number of time slots during searching the centralised web database storages when compared to broadcasting model which in turn increases the average query response time when the number of EPRs has reached 50.

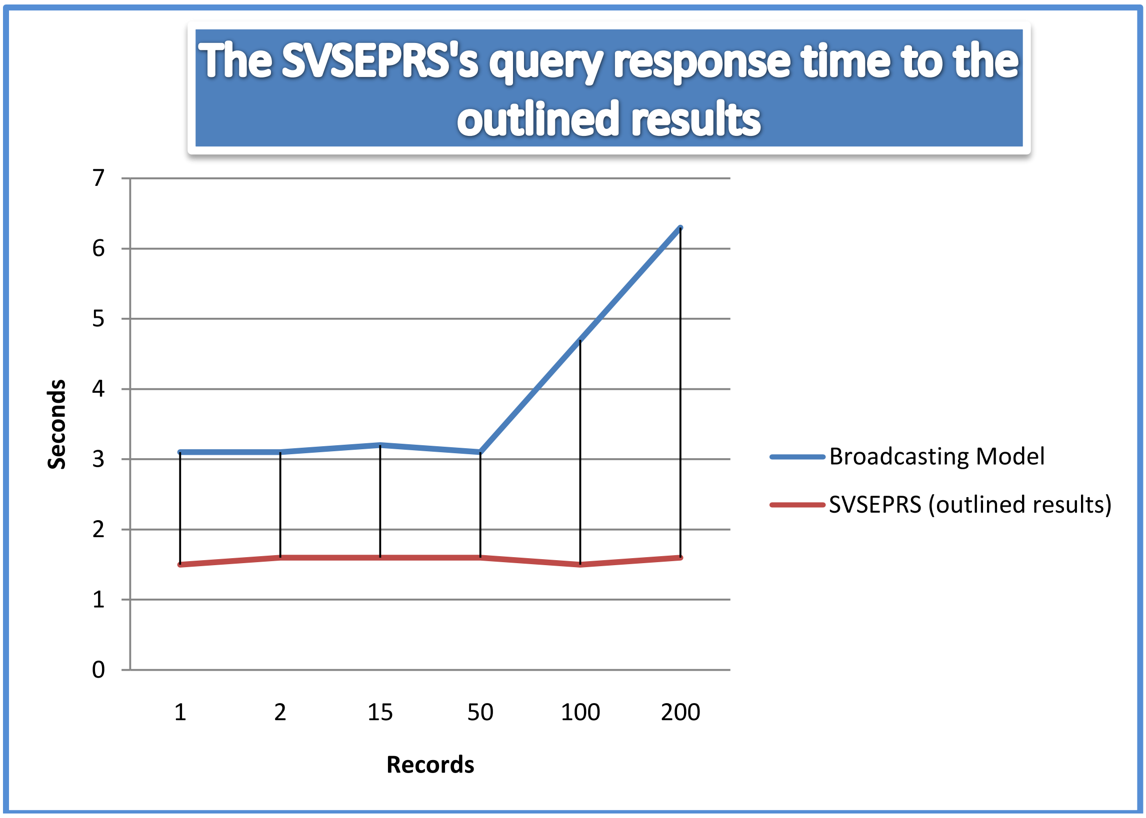

Figure 8.1: *Query response time to view outlined results*

The searching process using CMDSM (described earlier in section 7.6.2) deliver a list of outlined EPRs, each one attached with a key button to view detailed EPR segments that have been created and stored locally (see figure 8.2).

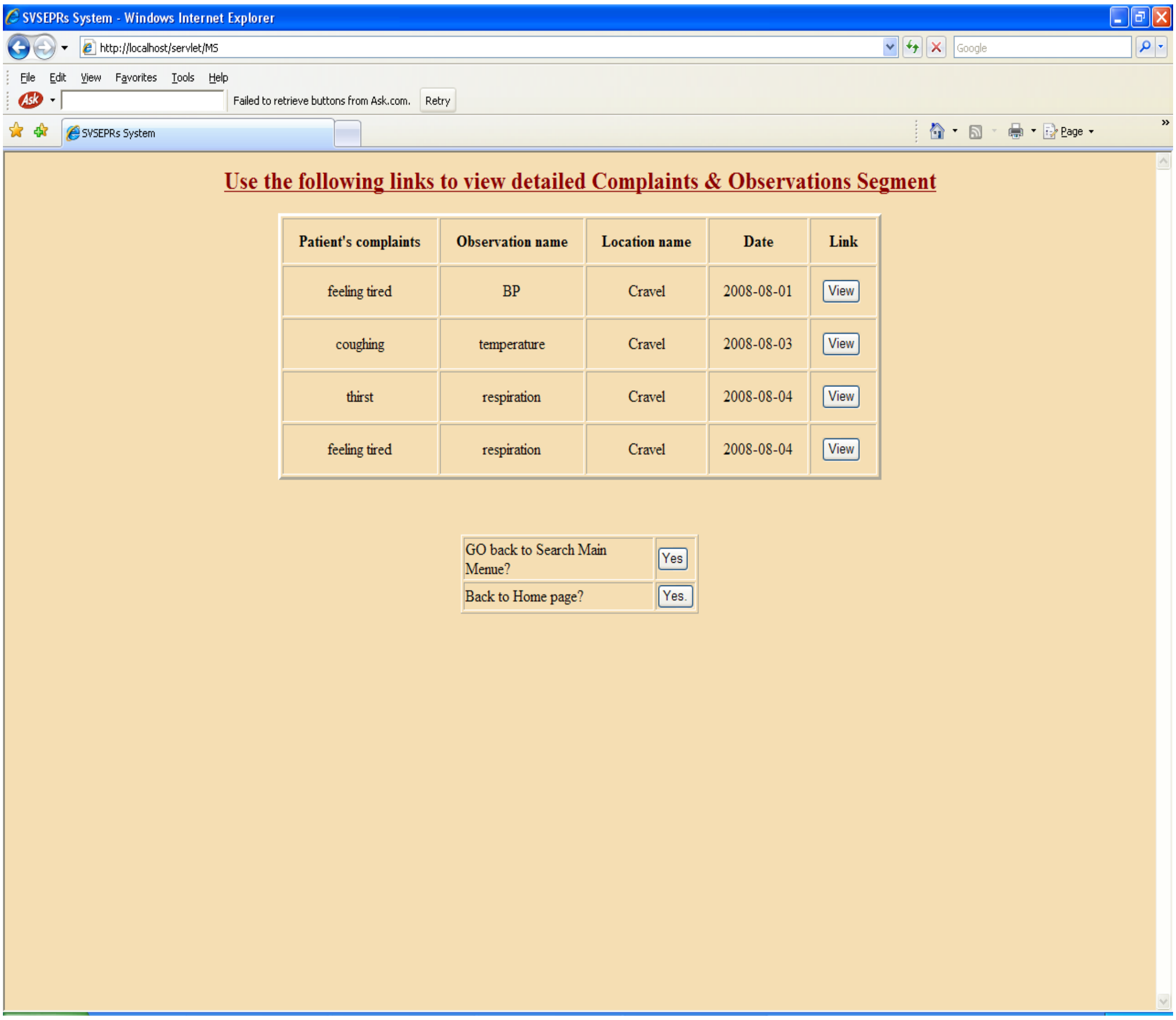

Figure 8.2: *Outlined EPR results for specific segment*

Selecting the required record via pressing its key button will generate a query to view the detailed EPR which was created and stored at the local healthcare institution. Figure 8.3, shows the SVSEPRS average response times of this query compared to the broadcasting query request time.

