Conducting Performance Evaluation of an e-Health Platform

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ABSTRACT
For increased awareness and adoption of e-Health implementations, results from evaluation must be catered towards three primary perspectives: organizational, end-user and technical perspective. This chapter addresses the issue of conducting performance evaluation of e-Health for the technical perspective. We present the design of metrics that enable us to evaluate the scalability, functionality and reliability of e-Health implementations. Using simulated patient data, experiments are conducted on an existing e-Health platform using our defined metrics. Results show that 100 simulated patient's data may interact with the e-Health platform under evaluation with a maximum round-trip time latency value of 6.6 seconds. By building upon the techniques we have used to conduct performance evaluation of e-Health implementations, along with the design of methodologies to enable evaluation to take place for the two other perspectives, i.e. end-user and organizational perspectives, we hope to see greater support for this technology in the near future.

INTRODUCTION
E-Health is the use of digital technologies for the provision of health care (Haeyrinen et al., 2008). A prime example of one such technology is Electronic Health Records (EHR). EHRs remove the need for large areas of physical storage space along with enabling medical staff to look up patient's medical records in a quick and efficient manner. Other examples of digital technologies which e-Health can use include the Internet, which enables prompt communication of medical data (Bland et al., 2007) and smartphones, which enable clinical staff to have real-time access to patient and medical data in a mobile manner (Wyatt and Krauskopf, 2012).

Clear advantages exist in the usage of e-Health for the provision of health care to patients. However, there has been much discussion in recent literature in regards to the lack of adoption of this technology (Mair et al., 2012; Wilson et al., 2010; Fitzgerald et al., 2008; Rodrigues, 2008). The background section of this chapter focuses on the key challenges in terms of e-Health adoption along with providing an overview on the fundamental concepts of e-Health including history, definition and categories of implementation. In reviewing existing literature, we find that the key challenges in adoption of e-Health may be grouped under three primary perspectives: organizational, end-user and technical perspective.

We propose that in order to see wider adoption and support of e-Health solutions from these three perspectives, concise evaluation data on existing and future e-Health implementations must take place. A concise evaluation of each e-Health implementation enables the three primary perspectives to gain better knowledge on the capabilities and limitations of offered each solution.
In making evaluation results available publicly, the three perspectives may then make an informed choice on which implementation is best suited to their needs thus, we may see increased adoption of this technology in the near future.

In the scope of this chapter, our key objective is to address the issue of conducting performance evaluation of e-Health for the technical perspective. Performance evaluation includes assessing the scalability, functionality and reliability of an e-Health implementation. The main body of this chapter presents the design of evaluation metrics along with defining a methodology for the gathering of such metrics. Using simulated patient data, experiments conducted on an existing e-Health platform, within a sandbox environment, shows the viability of our proposed evaluation approach in providing meaningful results for the technical perspective.

From experimentation, we find that conducting performance evaluation on an existing e-Health platform using our defined metrics provides meaningful results for the technical perspective. However, our methodology does have some shortcomings especially in regards to the lack of realism due to the use of simulated patient data along with conducting evaluation within a sandbox environment rather than a live clinical trial. To address such limitation, and to highlight key areas of work which must still be carried out in regards to evaluation of e-Health implementations, suggestions on the future directions which must be taken within this field of research is provided. The chapter concludes with a summary of research and work conducted for this chapter.

BACKGROUND

E-Health History and Definition

In the early 1970s, the concept of applying computer-based systems for the provision of health care services was termed Medical and Nursing Informatics (Hovenga et al., 2010). With the advancements in technology and communication networks, healthcare environments started replacing traditional paper-based systems with digital technologies such as EHRs.

However, the definition of using digital technologies for the provision of health care services is still debatable. In particular, there has been much ambiguity between the usage of the terms “e-Health” (alternatively termed “eHealth” in American English) and “Health Informatics”. In a technical report produced by the International Technology Union, they state that e-Health and Health Informatics may be used interchangeably (ITU, 2008) whilst others argue that e-Health refers to the provision of health care services which are predominantly Internet based (Oh et al., 2005; Slamanig & Stingl, 2008). On the other hand, some researchers have proposed that the concept of Health Informatics is concerned with the systematic processing of data, information and knowledge in medicine and health care via computational based systems (Haux, 2010; Hasman et al., 1996). In other words, they propose that Health Informatics is concerned with the handling and processing of tasks in regards to medical data using computers whilst e-Health simply implies the use of the Internet for health care provision.

From all definitions provided here, it can be stated that prior to the introduction of modern communication infrastructures, i.e. the Internet, it is apparent that Health Informatics referred to the process of using computer systems to manage and process medical data. However, when the Internet become widely used by the general population, the term “e-Health” was coined which
(at the time) specifically meant using the Internet as the primary means in the provision of health care services.

