Integrating Sentinel Surveillance Systems and Electronic Health Records – The case of Médicos Sentinela and the NHS

Hugo Paixão
Under supervision of
Mário Silva, INESC-ID/Instituto Superior Técnico, University of Lisbon
Ana Paula Rodrigues, Instituto Nacional de Saúde Dr. Ricardo Jorge

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Abstract

In Public Health, sentinel surveillance is an activity in which a selected number of health professionals provide regular reports on a set of health problems. Web-based applications with manual data are entry the current state-of-the-art reporting tool. However, the adoption of electronic health record (EHR) technology provides an emerging source of data to be tapped for surveillance reporting. I proposed an approach for the integration of a sentinel surveillance system and EHR systems, for the Portuguese sentinel network Médicos Sentinela (MS). It includes a tool for detecting notifiable cases in an EHR and extracting the relevant data to automatically fill MS notification forms. Physicians can then validate and complete the notification forms if necessary. An initial implementation of the tool was used to validate the proposed approach, showing that it could automatically fill almost all of the notification forms. A preliminary assessment with a group of sentinel physicians has shown that user satisfaction was high.

Keywords: Sentinel Surveillance, Public Health and Clinical Systems Integration, Public Health Informatics, Médicos Sentinela network

1 Introduction

In public health, sentinel surveillance is an activity in which a limited network of health care professionals voluntarily reports data on a set of health problems [1]. Sentinel surveillance can supply a sample of information to public health decision makers when data on the entire population are not available. Additionally, it allows collecting high-quality, detailed data about particular health conditions, which is not possible through passive surveillance methods, such as reports on notifiable diseases required by law.

Sentinel systems are usually based on data collection by a selected group of general practitioners (GPs), although they sometimes also include physicians from other specialities. Data are collected through structured notification forms. In state-of-the-art sentinel networks, data are manually entered in web forms and transmitted to central databases through secure internet connections. Nonetheless, many networks are still paper-based or use both paper and the web.

In their activity, physicians already dedicate a significant amount of work time to data entry. This has posed a problem to physicians since the introduction of computers in health care [2]. Notification forms in sentinel networks are manually filled, requiring an additional data entry process and consuming even more time. Besides, most of the data entered in notification norms is duplicated, which makes this process a repetitive task.

However, advances in information technology, along with the increasing adoption of the EHR as a standard in health care, provide an opportunity to facilitate the exchange of information between public health and clinical care. Since EHR systems capture the whole spectrum of medical data [3], it seems advantageous to use these data for automated filling of sentinel surveillance notification forms.

The opportunity to perform a study regarding the use of EHR data for automated reporting in a sentinel network motivated this project. The study was conducted in the context of the Portuguese sentinel network, Médicos Sentinela (MS), in collaboration with the Department of Epidemiology of the Instituto Nacional de Saúde (INSA), which coordinates the network. Its two main goals were:

1. To research the viability of using the data in EHRs to avoid duplicate data entry processes when providing data to a sentinel network.
2. Develop and evaluate a system integrating MS network and EHR systems, using one of the EHR systems of the National Health Service (NHS).

I implemented the proposed system, called Sentinela+, with an interface to the MedicineOne EHR system, to extract data for cases of MS-notifiable health conditions.

Sentinela+ includes a desktop client application, which communicates with MedicineOne server over the network, through HTTP protocols. To bypass security firewalls, I also developed a web service to be hosted in MedicineOne server. This service is able to query the MedicineOne database about notifiable events and return clinical data back to clients. The Sentinela+ client application can automatically fill most of MS notification forms using these data and send them to a server that I have set up for further processing, where they can be accessed by the MS system administrators.