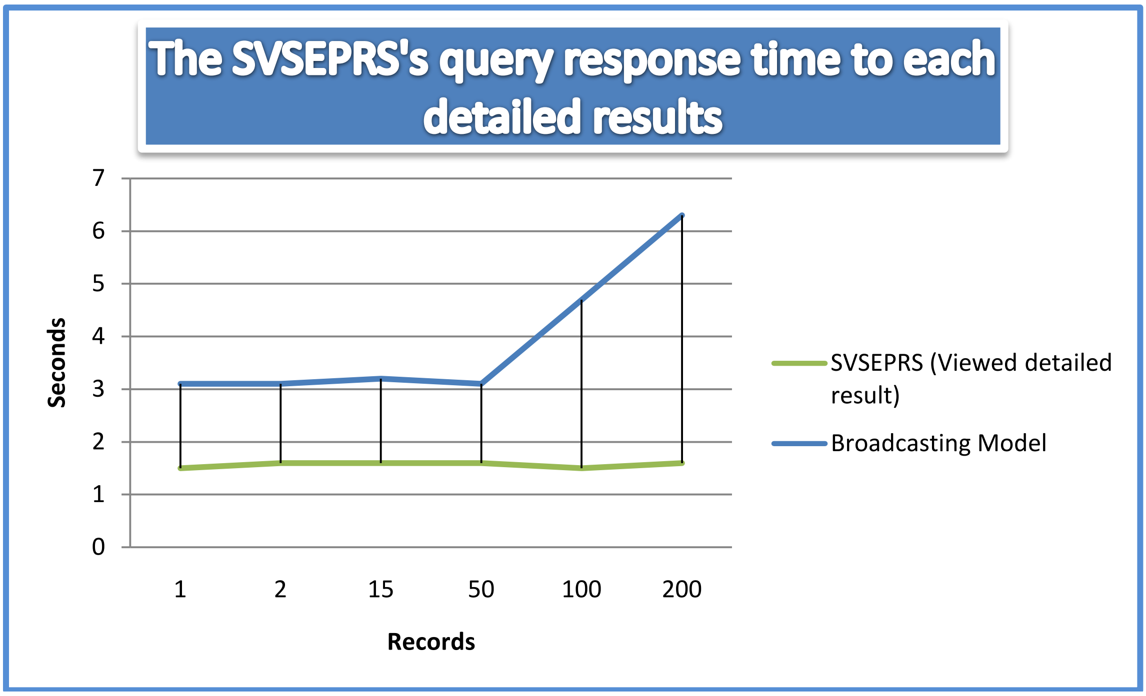

Figure 8.3: *Query response time needed to view detailed result*

Figure 8.4, shows the SVSEPRS total time (summing the previous two steps needed by the clinician to view the most required and detailed EPR segment) compared with the same broadcasting graph's model.

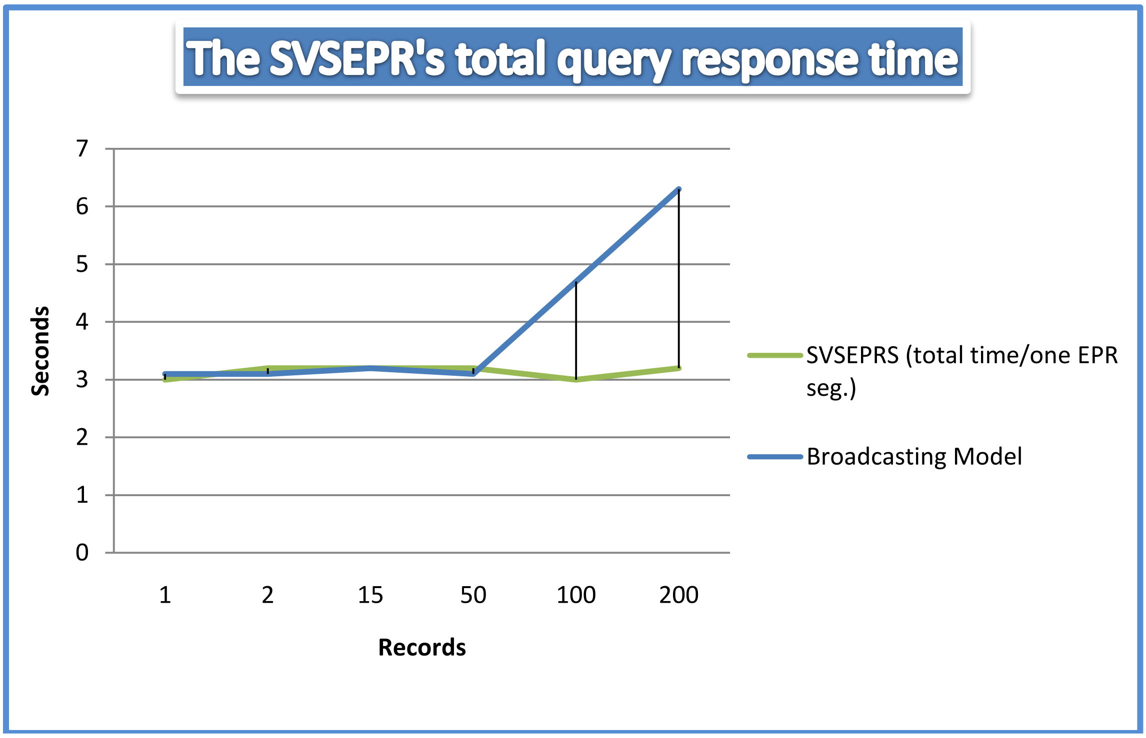

Figure 8.4: *Total SVSEPRS query response time*

8.4 Simulating healthcare network approaches for sharing EPRs

Throughout the last decade, there have been various regional, national and international plans concentrated on the development of healthcare network architecture for secure access and sharing of federated patient information.

The technology perfections can provide an easy way, on time access to a multiplicity of healthcare information scattered at different location to enhance the process of sharing EPRs.

Healthcare information in countries that are planning for developing an EHR system will be available for healthcare providers offering seemliness, 24/7 on demand services for sharing and viewing the required records.

The development of sharing healthcare information system requires a process of constructing and implementing multiform network topologies.

8.4.1 EPR sharing approaches

There are two different types of patient healthcare information that are required to create a collective view for healthcare providers:

- ✓ **Local information:** is the data that are created and stored by healthcare providers during the encounters time.
- ✓ **Shared information:** is the data that are created and stored by healthcare providers from other organizations and can be shared between different clinicians at different organizations.

The difference among local and shared information involves some intersect in the performing process among local and shared EPRs that is needed to illustrate.

Normally, local EPRs contain vastly detailed healthcare information on the periods of healthcare that patient is received with observing and clinical documentation. Shared EPR on the other hand will normally settle user interfaces with viewing the summarized healthcare information only (as described in the previous chapters).