In this chapter, we share the same view as stated by ITU (2008) in that, from a modern context, Health Informatics and e-Health are exactly the same concept. Thus, for the scope of this chapter, the use of the term “e-Health” refers to the practice of applying modern computing and communication methods, i.e. digital technologies, for the provision of health care services though this term is interchangeable with “Health Informatics”

**E-Health Platform and Services**

Implementation of e-Health comes under two primary categories: platform and services. It should be noted that some e-Health implementations may fall under both categories of implementation, e.g. an EHR implementation may consist of a platform (for the storage of data) along with a front end service (for user interactions), but we have attempted to separate these two categories for this chapter in order to provide for better disambiguation. Definition of these categories follows:

- **E-Health Platforms**: In essence, e-Health platforms, like all other computing platforms, consist of hardware architecture and a software framework. The primary purpose of an e-Health platform is to provide an infrastructure to enable the storage of patient and medical data along with interfacing with e-Health services via the software framework. Some recent examples of e-Health platforms include work by World Medical Card (2012), DOSSIA (2012), HealthVault (2011) Fan *et al.* (2011) and Rolim *et al.* (2010). All works proposed by the listed authors aim to provide an infrastructure to enable the management and storage of patient and medical data.

- **E-Health Services**: E-Health services can be considered computer based applications which enable improved health care practices to take place. In most cases, e-Health services aim to replace manual based process and/or paper based systems therefore increasing the efficiency in which health care is delivered to patients. A prime example of an e-Health service is Electronic Health Records (EHRs). An EHR service enables the retrieval and storage of medical data via interfacing with an e-Health platform. Any medical data retrieved by an EHR service from the platform can then be presented to the user in a meaningful manner. Another example of e-Health services include electronic based patient risk assessment services such as work conducted by de Jager *et al.* (2010) and Sufi *et al.* (2008) in which both propose the concept of migrating the Early Warning Score (EWS) system, traditionally a paper-based system, to an automated electronic counter-part.

**The Challenges for Adoption of E-Health**

Fundamentally, it can be stated that e-Health provides a positive impact for healthcare organizations. In using EHRs as the primary example again, prior to the introduction of this concept, all medical information regarding a patient was recorded on paper. EHRs enable healthcare environments to now manage their medical data in electronic formats, a practice which allows for a far more simple and efficient method of storing data (Haeyrinin *et al.*, 2008).
Further backing is provided by Grogan (2006) in which the author states that there is evidence to suggest EHRs provide a more complete and error free method for the storage of patient data. Ease of communication is another advantage of EHRs. Having all records stored electronically allows for medical staff to easily look up a patient’s medical record and - in the case of a patient moving to another hospital - such information can be easily transmitted to the new hospital with very little delay.

However, we find that adoption of e-Health solutions, including both platform and services, is still lacking within healthcare organizations. From literature, we can group the key challenges and issues of e-Health adoption to three primary perspectives: the organizational, end-user and technical perspective. The subsections below provide detail on the key challenges for adoption of e-Health from these three primary perspectives.

Organizational Perspective
In the work of Rodrigues (2008), who provides a summary of issues in regards to adoption of e-Health from the organizational perspective, the author states that part of the challenge in seeing increased adoption of e-Health solutions require answers to the issues of governance, standardization, and cost. Governance relates to how an organization, e.g. a clinical environment, controls and manages the usage of an e-Health technology with considerations to legal and ethical issues (Hill and Powell, 2009) whilst standardization relates to whether an e-Health solution provides a common and agreed upon method for the exchange, communication and interaction of medical data between existing and future systems.

Furthermore, the financial cost of using an e-Health implementation is of great interest to organizations too. The cost of e-Health not only relates to the initial spending required to have an operational implementation but also the maintenance and management costs required to ensure the solution works as expected during its expected life cycle. As shown by Maerian (2010), it can cost tens of thousands of dollars in the implementation of e-Health solutions and this does not even include the requirement of hiring teams of IT professionals to support and maintain the software on a day-to-day basis. Furthermore, as stated by Brailer (2005), the first healthcare organizations which chose to implement e-Health may see subtle, if any, benefits since they will need to wait for other organizations to implement similar solutions before advantages, such as communication of medical data, can be seen. In other words, healthcare organizations must weigh up the cost and benefits of an e-Health solution prior to deciding the viability of adoption (Hill and Powell, 2009).