A sample of MS physicians tested Sentinela+ and evaluated it through a user satisfaction questionnaire. Feedback received was positive. Users rated how the system impacted the notification process in two aspects: facilitation of the notification process (average score: 8,0 out of 9) and reduction of the time necessary to fill notification forms (average score: 7,3 out of 9). Additionally, users also rated four user interface aspects: screen components (average score: 7,3 out of 9), terminology and system feedback (average score: 7,9 out of 9), learning factors (average score: 8,1 out of 9) and system capabilities (average score: 8,5 out of 9). The system was also subjected to performance tests, which demonstrated that response times were acceptable: in the order of 50ms with 1 user extracting 10 cases and in the order of 400ms with 100 sentinel sending data.

The Sentinela+ prototype is fully functional and ready for deployment in primary care centres that use MedicineOne EHR system, to extract real patient data. Given the successful integration of MS sentinel surveillance system and MedicineOne EHR system, this development could serve as a starting point for integrating other sentinel networks with EHRs.

2 Sentinel Surveillance

Sentinel surveillance is a type of public health surveillance, in which a restrict number of selected healthcare professionals or sites voluntarily provide regular and standardized reports on a set of defined health events, generally using a specific reporting tool (*e.g.* paper forms, web applications) [1].

If the sample of healthcare professionals or sites is carefully selected, data collected in such systems can be used to estimate incidence rates for the events of interest without the need to survey an entire population [4]. Thus, sentinel surveillance is particularly useful when data on the whole population are not available. Additionally, it is an effective, rapid and flexible method for detecting large public health situations, using fewer resources. However, since it uses a limited number of reporting sites, its efficiency is largely decreased for detecting health events that are rare or beyond the reach of the reporting entities [5]. Moreover, since it involves a limited network of voluntary reporting healthcare professionals it can be used to collect high quality, high specificity data that would not be possible to collect for the entire population [1].

Current sentinel networks had their origins in the Weekly Returns Service (WRS), developed by the Royal College of General Practitioners in 1969, in which a group of GPs summarized diagnoses and consultations, providing weekly reports regarding specific health events for a defined population. This reporting method was very simple and effective [6]. Similar systems based on this approach were created afterwards in several European countries, such as the Netherlands in 1970, Belgium in 1979, France in

1984, Switzerland in 1986, Spain and Portugal in 1989. The aforementioned systems comprise a group of GPs that collect data about disease indicators and submit weekly reports [7]. Over the years, multiple works carried out by these sentinel systems established sentinel surveillance's validity and consistency [8]. Currently, sentinel surveillance systems are used in most European countries and in developed countries in general. Sentinel surveillance importance is particularly acknowledged when it comes to clinical surveillance of influenza viruses, with clusters of sentinel networks covering large areas, such as the European Influenza Surveillance Networks (EISN) [9] and the United States Outpatient Influenza-like Illness Surveillance Network (ILINet) [10].

Initially, physician's reports to sentinel networks consisted of filling out paper forms, sent by fax or post mail to public health agencies, where data was entered into local databases, for further processing and analysis. One notable exception was the French sentinel network, Réseau Sentinelles, which favoured the use of computer systems to report cases of notifiable events since its creation. In 1996 it adopted a visionary reporting tool: a web based interface, used to transmit data through secure internet connections [11]. This tool has been adopted by other sentinel networks, becoming the state-of-the art reporting method. However, many sentinel networks are still paper-based or use both web applications and paper. In 2012, the German sentinel network, Arbeitsgemeinschaft Influenza, introduced a new reporting tool: SEEDARE. This tool can query certain EHR systems and find cases of Acute Respiratory Infection (ARI) that need to be notified. Computer-aided detection of ARI cases is based on diagnosis codes and additional data regarding these cases are also extracted, including: age, gender, date of consultation, information about an eventual sick leave/hospitalization and influenza vaccination data for each patient with ARI. Afterwards, physicians generate a file containing all these data, which are sent by e-mail to public health agencies weekly [12].