There are various types of deployment approaches that assist healthcare organization's needs and limitations for executing shared EPRs.

Shared EPR development underway or being considered by various nations can be seen as one of three general approaches explained below. The process of shared EHR may require a combination of EHR plans and the integration of Healthcare Information Systems, especially when centralized approach is used. Selecting any one of the following approaches by healthcare organizations is based on patient healthcare information ownership, variations in the applied technologies, and organizational boundaries. The collaboration between healthcare providers through integration of health data sources become the objective of various health care systems throughout the world.

Data integration is the process of merging data stored at various locations and supplying the user with a unified picture of these data [176]. There are several examples from the literature regarding data integration not just in the field of information system but also in medical informatics [177,178].

8.4.1.1 Centralized single EHR repository

The centralization model (described in section 5.5.1) within the healthcare environment is based on a single, central data repository to which all healthcare patient information resources is integrated and stored, and from which shared patient information services to the whole participants are supplied. The core features of this approach comprise limitation, effectiveness and economy.

Centralized control is the main advantage of this approach which may require fewer technical risks, software and hardware which results in cost and time reduction.

Due to the appearance of client-server technology for accessing EPRs, numerous healthcare organizations are inquiring for the need to hold on to the centralized healthcare management services. The participant healthcare providers can access the central data repository using a web browser through a clinical portal in order to share the stored EPRs.

In this approach, data warehouse (the central consolidated physical data repository) is used, in which EPRs from various local data sources are extracted, transformed and loaded.

As described previously, one of the main examples that fall more to the centralized end is the National Programme for Information Technology (NPfIT) in England. It is the biggest single civil IT programme in the world that has been planned only for England [175]. Spine is the heart of the project, enabling healthcare providers and consumers to access the summary part of the EHR at anytime and from anywhere.

8.4.1.2 Federated (decentralized) approach

Federated approach offers local healthcare organization the accountability for controlling their own resources, and healthcare providers in one healthcare organization can directly communicates (querying access) with another (peer) system. Decentralized approach on the other hand is deficient in a centralized control. This can be extremely inconvenient as confliction and clashes in policy between various healthcare organizations arise during the process of sharing patient records leading to interruption and inefficiency which occurs as a consequence. Also, decentralization of control can create problems when it comes to sharing different levels of detailed EPRs between various healthcare locations as each location creates and stores their own patient records.

There is also a high level of resource duplication, effort and expertise, which may lead to a waste of cost and time.

8.4.1.3 Hybrid approach

The discussion over the centralization versus decentralization approaches within the healthcare environment is a never-ending one. However, trying to keep up an already existing various healthcare systems and avoiding the consequence of duplication process, utilize the advantages of centralized corporate efficiency and pressure on costs and advantage of control is challenging. On the other side, decentralized approaches may provide features like autonomy, local effectiveness and accommodation of specific local needs.

By examining the alignment between centralization and decentralization and the need for information sharing between healthcare organizations, another approach (SVSEPRS) was used to obtain the coordination, searching for, and controlling centralization while continuing to run all procedures at all distributed healthcare locations.

This approach mix features from centralized and decentralized approaches in order to improve the generic types of interaction between various healthcare locations which as a consequence will facilitate sharing of EPR process.

This model takes over the strengths of both models while efficiently organizing the association between corporate and local healthcare procedures.

Section 8.4.3, will prove the efficiency by measuring the networking system performance of this model in healthcare environment and comparing its performance with P2P broadcasting model using the OPNET simulator.

8.4.2 Network Access models

The main types of network access topologies are Peer-to-Peer and Client-Server, which are briefly explained in following sections.

8.4.2.1 Client-Server network model

Client-Server network model can be illustrated by a super node called a server, and one or more clients through one-to-one relationships. Client–Server networking access model can also be defined as “a distributed network which consists of one higher performance system and several mostly lower performance systems” [179]. This model planned to present a scalable architecture, whereby each computer on the network is either a server or a client, as showing in figure 8.5.

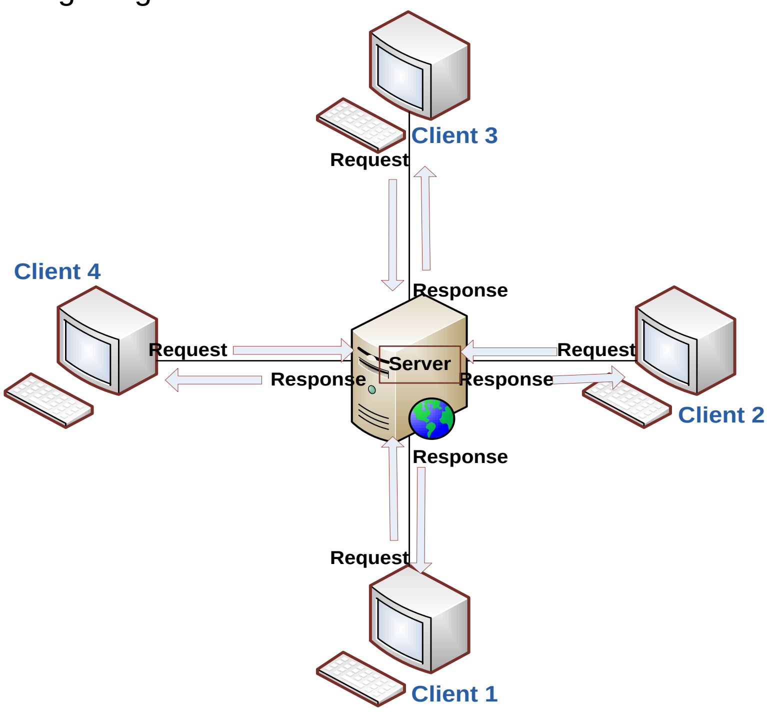

Figure 8.5: *Client-Server network access modelling*

The server is a passive tool which obtains numerous requests generated by clients, which are served and sent back to the client. This type of network gives healthcare users stability and consecutive services, and assured permanent access to healthcare data resources stored within the network system which offers several benefits such as availability and security. The number of request for web pages and online transactions have cause Web traffic that has faced massive enlargement during the last decade, leading to substantial long waiting time of the Web server functioning.

For healthcare environment, this long delay in response time is harmful and would frustrate healthcare provider's interest in contact with the web server. They may quit browsing the web site, especially in the time when the encounter is very limited. As described previously in section 7.4, the cluster web server can be a principal architecture in developing influential web based system especially when a number of clinicians are grows numerously.

Finally, a Client-Server is the prevailing concept in network architecture. Even though it is extremely reliant on the centralization approach, it will provide high interoperability for sharing healthcare information and retrieving the most required patient information, within a particular edge.

8.4.2.2 Peer-to-Peer (P2P) network accessing model

Peer-to-Peer network accessing model is described as self organization, homologue communication and distributed control [180]. As shown in figure 8.6, the construction is based on a distributed/decentralized approach. Typically, there are no centralized server(s) to control which gives the clinician an ability to search for a specific EPR's location [181].