End-User Perspective
Both clinical staff, e.g. doctors and nurses, and patients can be considered the end-users of an e-Health solution. A key challenge for e-Health adoption is in gaining the end-user’s trust in the usage of this technology. Various reports on the inadequacy of e-Health have emerged in UK news these past years. A prime example of this is in 2009, when the National Health Service (NHS) in England lost thousands of medical records (Savage, 2009) due to a lack of security in their computer systems. More recently, in July 2011, the NHS was once again put under the spotlight when computer criminals attempted to gain access to their systems that held patient medical records (Campbell, 2011).
From such alarming reports on the issues related to e-Health, one can understand why patients may feel rather uneasy about medical facilities storing their personal data in an e-Health environment. The lack of trust in e-Health is also a key issue with clinical staff of healthcare environments. Rather than concerns over security, the main reason for this lack of trust comes down to two primary points: 1) resistance to change and 2) lack of education and training on the usage of this technology (Fitzgerald et al., 2008; Vinegar, 2012). Resistance to change stems from the fact that clinical staff fear that e-Health may replace their jobs whilst the lack of education and training results in less understanding on the benefits and usage of e-Health therefore resulting in less trust given to the technology.

In regards to the patient’s perspective, assessment of their satisfaction on the overall health care provided by an e-Health solution is equally important. Traditionally, patient satisfaction is a measurement of the patient’s opinion on the quality of service provided during treatment within a healthcare environment. According to multiple sources, assessment on patient satisfaction is a key outcome of care (Donabedian, 1988; Williams, 1994; Lin and Kelly, 2005; Gill and White, 2009). Ensuring positive patient satisfaction of e-Health solutions not only proves the viability of an implementation but - we propose - it may also help to ensure wider adoption of this technology takes place (in the case of positive patient satisfaction results).

Since patients, and their data, form the key attribute in which most health care revolves around, gaining and ensuring trust from their perspective for e-Health is absolutely essential to see wider adoption of this technology (Matysiewicz & Smyczek, 2009). Ensuring positive patient satisfaction is also critical for the future growth of e-Health solutions. Finally, without support of e-Health from clinical staff, adoption and usage of this technology will greatly suffer hence trust from this perspective is essential too.

**Technical Perspective**

The fundamental question for the technical perspective, when choosing whether or not to adopt an e-Health solution, is does the implementation work (for its given purpose) and how well it works. Answers in regards to the performance of an e-Health solution are generally catered towards IT support staff and administrators of healthcare environments since they in the best position to decide whether or not to adopt a proposed solution from the technical perspective.

From a technical perspective, key criteria we must focus on include the scalability, functionality, and reliability of an e-Health implementation (Pagliari, 2007; Ammenwerth et al., 2003; Henderson et al., 1999). Having a functional and reliable implementation may be taken for granted but Ammenwerth et al. (2003) highlights just how important these two aspects of an e-Health implementation are. In their work, Ammenwerth et al. (2003) found that inadequately implemented e-Health solutions would crash often, therefore resulting in delays with the transmission of key medical information and/or forcing the clinical environment to revert back to paper-based systems. In both such scenarios, it was noted that the lack of functionality and reliability in the e-Health implementation may very well have endangered the lives of patients.

Scalability, the third criterion, is also of utmost importance for e-Health implementations. To justify, statistical data provided by Dew (2012) show that between the periods of May 2011 to April 2012, 7.5 million finished consultant episodes were logged throughout NHS hospitals in
England within the space of 12 months. Assuming, at minimum, one form of patient data interaction takes place between an e-Health solution and each consultant episode, it can be seen that a vast volume of patient data may interact with an implementation on a day-to-day basis. Furthermore, it should be noted that the statistics only account for the country of England. Any e-Health implementation which enables communication of medical data between different locations, i.e. cross-country or cross-border communication, will have to account for even greater number of patient data interactions on a day-to-day basis. Ensuring an e-Health solution is capable scaling to meet ever increasing volumes of patient data in a reliable and functional manner is, therefore, essential for the technical perspective when it comes to choosing a suitable e-Health implementation for adoption.

The key objective of this chapter is to addresses the issue of conducting performance evaluation of e-Health for the technical perspective. Our proposed performance evaluation metrics and methodology used to obtain answers regarding an e-Health implementation’s functionality, scalability and reliability are the focus of the next section of this chapter.

E-HEALTH PERFORMANCE EVALUATION

Overview

With such a wide range of challenges e-Health still faces in terms of adoption, for the scope of this chapter, we aim to focus on and address the issue of adoption from the technical perspective. Our proposed solution is to define a methodology which enables meaningful performance evaluation of e-Health implementations to take place. In doing so, performance evaluation results may be presented to the technical perspective, i.e. IT support staff and computer administrators of healthcare environments, thus enabling this group to make an informed choice on which implementation is best suited to their healthcare organization’s needs.

This section of the chapter presents the design of evaluation metrics catered towards evaluation of e-Health implementations from a technical perspective. We conduct an evaluation of an existing e-Health platform using our defined evaluation metrics to show the viability of our proposed metrics for providing meaningful results for the technical perspective, i.e. scalability, functionality and reliability of an e-Health implementation. The methodology used to obtain these results is documented so that future researchers may apply or improve upon our techniques. We first look at related works in regards to e-Health evaluation and define how our research differs in the section which follows.