2.1 Médicos Sentinela

The Portuguese sentinel surveillance network, Médicos Sentinela (MS), was developed in 1989, and it is coordinated at the Instituto Nacional de Saúde Dr. Ricardo Jorge. MS comprises 107 sentinel GPs, exercising their professional activity in primary care centres encompassed in the National Health Service (NHS). Presently it allows the surveillance of six notifiable events: influenza-like illness (ILI), hypertension, diabetes mellitus, cerebrovascular accident (CVA), acute myocardial infarction (AMI) and oral anticoagulants prescription. Sentinel physicians submit notification forms regarding all cases of these health events. Notification forms can be filled through a web interface or paper, requiring manual data entry by physicians [13].

MS network encompasses sentinels that notify voluntarily, guaranteeing data quality and timeliness. However, since participation in MS network is voluntary, the group of sentinels is a convenience sample of the GPs in the NHS. Thus, it is desirable to increase the number of sentinels in the network, to increase the representativeness of this sample. Furthermore, only a portion of the sentinels in MS network notify actively. Data collection for MS notification forms requires time from the physicians. The longer the reporting task takes, the more it disrupts the physician's workflow. This project seeks to enhance data collection processes in MS, by proposing a notification tool that uses EHR data to automated reporting. By improving time efficiency and effectiveness in the notification process, this tool can engage more physicians in the MS network.

3 Sentinela+

Sentinela+ is a system that integrates EHR systems in the MS network. The basic concept of the system is to detect all cases of MS-notifiable events in the EHR and to extract data for automated filling of MS notification forms. Sentinela+ includes a desktop client application used to fill notification forms, with data retrieved from clinical information systems. Additionally it comprises a server, to where forms data are sent. Datasets in the server can be exported through a web application, which can be accessed in a web browser by MS system administrators. These datasets are further processed and analysed by public health professionals. The conceptualization of the system is illustrated in Figure 1.

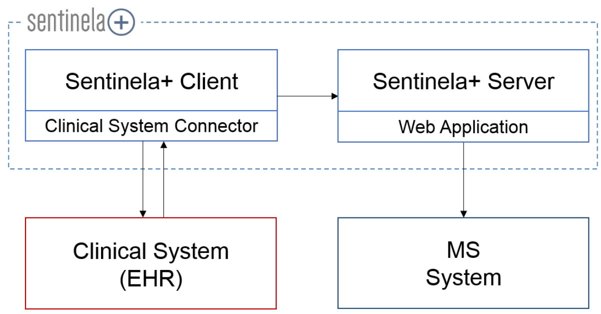

Figure 1: Conceptualization of Sentinela+ system.

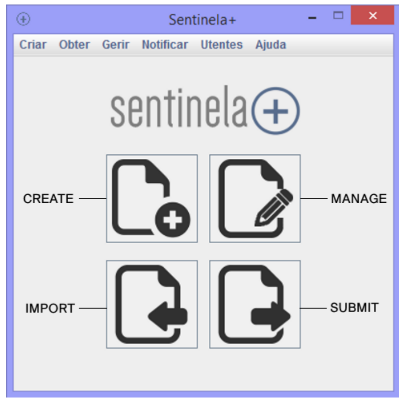

Figure 2: Sentinela+ client main window.

The Sentinela+ client code was written in Java language and its graphical user interface (GUI) was developed in Netbeans IDE 8.0.1, using Java Swing components. Its local database is an Apache Derby database. The Sentinela+ server runs on a virtual server, set up for this project, comprising a database server with Microsoft SQL Server 2008 and an application server with operating system Windows Server 2012 R2 and an IIS 8.0 web server. The Sentinela+ web client to return data to MS system administrators is an ASP.NET web application developed in Visual Studio 2013 for Web, using code-behind the page in C# language and a user interface in HTML.

3.1 Sentinela+ Client

Sentinela+ client is a desktop application used to fill notification forms using data from EHR systems. The application also includes a local embedded database, where notification forms data are stored. Sentinel+ client comprises four main actions: CREATE, IMPORT, MANAGE and SUBMIT (see Figure 2). Each action has a distinct purpose:

- CREATE – Report a new occurrence manually.
- IMPORT – Request data extraction processes from the EHR system, receiving the response and storing data in the local database.
- MANAGE – Manage all extracted notification forms, that can either be completed or eliminated.
- SUBMIT – Send data to Sentinela+ server, for further processing.