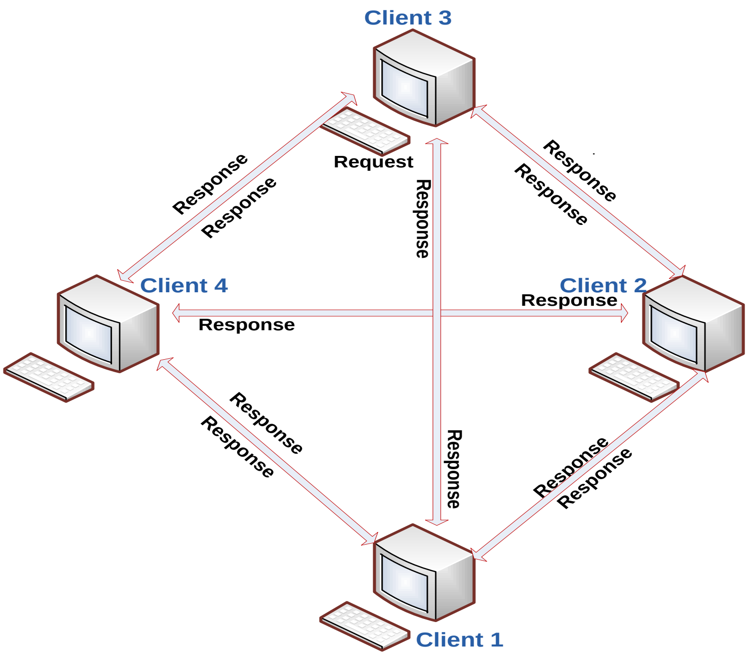

Figure 8.6: *P2P network modelling*

Within the healthcare environment, Peer-to-Peer is a communication between millions of computers that are placed at various healthcare locations, where all machines are equivalents (peers) and no one is a client or server.

As centralised super storage server with huge capacity is not required with this model, the cost to build the network can be reduced.
However, a growing number of P2P clients and shared documents cause a crucial complexity and uncertainty for the users retrieving required contents within the network [182]. Therefore, in order to retrieve valuable contents in the P2P network, vast messages are required to be broadcasted all over the network.

8.4.3 Performance measurements

Here, a second series of experiments based on OPNET simulation runs are presented. To validate the relative performance of distinct redirection policies of the proposed model, two scenario network models are constructed for simulation, the proposed SVSEPRS and the broadcasting peer to peer model that are considered for comparison using OPNET Modeler 14.5.
OPNET presents a complete development environment assisting the modelling of communication networks and distributed systems.
The comparison process shows that the collaborative operation mode in the SVSEPRS client server approach can be categorised as a client server approach, as all participants' healthcare providers can share EPR information segments using the central server.
For simulation purposes, the two models that have been designed as two scenarios in OPNET are shown in figures 8.7 and 8.8.