Related Works in Evaluation

Recent literature has shown that the primary method which e-Health evaluation takes place is live clinical trials. This, in essence, involves deploying an e-Health implementation in a live clinical environment, e.g. hospital, and obtaining evaluation results from clinical staff and patients using the system on a day-to-day basis.

Research conducted by Cobb et al. (2005) present a live clinical trial of an e-Health system that provides support for patients wishing to quit smoking whilst Kessler et al. (2009) present a system for the delivery of psychotherapy via the internet. The work of Flynn et al. (2009) presents a third example of a live clinical trial in which they evaluate the effectiveness of an e-Health patient booking appointment service. This research differs from all three author’s work
since our aim is to evaluate the efficiency of an e-Health implementation in terms of its performance capabilities, i.e. scalability, functionality and reliability, rather than the effectiveness of the implementation for the provision of health care services, e.g. smoking cessation, therapy and appointment booking systems.

Various e-Health evaluation frameworks have been proposed from a development perspective. The key theme found within this group of literature is that although many propositions have been made on what should form part of an evaluation framework for testing e-Health implementations, little work has been presented on defining a clear methodology to conduct such an evaluation. Dansky et al. (2006) has explicitly noted that “few blueprint for effect evaluation methodologies” (Dansky et al., 2006, p. 397) exist whilst the same backing can be provided in the work of Lilford et al. (2009) in which they state that no general consensus can be found in techniques used to evaluate e-Health implementations. Furthermore, although the work of Glasgow et al. (2007) highlights some of the key metrics which an e-Health evaluation should obtain, including appeal, use, cost and robustness, no fundamental answer on how such metrics should be measured is given.

Perhaps the most concise evaluation framework, from the e-Health development perspective, was found to be in the work of Catwell et al. (2009) in which the authors propose that evaluation of e-Health should take place from the very initial steps of designing an implementation. However, although they present workflow on how such an evaluation should take place, Catwell et al. (2009) do not provide specific metrics of evaluation. This research differs from the work of Catwell et al. (2009) in that our work is designed to evaluate already existing e-Health implementations, in terms of performance, rather than systems that are still in early stages of design.

Within the scope of research related to performance evaluation of e-Health implementations, the work of Martinez et al. (2006) conducts a study on the of Quality of Service (QoS) of e-Health services. In particular, they aimed to establish the maximum number of simultaneous users which may connect to a clinical environment from a rural area in order to improve upon QoS management for these areas. Another area of work related to QoS can be found in the research of Zvikhachevskaya et al. (2009) in which the author’s evaluate the effectiveness of the IEEE 802.11 wireless standard for use with medical scenario such as transmission of patient data from ambulances to hospitals in terms of bandwidth usage and availability.

Similarities can be seen between this chapter’s work and the research conducted by Martinez et al. (2006) as we both aim to measure the scalability of e-Health implementations. However, our research differs as we focus also on evaluating e-Health in terms of functionality and reliability. Furthermore, in terms of the work conducted by Zvikhachevskaya et al. (2009), our primary goal is on conducting performance evaluation of e-Health implementations and gathering of results catered towards the technical perspective, in order to increase adoption of the technology, rather than focusing on the QoS measurement for specific scenarios and usage.

**Performance Evaluation Metrics Design**

As the name implies, Performance Evaluation focuses on assessing an e-Health implementation from a technical standpoint. Our model aims to evaluate the scalability, functionality and reliability of a chosen e-Health implementation. Scalability relates to the volume of patient data
interactions, i.e. uploading, downloading and processing of data, which the implementation can handle concurrently whilst functionality aims to assess how well the implementation works. Reliability aims to answer the question the integrity of an implementation in ensuring no data loss occurs during the evaluation process – a common situation which occurs when a system is under high load and begins dropping data packets that it is unable to process.

The following is an outline of performance evaluation metrics which are currently defined as part of this chapter:

- **CPU Utilization**: relates to how much processing time is required for the upload and/or download of health care data along with general interaction with the e-Health implementation. The measurement of this metrics provides us with an overview on whether the current hardware infrastructure is up to a sufficient standard for the hosting of a chosen e-Health solution. Results obtained via this metric are dependent on the processor(s) of the hosting platform. CPU utilization is measured under the unit of percentage (%).

- **Packet Loss**: relates to the number of healthcare data samples that are lost or dropped during an evaluation. A low packet loss (preferably zero) is highly desirable, if not essential, for e-Health implementations since the key attribute in which all interactions revolve around is healthcare data.

- **Upload / Download Time**: the duration of time taken for a healthcare data to be uploaded or retrieved from an e-Health solution. Results obtained from this metric are dependent on the network interface cards (NIC) and protocols used by the e-Health implementation under evaluation. Measured in units of ms (milliseconds).