Before users can extract or send data, they must provide a username and password. For data extraction, these correspond to the login credentials of the EHR system. For data sending, the username corresponds to the sentinel identification number and a Sentinela+ password attributed to that sentinel.

The data model used to represent notification forms in Sentinela+ client is simple and straightforward. Each notification form data (see Figure 3) are stored in a single row of the table *NOTIFICATIONS* in the local database.

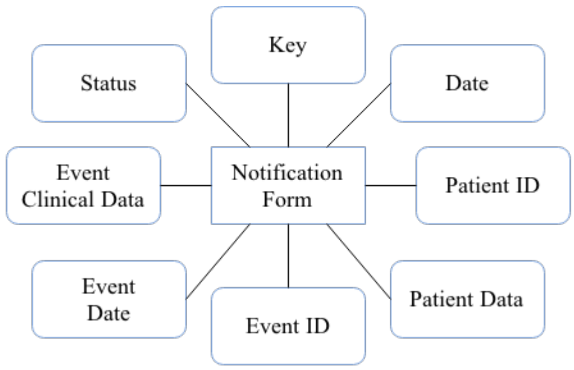

Figure 3: Notification forms data elements.

Additionally, the local database includes another table, *ACTIONS*, which comprises data to track user's actions within the application, such as the date when extraction processes take place, to determine which events were previously extracted.

Notification forms can be filled, edited and stored using the client GUI (see general structure in Figure 4). The code behind each notification form manages the process of capturing data entered by users through GUI elements and pro-

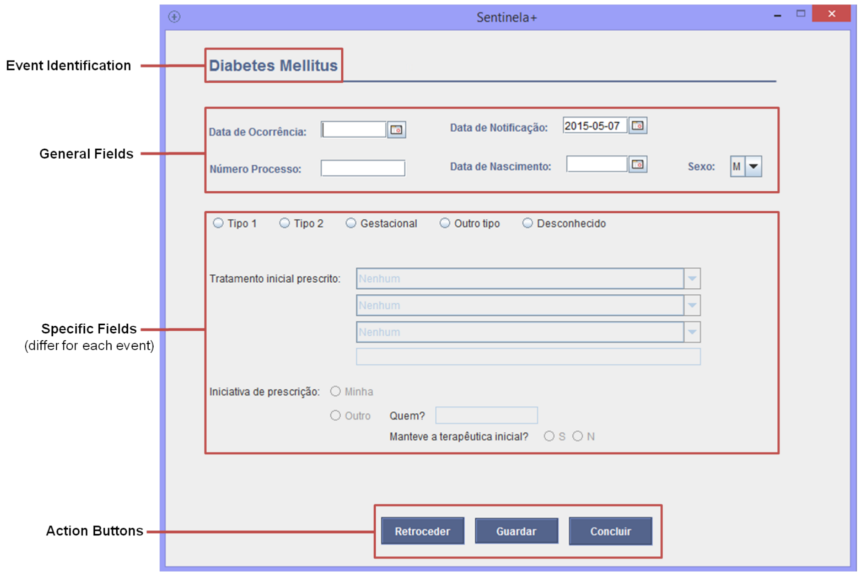

Figure 4: Interface of Sentinela+ web application to download datasets.

cess it for storage in the local database. There is a different notification form for each reportable clinical event.

3.2 Sentinela+ Server

Completed forms data are sent to Sentinela+ server, where they are stored in a database. This database is identical to the client's local database, facilitating data exchange processes. Forms data are sent to the Sentinel+ server via HTTP POST requests, which invoke a data upload web service in the server that inserts data in the database. Patient's identification is never sent from the client, guaranteeing that data remains de-identified. Furthermore, there is an authentication process before data upload takes place, to ensure only sentinels can submit data to the server.