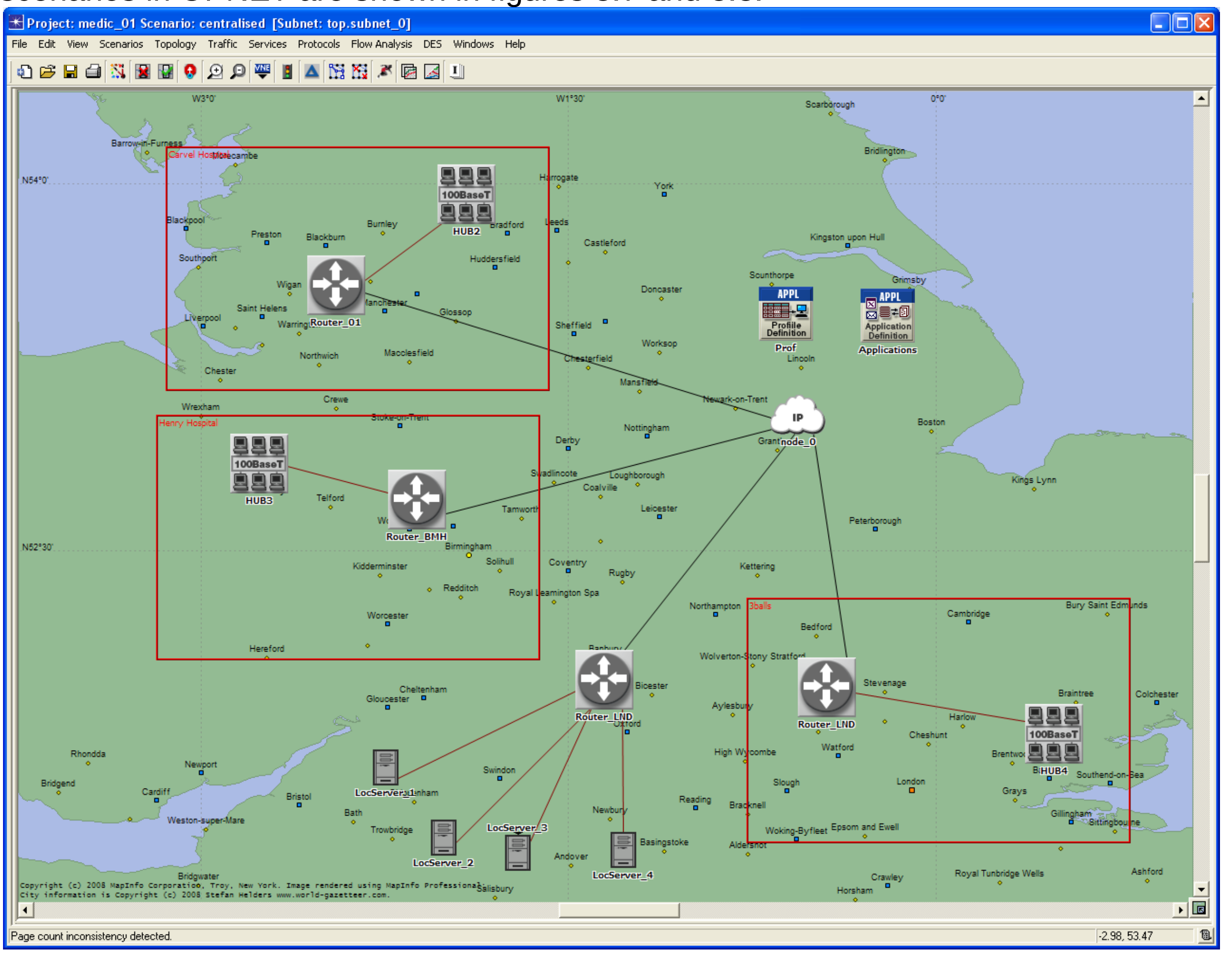

Figure 8.7: *SVSEPRS model scenario*

The first scenario (illustrated in figure 8.7) was constructed to model the SVSEPRS client-server system consisting of three subnets (Carvel Hospital, 3ball surgery and Henry Hospital) clients and four cluster web servers connected through the load balancing switch.
Each one of those subnets has 10 workstations with TCP transport protocol in the modelled LAN network.
The LAN represents a fast (100BaseT) Ethernet LAN in a switched topology.
The subnet contains a total number of clinicians in the LAN network. Application support includes database, http, email and video which run over TCP. The rate at which packets are switched from the switch processor to the appropriate output port is set to be 500pkts/sec in order to determine the service time for each packet.
Each subnet supplied with Ether_PPP_router_adv device contain Ethernet technology with 4 ports which links all subnets, using ppp_DS3 point-to-point link model, to the web server through the cloud node.
An ip8_cloud node model represents an IP cloud which supports up to 8 serial line interfaces at a selectable data rate through which IP traffic can be modelled.
Note that IP packets that arrived on cloud interface will be routed to the specified destination output IP address which is the web server.
This cloud requires a fixed amount of time to route each packet and served as first come first serve basis.
Figure 8.7, also shows the cluster web server for the SVSEPRS OPNET scenario, which consists of a load balancing switch for appending requests generated by one of the mentioned subnets to the four web servers for processing procedures.
This web-switch obtains requests from end users, and chooses a server from the web server pool for future processing.
Each web server at the client server scenario is an Ethernet_server model representing a server node running over TCP/IP. This node supports one underlying Ethernet connection at 1Gbps.
However, figure 8.8, represent P2P broadcasting request scenario. It has the same setting as scenario one, except it is not based on the client server and there are no clustering web servers. It is purely a federated system connected to each other as P2P network model.

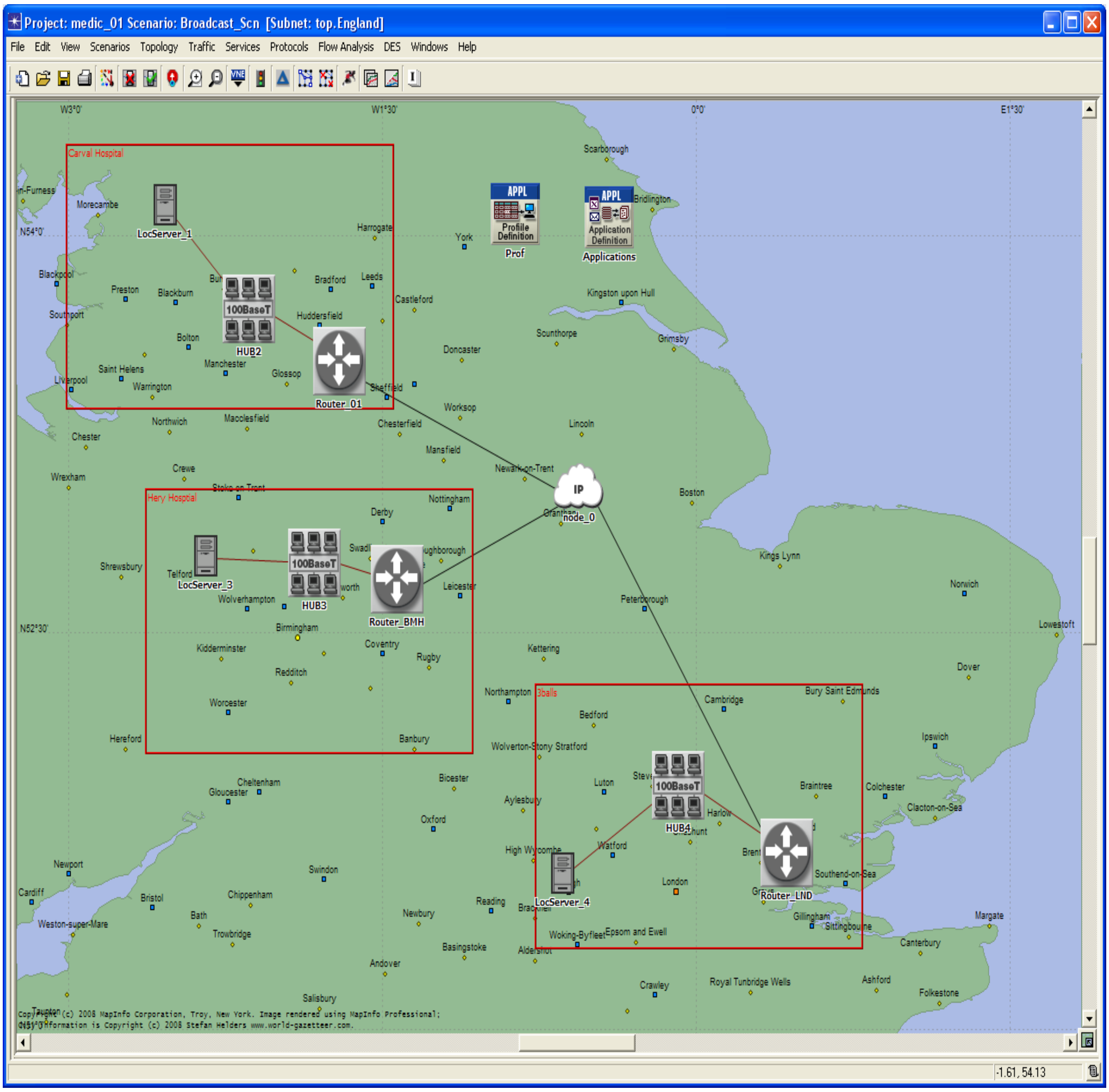

Figure 8.8: *Broadcasting model scenario*

8.4.3.1 Simulation results

As the congestion control is the main concern during measuring the performance of these models, the interest is mainly focussed in analyzing the database query response time as well as the database traffic received and sent on the network.

Three graphs results have been chosen during the simulation process (figure 8.9, 8.10 and 8.11). All figures show a combination of the 2 scenarios illustrated above.

As expected, the results show that implementing SVSEPRS model using the client server approach (centralised server) had a substantial improvement in the performance of the database query response time, query traffic received and query traffic sent.

It shows that the DB Response Time of the P2P (broadcast-Sce) model is longer than the proposed SVSEPRS client server (centralised) model.

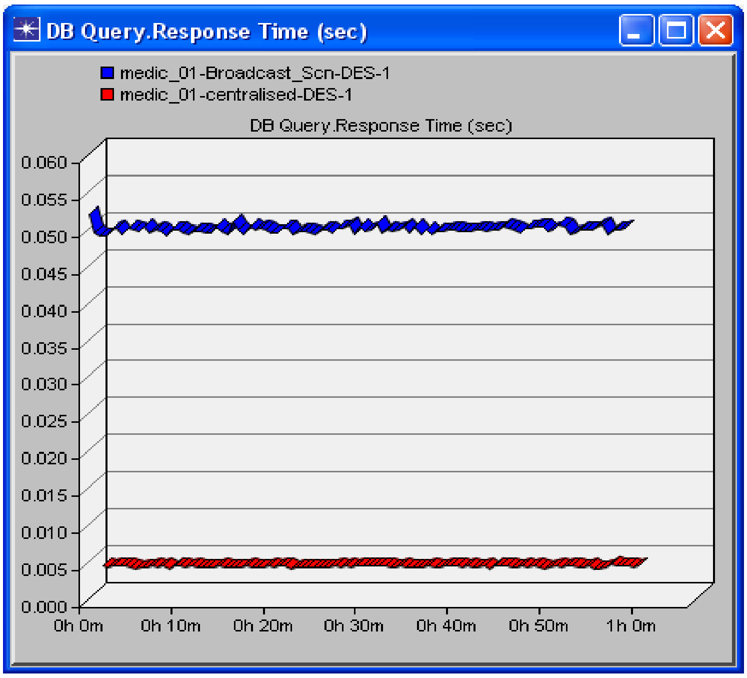

Figure 8.9: *DB Query Response Time (sec)*

Also, applying the suggested clustering client server's policy to eliminate traffic loads, the SVSEPRS model is able to achieve the required performance for searching and sending query to the other location.
Figure 8.10 shows that the traffic received for the DB query of the P2P model (broadcast_Scn), is greater than the SVSEPRS client server (centralised) model; from about 4 (packets/sec) to about 35 (packets/sec).