- **Round-Trip Time (RTT)**: the duration of time taken for healthcare data to be uploaded to an e-Health platform, processed and then outputted to an e-Health service. As before, results from this metric are also dependent on NICs and the protocol used by the e-Health implementation under evaluation. The metric of RTT enables us to assess how well an e-Health implementation works for real-time scenarios such as uploading of healthcare data to a platform, processing of the data and outputting the data to an end clinical service, e.g. a patient monitoring system. A low RTT is obviously preferable in such scenarios. Measured in units of ms (milliseconds).

In order to obtain our defined performance evaluation metrics, it can be seen that some form of healthcare data must first interact with the e-Health implementation under evaluation. We have chosen to use patient data for interaction with the e-Health platform under evaluation since this is the primary attribute which clinical environments revolve around. For the scope of this chapter and experiments conducted, we have opted to use simulated patient data in place of real world patient data. Justification for the use of simulated data along with design of this software, named the Patient Simulator, is discussed in the next section.

*Simulated Patient Data*

To conduct a performance evaluation of an e-Health implementation, and obtain results under the metrics defined in the previous section, patient data is required. To enable rapid evaluation of e-Health implementations to take place, we have chosen to simulate patient data instead of using real-world patient data. Simulating patient data also mitigates legal (Madsen *et al.*, 1999) and
ethical (Hardiker and Grant, 2011) barriers which real-world patient data imposes. In essence, the Patient Simulator is a software application that models and simulates virtual patient’s data and uses this data to interact with the e-Health platform under evaluation. The Patient Simulator was developed using Microsoft .NET C#.

The patient data we have chosen to simulate is known as the vital physiological signs of a patient. This includes the heart rate, blood pressure, temperature, respiratory rate and oxygen levels of a patient. In other words, these are the key attributes of a patient which would interact with an e-Health platform within a clinical environment. For the simulation of vital physiological signs, a Discrete Event-based Simulation (DES) method (Banks et al., 1984) is employed. DES refers to a simulation system in which variables only change at specific points in time (known as the time interval). A vital sign value is generated periodically using random normal distribution techniques (Martin, 1971). Table 1 presents the default mean and arbitrary standard deviation applied to all five vital physiological signs which are simulated in a patient by default.

The mean value of blood pressure is based on the work of Pesola et al. (2001) in which they state that a normal systolic blood pressure is found to be 112 mmHg. From studies carried out by both Mackowiak et al. (1992) and Shoemaker (1996) the result of 36.8°C is applied for the mean body temperature. O'Driscoll et al. (2008) defines normal Spo2 as 96–98%, hence the average value of 97% is used. Finally, both Sherwood (2006) and Tortora and Derrickson (2008) agree that the mean respiration rate is found to be 12 breaths per minute.

<table>
<thead>
<tr>
<th>Vital Sign</th>
<th>Mean Value</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Rate</td>
<td>80 BPM</td>
<td>1.5</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>112 mmHG</td>
<td>2</td>
</tr>
<tr>
<td>Temperature</td>
<td>36.8 C</td>
<td>0.2</td>
</tr>
<tr>
<td>SpO2</td>
<td>97 %</td>
<td>0.5</td>
</tr>
<tr>
<td>Respiratory Rate</td>
<td>12 Breaths per Minute</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 1. Mean and standard deviation of vital signs

In this chapter, although variance and randomization techniques were applied to the simulated patient data, the values generated were found not to be sufficiently realistic in comparison with real-world patient data. However, we propose the data simulated is still valid for experiments presented in this chapter since we are evaluating our chosen e-Health platform from a technical perspective, e.g. measuring response time and packet loss of arbitrary healthcare data samples, rather than evaluating the accuracy of clinical services, e.g. patient monitoring systems or EHRs. We outline our performance evaluation along with experiments conducted using simulated patient data in the sections which follow.

**Evaluation Experiments**

**Test Bed Description**

We have chosen to conduct our experiments on an existing e-Health implementation known as the Cloud4Health (Fan et al., 2011) platform (formally known as the DACAR project). It should be noted the Cloud4Health project has been developed from within the same institute as this chapter’s research. The Cloud4Health platform is deployed as a private cloud service, with focus
on the Platform as a Service (PaaS) layer. In essence, it provides a secure method for the capture, storage and consumption of medical and patient data.

The Cloud4Health project provides an API in order for the simulated data to interact with the platform but we do not consider the underlying hardware architecture or source code during evaluation. We propose that this helps provide a non-bias evaluation of the platform along with ensuring our defined evaluation metrics are not restricted to evaluating only one specific e-Health implementation for future work. For the scope of experimentations carried out in this chapter, the Cloud4Health platform is hosted within a sandbox virtual environment.