Additionally, Sentinela+ comprises a web application, to return datasets from the Sentinela+ server in CSV format. This application allows to export notification forms data to MS system administrators, for further processing and analysis. Data are exported by clinical event. The users can access the web application through a web browser, and download the generated CSV as an attachment (see Figure 5).

Figure 5: Screen shot of the application developed for data extraction

3.3 MedicineOne Connection

At the moment, Sentinela+ provides a connection to one of the major EHR systems used in the NHS, MedicineOne.

Detection of cases in the MedicineOne EHR were based on the ICPC2 diagnosis codes for MS-notifiable diseases (ILI, diabetes, hypertension, AMI and CVA) and on the ATC codes for anticoagulants prescription cases. In MedicineOne, ICPC2-coded differential diagnosis and prescribed medications ATC codes for a given consultation are stored in the Medicine database, which allows to detect cases of MS-notifiable

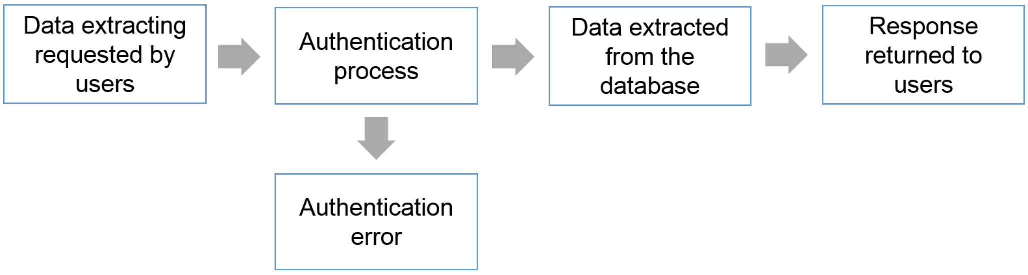

Figure 6: Extraction process overview.

events that arise during medical practice. The data extracted regarding those cases includes administrative, diagnosis and medication prescription data. Data mapping allowed to determine which elements from the MedicineOne data model could be used to fill MS notification forms (see Table 1).

To detect and extract data, a ASP.NET web service was developed, called *Sentinela-MedicineOne* service. *Sentinela-MedicineOne* queries MedicineOne database, extracting data regarding all cases of detected MS-notifiable events and returning them to the client. The service is invoked by HTTP POST requests from the client. Requests enclose a set parameters within their body, that limit queries range, such as the last extraction date and the user that requested data extraction. After completing the extraction process, *Sentinela-MedicineOne* web service returns an XML response with a well-defined structure to the client. Additionally, before any query is performed, there is an authentication process to verify if the credentials provided by the user match a MedicineOne password (see Figure 6).

Extracting prescribed medications for disease cases (diabetes and hypertension) required crossing diagnosis dates and prescription dates, and then apply a filter to select exclusively the possible medications for the respective disease. Moreover, data regarding disease's symptomatology, necessary for ILI cases, was not extracted, since there are no specific fields in the MedicineOne EHR database to store disease's symptoms.

To request data extraction processes and read the returned response, a module was developed in Sentinela+ client, providing a connection to MedicineOne. The connector is called whenever users request data extraction processes, through the IMPORT button. It sends the HTTP requests to MedicineOne server and reads the XML response, storing its data in the client local database.

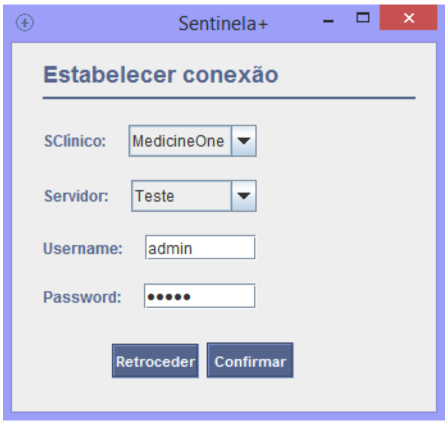

Figure 7: MedicineOne connector GUI.