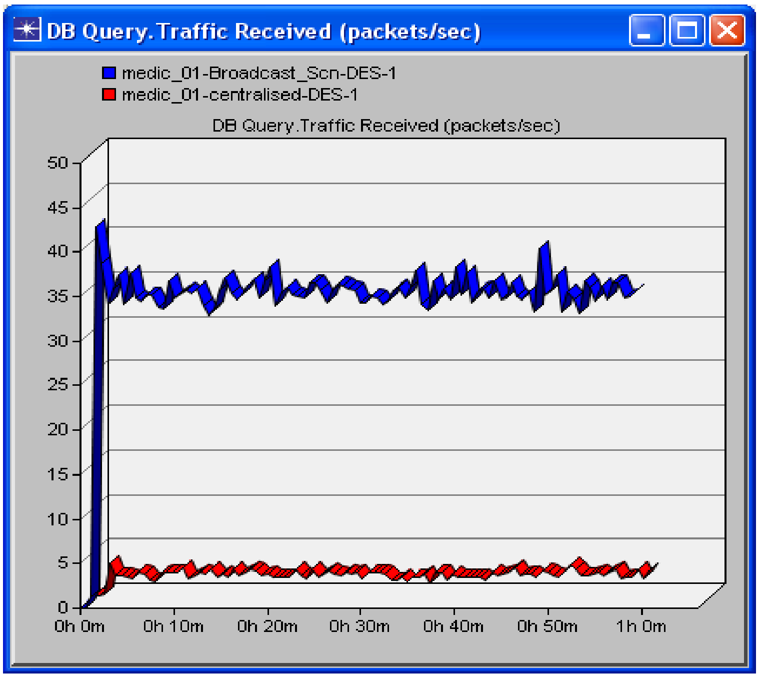

Figure 8.10: *DB Query Traffic Received (Packets/Sec)*

Figure 8.11 shows also that there is big difference between the two scenarios in the database query traffic sent.

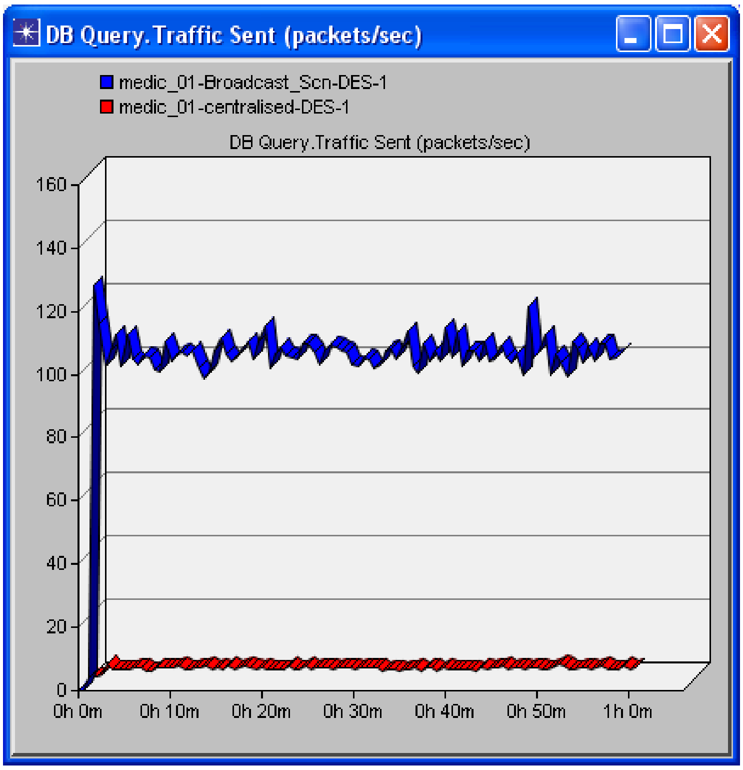

Figure 8.11: *DB Query. Traffic Sent (Packets/Sec)*

The simulation results showed that by designing SVSEPRS as a client server topology network model, it has empowered the system in terms of database query response time as well as low rate of traffic received or sent, which as a consequence produce high performance application model.

8.5 Scalability, Reliability and Availability performance

Traditional evaluations of systems concentrate on the achievement of utilising the results. The achievements of the proposed SVSEPRS have been measured by different healthcare professionals in primary and secondary healthcare, in order to obtain their own and their organisational perspectives, before, during and after developing this model (see section 1.7).

The knowledge of the healthcare provider’s feedback, which are assessing the systems developed through this research and of any suggestions at times expressed by the them about the proposed model, shows that their main interest has been about the whole system performance, visual appearance, the set of function and their performance, and the requirements for further features to be added within the web applications.

Scalability and reliability needs to be answered for large-scale distributed systems. The typical definition of scalability can be introduced as follow: "A scalable system is one that maintains constant, or slowly degrading, overheads and performance as its size increases". Reliability on the other hand can be defined as a capability of web systems to be continually accessible, around the clock and around the world, despite the number of clinicians accessing it [183].

In this section we describe the actions that have been taken to enhance the scalability, reliability, and availability of the SVSEPRS system model.

8.5.1 Autonomy

Using the SVSEPRS model, healthcare organizations can develop and manage their own local information systems autonomously as healthcare patient information is created, stored and managed at the place it is generated.

SRVEPRS uses an endowed and well structured multidimensional search engine CMDSM, which defines different common outlined facts and dimensions stored at the centralised database server (e.g. Chief-complain, lab-result and diagnosis).

Based on the multidimensional data query a list of outlined results will be displayed.

To view detailed EPR segment, the query is sent to the required local healthcare databases and requested segment is virtually viewed.

That means, every time a list of outlined EPR segments are resulted from the CMDSM engine, a new query is executed after clicking on view detailed EPR button to view the details of this segment.

This process enhances the system's scalability and quality performance since no central or local database locks are assumed through the network.

The system throughput has been managed by using a technology such as partitioning of database. The centralised database server has been partitioned based on clinical segment field so that the database tier keeps up with the expected high load (see section 7.3.4).

8.5.2 Clustering web tier provides optimal scalability, reliability and availability

As described earlier in section 7.4, applying a cluster of Web servers will enhance the sustentation of throughputs and create high availability system.

A cluster is a group of server nodes that collaborates to grant the high scalable system and failover server infrastructure. For a participant healthcare user, a cluster seems as a single server that deals with requests with a single point of entry.

Besides enhancing scalability via clustering and load balancing, the idea of clustering increases reliability through failover. With SVSEPRS, failover denotes that if one node Web Server crashed because of one fault or a hardware failure, user sessions will be forwarded to a different free node in the cluster.