**Methodology**

We present two primary sets of experiments in regards to performance evaluation of the Cloud4Health platform. Both experiments were conducted using simulated patient data generated on-the-fly at the start of each test. In each experiment, the only variation is the number of patients we choose to simulate. Experiment 1 aims to measure the performance evaluation metric of Upload Time whilst Experiment 2 measures the metrics of RTT and CPU utilization. Furthermore, we monitor packet loss in both experiments. The scenario for each experiment is outlined as follows:

- **Experiment 1: Baseline Test** - The first test is very simplistic in nature. In simulating 100 samples of a single patient's data, the upload time was monitored for intervals of 0.5, 1 and 3 seconds. In other words, 100 samples of a single patient’s data was uploaded with three different time delays in order to evaluate whether any performance impact was found on the Cloud4Health platform based on how "talkative" the client, i.e. Patient Simulator, is. The primary aim of this experiment is establish a baseline result for how well the Cloud4Health platform handles a single patient's data being uploaded.

- **Experiment 2: RTT and CPU Utilization** - The second experiment aimed to evaluate the RTT and CPU utilization of the Cloud4Health platform. Up to 100 patient's data was uploaded concurrently. Each patient simulates 100 samples of data. The aim of this experiment is to assess the Cloud4Health platform's latency under a more realistic scenario which involves the input, processing and output of patient data. Figure 1 provides the workflow of the second experiment.

![Figure 1. Workflow of the second experiment](image)
The methodology for gathering our defined metrics is as follows:

- **CPU Utilization**: A Microsoft Powershell script running directly on Cloud4Health server was used to obtain this metric. The script monitors the counter referred to as `\processor(_total)` % processor time (Edmead and Hinsberg, 2011). This counter returns the overall CPU utilization of the server and the current value is logged to an output file every 1 second interval.

- **Packet Loss**: The total current samples stored in the Cloud4Health platform for each virtual patient was noted prior to the start of an experiment. The total samples simulated (100 per patient) is then subtracted from the current samples for each patient. A numeric value greater than 0 gives indication on the number of packets lost during the experiment.

- **Upload Time**: We gather upload time directly from the Patient Simulator application via the StopWatch class (Microsoft, 2011) provided by .NET C#. An instance of the StopWatch class is started upon uploading of data, and once the upload operation is complete, the StopWatch is stopped. The elapsed time produced by the StopWatch class results in the time taken to upload a single patient's data to the Cloud4Health platform.

- **RTT**: A push notification (Franklin and Zdonik, 1998) service was implemented on top of the Cloud4Health platform. Via the implementation of a Receiver client (acting as an example clinical service), the RTT metric is calculated based on subtracting the time stamp a packet was received (by the Receiver service) against the time stamp of when a patient data sample was sent to the e-Health platform (via the Patient Simulator). Strong time synchronization was achieved via an Active Directory server acting as time synchronizer (Smith, 2010) between the Patient Simulator and Receiver client machines.

**Results**

Figure 2 provides the average upload time for 100 samples of a single virtual patient's data uploaded at intervals of 0.5, 1 and 3 seconds. No packet loss occurred during the running of this experiment. As the interval time decreases, the time taken to upload a single virtual patient’s data increases. Two conclusions can be made from this first experimental result: 1) talkativeness of a client, when upload a single patient’s data, only affects the Cloud4Health platform in a very minor manner and 2) upload times for a single patient’s data is exceptionally good with results of less than 58 ms when uploading data in intervals of 0.5 seconds.

As part of the second experiment, we present the performance evaluation results of RTT latency and CPU utilization of the Cloud4Health platform. No packet loss occurred in the instance of running this experiment. Figure 3 shows the average RTT latency when simulating and uploading 20, 60 and 100 patient’s data whilst Figure 4 shows the CPU Utilization results. Due to wide variance, Table 2 is also presented to give an overview of the minimum and maximum RTT latency values gathered during this experiment.

The results from the RTT graph show that in the case of simulating and uploading data for 20 virtual patients concurrently, the average RTT latency was very reasonable at 62.93 ms. In simulating 60 virtual patient’s data concurrently, the average RTT latency was found to be 64.80 ms – which is only a very minor increase in comparison with 20 patients. On the other hand, simulating 100 patients produced a significantly higher latency of 173.56 ms on average.
Furthermore, with a maximum latency of 6674.21 ms and minimum latency of 51.11 ms, there is far wider range of variance in RTT latency when simulating 100 patients. This wide range of variance is an indication that a bottleneck may be present on the Cloud4Health platform. CPU utilization was the primary suspect in this increased variance with RTT latency but Figure 4 shows this is not the case. Even in the scenario of simulating 100 patients, the average CPU utilization of the Cloud4Health platform was only slightly greater than 20%. Hence, it can be stated from this experiment that although RTT latency values grow as the number of patients simulated increase there is currently no direct evidence to show that this has any correlation with CPU utilization.