These steps will permit a number of servers to share the load, expanding the number of concurrent requests that can be managed and offering failover. This means that the system will stay on even when one or more servers have crashed.

It is often required that all of the cluster web servers to be from a single compatible hardware vendor using a reliable operating system. In other words, in order to obtain high scalable performance, it is not preferred to create a client-server system model that utilises servers from IBM, DEC and SUN running the same version of operating system.

With software failure, the case is more complicated; the entire nodes in a cluster process the same software. Thus, if one node goes down due to a software fault, it will probably cause the whole cluster to become inoperable. In order to enhance the reliability of a software application, the solution for these kinds of faults is to follow a precise examination and analysis with tools that assist developers find precisely what the main stimulant for within the programs is.

8.5.3 Java inherit high performance, scalability and reliability

As discussed previously in section 7.3, developing the SVSEPRS as a multi-tier architecture was based on J2EE in which Java Server Pages (JSP) and Servlets provide the presentation logic, and the Enterprise Information Systems (EIS) represent the database tier.

The data processing system implemented using Java language is normal and have the qualities of the Java language based on object-oriented language such as high maintainability and reliability.

Java presents the capacity for creating a client-server environment from a different group of hardware platforms with its VM design. For instance, if platforms such as IBM, DEC or SUN had VMs for Java, then theses disparate platforms could be treated as harmonious servers in a client server environment. This would facilitate healthcare systems to enlarge their savings in hardware platforms.

The servlet mechanism tier is critical to the overall performance, scalability and reliability, and better EPR sharing with local server technologies (see section 7.6.2).

8.5.4 Enhancement of Reliability and robustness

The reliability and robustness are significant topics that may settle on the success of the proposed model.

Reliability is as significant as scalability, since clinicians who are incapable to reach the system are expected to search elsewhere for the healthcare information they require. In a healthcare environment, this means putting patient's life in danger.

In the healthcare environment, problems like communication failures, lost data or tool crashes may lead to a substantial inconvenience and degrade the sharing of EPR process. Protecting SVSEPRS from whole or part failure was the key design objective.

8.5.4.1 Multithreading architecture

Multithreading also enhances the scalability and reliability performance of the proposed model. It permits a number of functions to be performed by different healthcare providers simultaneously.

It is very significant to a clinician's perception of performance, as the healthcare provider never has to wait for any task in the SVSEPRS application to be finished before the clinician's task is completed.

In other words, with multithread environment, one clinician can be querying the database server to obtain outlined EPR results, and at the same time other clinician may request a detailed EPR for a different patient, and another can be searching for other patient's EPR.

Java was designed to provide multithreading functionality as part of its core capabilities. Though the web application is probably not quite as popular as Google, however, the servlet container manages the multithreading for the proposed model. Thus, multithreading within the Java environment can be easily implemented by software developers and transcends all environments that provide VMs to support Java operations.

8.5.5 Accessibility

At present, security accessing is one of the supreme precedence within healthcare delivery systems. Permitting access to EPRs by healthcare professionals associated with the patient's care while also guaranteeing confidentiality of the patient's data is a substantial challenge.

In order to provide more efficient access to patient healthcare information, SVSEPRS using web based applications provides healthcare providers a secure access to EPRs.

SVSEPRS provides healthcare organisations with the ability for online registration, during which the authorized person from the local institution should fill in the registration application form on the system home page and provide all the detailed information about the institution as well as all the names of the eligible clinicians who are able to login and share EPRs. Subsequently, each one of those qualified clinicians would be able to create and change username and password by providing his/her name and the registered institution name and number.

Based on the type of clinician's role, each will have a specific type of access level to the individually identifiable health information. However, the assignable security levels will define the limitation of data accessing, with essential constrains for not allowing any clinician to modify, delete or transmit certain EPR data.

Also, patient's consent must be obtained before giving permission to participating healthcare providers to view his/her EPR.

8.5.6 Uniform Access

In healthcare environment where system application is used by multiple clinicians when it is needed, transferring the SVSEPRS to the Web allows the disparate healthcare providers at different healthcare locations to utilise single display formats. The consequential benefits include less training costs and simpler EPR sharing between healthcare locations.

Moreover, clinicians are not needed to remember complex operations in order to share EPRs, because the WEB-based SVSEPRS present an identical user interface via a WEB browser.

8.5.7 Security for data backup and storage

Viewing Virtual EPR should be accessible from a backup of the local healthcare institution. Security authentication for the requester is required to be enacted to reduce the risk and vulnerabilities to locally stored EPRs (see section 7.3.7).

Finally, the local database and backup storage units must be in a secure location.

8.5.8 Automatic Logoff

The healthcare provider should logoff from the system when their workstation is unattended. However, there will be a period of time when the clinician may not be able, or not remember to log off a workstation. Automatic logoff is an efficient way that has been added to the system to avoid unauthorised clinicians from accessing the SVSEPRS on a local workstation when it is left for a period of time.

8.6 Summary

Two types of experiments have been used to measure the performance of the proposed system model, during which, a comparison between the proposed model and broadcasting technique has been achieved. The first comparison of experimental results is based on java software code for counting query response time.

Different types of healthcare network architectures have been described as an overture for our second simulation results, which was based on OPNET Modeler 14.5. It showed that the SVSEPRS network model has empowered the healthcare system in terms of sharing EPR between scattered healthcare locations. Fast database query response time as well as the low rate of traffic received was the main results of this simulation process, which as a consequence improved the performance of the application model.

This performance evaluation indicates that the proposed SVSEPRS model achieves significantly a way for searching and viewing the required EPR segments when compared to other models. It shows that SVSEPRS accomplishes a much lower query response time and can operate over higher rates of EPRs that have been created and stored locally with minimal increases in response time.

It saves the clinician’s time by offering them immediate access to the most required EPR fragment at anytime and from any location.

In the long run, ideas proposed in the design and development of SVSEPRS should also be integrated to future projects, satisfying the requirements and implementation tasks for clinical observation procedure, notifying actions triggering, data mining, and other complex patient healthcare information management elements.

Chapter 9

Conclusions and future work

9.1 Conclusions

Moving towards Electronic Patient Record means patient healthcare information is tended to be more readable, precise, confident, and available when needed, and can be more rapidly shared.

The obtainable of detailed EPRs at the point of healthcare delivery, together with direct access to the relevant EPRs fragments, such as tentative diagnosis, final diagnosis, laboratory, radiology results, etc from different clinical locations more quickly and accurately would be an effective element to facilitate and speed up therapy selection decisions, reduce redundancy and developing clinical pathways by healthcare professionals.

The proposed SVSEPRS as a healthcare system model can be used by healthcare professional to facilitate the process of searching for and viewing the most required EPR segments in efficient and effective way. It is to ensure that healthcare professionals would be able to view the previously created EPR fragment and consequently the ability to reveal the entire virtual EPR context.

This has the benefit that, for instance, EPR segment can be identified from within a range of EPR segments such as a Chief-complaint, observation, Lab-test, or outpatient consultation among numerous EPRs that have been created and stored at different locations. This is a solution for solving the complication of displaying all EPRs (straight away) that containing the required segment from various healthcare systems, in which the result will be enormous, takes so much time from clinicians to reach the required segment and may also contain segments under titles such as preliminary clinical diagnosis or patient's concerns which none of these would show what the clinicians actually wanted to view.

The SVSEPRS model does not in itself perform coherence in this area, but it can be achieved by inciting the participant local healthcare systems to dispatch an outline of every new created EPR to the central SVSEPRS using special software adapter to perform the coordination process. The ability of local healthcare institutions to dispatch the individual fragments gives participant healthcare requester a wide space to search on most required segment using CMDSM, which consequently permit numerous EPR concepts to be shared among healthcare systems using SVSEPRS web applications.

Different phases of the implementation have been implemented at different times. Java Servlets, JSP, HTML and MySQL that has been chosen to deliver web server components have confirmed a successful choice. Developers, and for future expansion, can easily recognize and provide any performance associated with the scalability of applications before they affect the healthcare provider's knowledge.

Different lessons have been gathered during the implementation of the SVSEPRS system model, primarily in relation to options made and some technical features of interconnection to the local and central databases.

Coordination between the local healthcare systems and centralised SVSEPRS must be carefully defined to ensure that the outlined EPR segment which has been used by CMDSM are based on real detailed EPR.

The performance results of the SVSEPRS system model (Web-based approach) was compared with a strategy that generates a query based on a broadcasting request (P2P approach). However, the main purpose behind this comparison is to demonstrate the features of the proposed system.

During the initial time of comparison process, MySQL showed to be extremely fast at viewing the selected EPR segments, this is because of the low number of EPRs that have been created and stored at the hypothesis local healthcare systems.

However, searching for and viewing all EPRs belong to particular patient across several scattered healthcare systems which contain, for instance, twenty years of legacy data, would normally take longer time. This has involved a diversity of work- around such as the implementation of a secondary cache to speed up the process of search.

The performance of planning and implementation has reliably referred back to the requirements described in section 7.2, and the overall key objectives have been met. In the time available, some of those concepts could not be implemented, such as:

- ✓ The demonstration of time-series information, for instance cardiac monitoring results;
- ✓ The demonstration of clinical multimedia information, for instance Digital Imaging and Communications in Medicine (DICOM);
- ✓ The verification of a countersigning clinicians, as a key elemental for various purposes such as prescription process in hospitals;

The potential significance of the SVSEPRS model lies in its capability to facilitate the sharing and viewing of EPR data segments even if the initial records have been created and stored at scattered locations.

However, this occasion of shared virtual EPRs is encouraging healthcare convergence on the organisational structure of patient health record information. It is obvious that once healthcare providers are able to share and view segments of EPR by getting advantages directly from the reliable SVSEPRS model they will obviously seek convergence.

However, bottom-up approach for healthcare institution’s convergence is commonly more achievable, although bit slower, than a top-down requirement of consistencies of data sets.

Robustness, reliability, scalability and availability of the proposed SVSEPRS system model have been good, as verified by performance measurements described in section 8.5 and from the feedback provided by the clinical experts who are regularly asked to assess the system performance.

9.2 Future work

The short-term strategy for future performance is needed to consolidate the results accomplished so far.

The proposed centralised approach overcome various drawbacks by enabling healthcare system to build and manage a centralized data warehouse to create comprehensive and true longitudinal records (summarized, detailed or specialized patient records) that utilize different specialists of clinicians to provide a high quality of healthcare to consumers.

Further advantages of this approach are:

- Using this approach, healthcare professionals will be able to derive the most valuable and high quality healthcare information. This will increase the quality and efficiency of healthcare service provided and reducing medical errors.
- Improve the quality of care record reports and clinical decision-making through allowing clinicians to educe queries along hierarchies of dimensions by slice the cube or drill down to more detailed levels.
- High level of surveillance and measurements can be achieved through using this approach.

Healthcare professionals and researchers will benefit from this approach, which makes electronic transfer of data elements into a clinical data warehouse feasible, efficient, and accurate to utilize and support analysis and evaluation processes.

Precise evaluation and validation of the SVSEPRS system model is vital.

In the ideal conditions, several engineering teams should implement the requirements in order to validate that they are technology self-reliant.

Although the author was the only persons who designed and implemented this model, the information architecture specified here needs some improvements and the implementation of missing functionalities should continued gradually, consistent with healthcare provider’s needs.

WEB technology has become gradually more frequent, and WEB browsers can be utilized to browse different kinds of files, such as PDF files, picture files, and movie files. Thus, SVSEPRS which was developed based on WEB technology can be certainly expanded to systems that can handle files such as x-ray, ECG, Pictures, Movies, etc.

The sharing of electronic patient records between various healthcare systems via the World Wide Web generates essential challenges in relating to the security of patients data privacy. Many healthcare experts argue that the Internet may not provide sufficient protection for transmission of EPR’s segments. Therefore, latest technologies, such as virtual private networking, that generates secure connections within the public Internet and multiple biometrics to incorporate face recognition, fingerprint verification, and speaker verification would really improve the security in accessing patient healthcare information. For the same reason, when local healthcare system tends to dispatch the outlined EPR segment to the relevant storage at central SVSEPRS, only anonymous data should be sent. All individual and private case information should not send but stored on local healthcare system at the diverse participant healthcare organisations.

On a longer-term basis, further research should be conducted to extend the clinical information system to other EPR segments.

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Appendix A

Questionnaire Survey

Dear Sir/Madam,

I am currently conducting a research on searching for and viewing a required segment of Electronic Patient Record (EPR) among scattered healthcare systems. I am attaching the questionnaire survey and I would very much like you to answer the multiple choice questionnaire. I will be pleased to make available to you the outcomes of the research when it is concluded. Will you be so kind as to take a few minutes to answer the attached survey?

I will be also doing interviews with some of the survey takers, please inform me if you would like to be part of these interviews.

I want to participate in future interviews Yes☐ No☐.

Thank you

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August 2008

1. In which Healthcare environment you spend most of your workday?

Hospital (acute care) ○ Emergency care (A&E Care) ○
Mental Health Trusts ◉ GP ○ Dental Surgery ○

2. How much information have you had about EHR or EPR?

3. How would you describe your role in using EPRs?

4. How would you describe the improvement in clinical diagnosis via utilising EPRs?

Not much - 1 ○ 2 ○ 3 ◉ 4 ○ 5 ○ - A lot

5. Please identify the quantity of data that is needed to deliver high quality of health service:

Detailed Patient Record (DPR) ○
Summary Patient Record (SPR) ◉
Paper-Based Record (PBR) ○

6. What do you consider to be the major barriers for sharing the most required EHR?

Standardisation ○
Time consuming through search process for the most required EPR ○
Needs extra time for training ○
Other ◉

7. **Do you agree or disagree with the statement: "Searching for segments of EPR between clinicians will improve the quality of HCS and speed up the process of clinical decision making"?**
Less True - 1 ○ 2 ○ 3 ○ 4 ○ 5 ◉ - More True
8. **Do you agree or disagree with the statement "Internet is the excellent tool that can be used for sharing EPRs"?**
Less True - 1 ◉ 2 ○ 3 ○ 4 ○ 5 ○ - More True
9. **Would you like to add any extra comments?**