![Figure 2. Average upload time](image)

![Figure 3. Average round-trip time](image)

![Figure 4. Average cpu utilization](image)

<table>
<thead>
<tr>
<th>Number of Patients</th>
<th>Min RTT Value (ms)</th>
<th>Max RTT Value (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>32.57</td>
<td>526.65</td>
</tr>
<tr>
<td>60</td>
<td>31.33</td>
<td>578.02</td>
</tr>
<tr>
<td>100</td>
<td>51.11</td>
<td>6674.21</td>
</tr>
</tbody>
</table>

*Table 2. Minimum and maximum latency values*
Overall, the key findings in conducting a performance evaluation of the Cloud4Health platform based on the criteria of functionality, reliability and scalability using our proposed metrics is as follows:

- **Functionality:** Both experiments have proven the functionality of this platform. The main goal of the Cloud4Health platform is to enable the storage of patient data with strong focus on security. Using simulated patient data, our experiments have proven that the implementation is capable of handling both the uploading and downloading of patient data whilst conducting authentication and authorization via security protocols.

- **Reliability:** In both experiments conducted, no packet loss occurred between the patient simulator and the Cloud4Health platform. Hence, it can be stated that the implementation is very reliable in ensuring that patient data is retained during any general interaction.

- **Scalability:** Scalability is perhaps the current primary limitation in the Cloud4Health implementation. Experimentation results were stopped after simulation of 100 patient’s data as we found the Cloud4Health platform was unable to handle any higher volumes of patient data without unexpected errors. Though the Cloud4Health platform has been resourceful in the usage of CPU utilization, there is still a wide variance in the RTT latency values when processing 100 virtual patient’s data concurrently hence scope for improvement and optimization to ensure this platform is capable of handling higher volumes of patient data.

Section Summary and Discussion on Limitations

We have proposed that in order to provide for meaningful performance evaluation of e-Health implementations to take place, key metrics which must be obtained include CPU utilization, packet loss, download & upload time and RTT. Such metrics provides us with answers to the scalability, functionality and reliability of an e-Health implementation. Using an existing e-Health implementation, known as the Cloud4Health platform, as our primary test bed, we have documented a methodology for how our defined performance metrics may be obtained from this platform during evaluation.

Evaluation has been conducted using simulated patient data in place of real patient data in order to mitigate legal and ethical barriers. With capabilities of processing up to 100 patient's data concurrently with no packet loss, the experiments have shown that the Cloud4Health platform is very reliable in ensuring the safe arrival and storage of patient data in a very reasonable time (maximum of 6.6 seconds). Furthermore, in terms of performance, it is very resourceful in the usage of CPU utilization. However, we have also shown that, from our defined performance evaluation metrics, there room for improvement for the scalability of the Cloud4Health platform since a live hospital and clinical environments will most likely have to cater for more than 100 patient's data being uploaded and download concurrently.

It can be stated that our defined performance evaluation metrics have proved viable in the presentation of evaluation results for the technical perspective. Although the evaluation results obtained from the Cloud4Health platform do not show the implementation in the most positive light, the results have been meaningful and optimization on this platforms implementation can now take place to better improve its overall technical capabilities.
Although the key objective of this chapter has been met, limitations in the experiments conducted should be acknowledged. The two primary limitations of this work is that 1) experimentations of the Cloud4Health platform have been conducted in a sandbox virtual environment and 2) the patient data we use to interact with the Cloud4Health platform has been simulated. Although clear advantages exist in using simulated patient data and deployment within a sandbox environment, i.e. rapid evaluation of the platform may be achieved, it is acknowledged that evaluation results obtained within a live clinical environment, i.e. deploying the Cloud4Health platform in a hospital environment and using real life patient data, would provide us with more accurate evaluation results. To address this issue, we propose that our solution in providing performance evaluation of e-Health implementations should not be the final stage of any evaluation process. We argue that the methodology we have applied in conducting a performance evaluation of e-Health implementations provide for meaningful results but additional live evaluation and risk assessment studies must be conducted on any given e-Health implementation prior to use with real life patient data.

Another limitation of this work is that foreseeable difficulties may arise in attempting to apply our defined technical evaluation metrics to a live scenario or a different e-Health implementation. Firstly, applying our metrics to a live environment may prove difficulty due to the lack of control in comparison with a sandbox environment and, secondly, we note that not all e-Health implementations may use Microsoft .NET technology hence changes to the techniques used to gather the metrics may be required. To address this issue, there is need for standard and agreed upon framework to evaluate e-Health implementations. The next section of this chapter looks at the future research directions which may be undertaken within this area of work.

**FUTURE RESEARCH DIRECTIONS**

It has been identified that a key requirement within this field of research is the need for a standard methodology to enable e-Health evaluation to take place. We propose that an evaluation framework (Figure 5) which aims to evaluate e-Health implementations under the categories of organizational, end-user and technical evaluation may achieve this goal.
Within the scope of this work, we have covered one aspect of Technical Evaluation: assessing the performance of an e-Health implementation. There is also need to conduct evaluation on the security of e-Health implementations which is, arguably, a far more difficult challenge due to the wide number of areas which must be considered during the evaluation process, e.g. physical security, software security, network security and encryption techniques to name a few. We share the view of Schneier (1999) in that there is no one comprehensive methodology which is capable of evaluating the security of a single computer system, let alone an e-Health implementation which may be vastly more complex. We propose that security should be a focal point from the initial design stages of any e-Health implementation with strong adherence to global standards such as the ISO 27001 standard as discussed by Brenner (2007). Upon successful implementation of an e-Health solution, risk assessments may be carried out to validate how successful the implementation has been in meeting all criteria listed in such global standards.

To meet the goals of end-user evaluation, we propose that two primary categories must be considered for evaluation: usability of an e-Health implementation and quality of education and training given for usage of an implementation. We believe both criteria of evaluation may only be achieved via live clinical trials of e-Health implementations. By conducting interviews, surveys, observations and general interaction with clinical staff and patients, i.e. the end-users of an e-Health implementation, qualitative evaluation results may be gathered to show whether an e-Health implementation has been successful in gaining trust and support from the end-user perspective. A prime example of research which can enable meaningful end-user evaluation to take place is the Normalization Process Theory (NPT) discussed in the work of May and Finch (2009). Furthermore, usability evaluation may also encapsulate research involved in assessing patient satisfaction, a key requirement in ensuring wider adoption of e-Health technologies as discussed earlier in this chapter. Methodologies which may be applied in order to assess patient satisfaction of an e-Health implementation include traditional standardized questionnaires (Guzman et al., 1988) to more modern methods such as an internet based patient system (Yet et al., 2008). Overall, achieving positive end-user evaluation results from even one clinical trial may boost the adoption of e-Health technologies since other clinical environments are more likely to trust the implementation if the results are positive.

The final aspect of evaluation which needs to take place for e-Health is organizational evaluation. The results of this type of evaluation are catered towards the organizational perspective and the two criteria of evaluation include governance and logistics. Governance includes evaluating the laws, ethics, interoperability and standardization of an e-Health implementation whilst logistic evaluation aims to answer the cost and benefits involved in adopting this technology. Evaluation of all these criteria may be a vast undertaking but it is essential in order to see wider support and adoption of e-Health from the organizational perspective. Government bodies have proposed the e-Health Governance Initiative (Giorgio et al., 2013) which provides policies on ensuring interoperability and standardization of e-Health implementations whilst similar goals are shared with the Future Internet platform (Castrucci et al., 2011) which aims to provide for a heterogeneous implementation of the internet and systems for future use. We propose that such areas of work may provide the basic guidelines for research related to evaluation of e-Health from the organizational perspective.
CONCLUSION
From existing literature, we find that adoption of e-Health technologies is still lacking within healthcare organizations. Key challenges in adoption of e-Health come from three primary perspectives: organizational, end-user and technical perspective. We argue that in order to see wider adoption of e-Health technology, meaningful evaluation data must be available for existing and future implementations. By conducting evaluation of e-Health implementations catered towards these three perspectives, results may be presented and an informed choice may be made by these three groups in deciding which implementation is best suited to their requirements and needs. We propose that wider adoption of e-Health technology may take place if these three groups are better aware of the capabilities and limitations of each implementation.

In the scope of this chapter, our key objective was to provide performance evaluation results catered towards the technical perspective. In order to meet this objective, we define key metrics which should form the basis of a performance evaluation. These metrics include CPU utilization, download/upload time, RTT and packet loss. The defined metrics aim to provide answers in regards to the scalability, functionality and reliability of the implementation under evaluation. Concise methodology for how each of these metrics may be captured has been provided so that future researchers may apply them to their research along with providing improvements if necessary. In order to provide proof in the viability of our proposed evaluation metrics in providing meaningful results, we conducted a performance evaluation on an existing e-Health implementation known as the Cloud4Health platform. Simulated patient data was used for the purpose of this evaluation in order to mitigate legal and ethical barriers which are imposed when using real life patient data. From experiments carried out, we can state that the key objective in this chapter was met as meaningful results were successfully obtained from the implementation under evaluation.

The results showed that with capabilities of processing up to 100 patient's data concurrently with no packet loss, the experiments have shown that the Cloud4Health platform is very reliable in ensuring the safe arrival and storage of patient data in a very reasonable time (maximum of 6.6 seconds). However, there is also room for improvement for the scalability of the Cloud4Health platform since a live hospital and clinical environments will most likely have to cater for more than 100 patient's data being uploaded and download concurrently.

By building upon the techniques we have used to conduct performance evaluation of e-Health implementations, along with the design of methodologies to enable evaluation results to be obtained and presented to the two other perspectives, i.e. end-user and organizational perspectives, we hope to see increased awareness, support and adoption of e-Health solutions in the near future.

REFERENCES


ADDITIONAL READING


**KEYWORDS**