4 Sentinela+ Evaluation

4.1 User Satisfaction Evaluation

To ascertain Sentinela+ users satisfaction I organised a survey. An adapted version of the Questionnaire for User Interface Satisfaction (QUIS) was used. QUIS was designed to assess users' subjective satisfaction regarding aspects of the computer interface and usability [14]. Four specific interface aspects were measured through QUIS: screen components, terminology and system feedback, learning factors, and system's capabilities. Additionally, since QUIS does not measure specific functions in systems, I added a section regarding users perception of the system value to fulfil the task it was designed for. QUIS ratings measure user's objective satisfaction through a 9-point scale. The lowest and highest values on the scale (1 and 9, respectively) are associated with a word to describe user assessment. The evaluation results are summarized

Notification forms fields	MedicineOne Table	MedicineOne Column
Patient identification. Date of birth of the patient. Gender of the patient.	CLI_UTENTES	Np Data_n Sexo
Identification of the clinical event notified.	CLI_PATOLOGIAS_UTENTES	Codigo_patologia
Date of the clinical event notified.	CLI_PATOLOGIAS_UTENTES CLI_PRESCRICOES_UTENTES	Data_registo Data_prescricao
Prescribed medications (diabetes, hypertension and anticoagulants prescription).	ATC_LINK	Pk_ATC
Responsible physician for the prescription of the medications (diabetes, hypertension and anticoagulants prescription).	ORG_UTILIZADORES ORG_PESSOA	Username,Nome
Type of diabetes (diabetes)	CLI_PATOLOGIAS_UTENTES	Codigo_patologia

Table 1: Mapping between fields in MS notification forms and the fields in the MedicineOne EHR where the information regarding those fields could be found.

in Figure 8. The questionnaire was answered by a sample of 4 sentinel physicians, which represent 6% of the total number of active sentinels and 3.8% of the entire network.

4.2 Performance Evaluation

To evaluate Sentinela+ performance, I resorted to JMeter, an open-source tool to load test functional behaviour and measure performance. JMeter can be used to simulate a heavy load on a server to test its strength [15]. I tested data extraction from MedicineOne server and data ingestion into Sentinela+ server. MedicineOne server has an Intel Xeon CPU E5520 2,27 GHz, 1,67GB RAM, running Windows Server 2012 R2 as the operating system. Sentinela+ server an Intel Xeon CPU E5-2670 v2 2,50 GHz, 1GB RAM, running Windows Server 2012 R2 as the operating system. For these tests I used a machine with an Intel Core i7-3537U 2,00 GHz processor, 8GB RAM and network with symmetric bandwidth.

I simulated the ingestion of notification forms data into Sentinela+ server, through HTTP POST requests, varying the number of users (see Figure 9. The test intended to observe how the server would respond to different stress levels and if its response was adequate for the current number of users. The collected performance indicator was the response time, *i.e.* the time the server takes to accept a notification form.

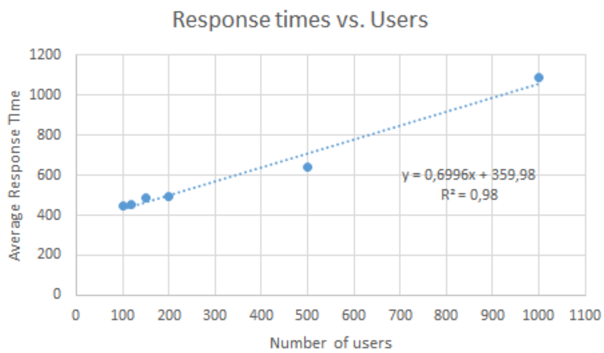

Figure 9: Average response time versus the number of users requesting data sending processes.

It is possible to observe in Figure 9 that the response times increase linearly with the number of users, which was expected. This allows to predict well how the system need to be scaled as the number of users (sentinels) increase. Additionally, for the current number of users (107), the response time averaged is in the order of 400ms.

I also simulated the extraction of data from MedicineOne EHR system by a single user,

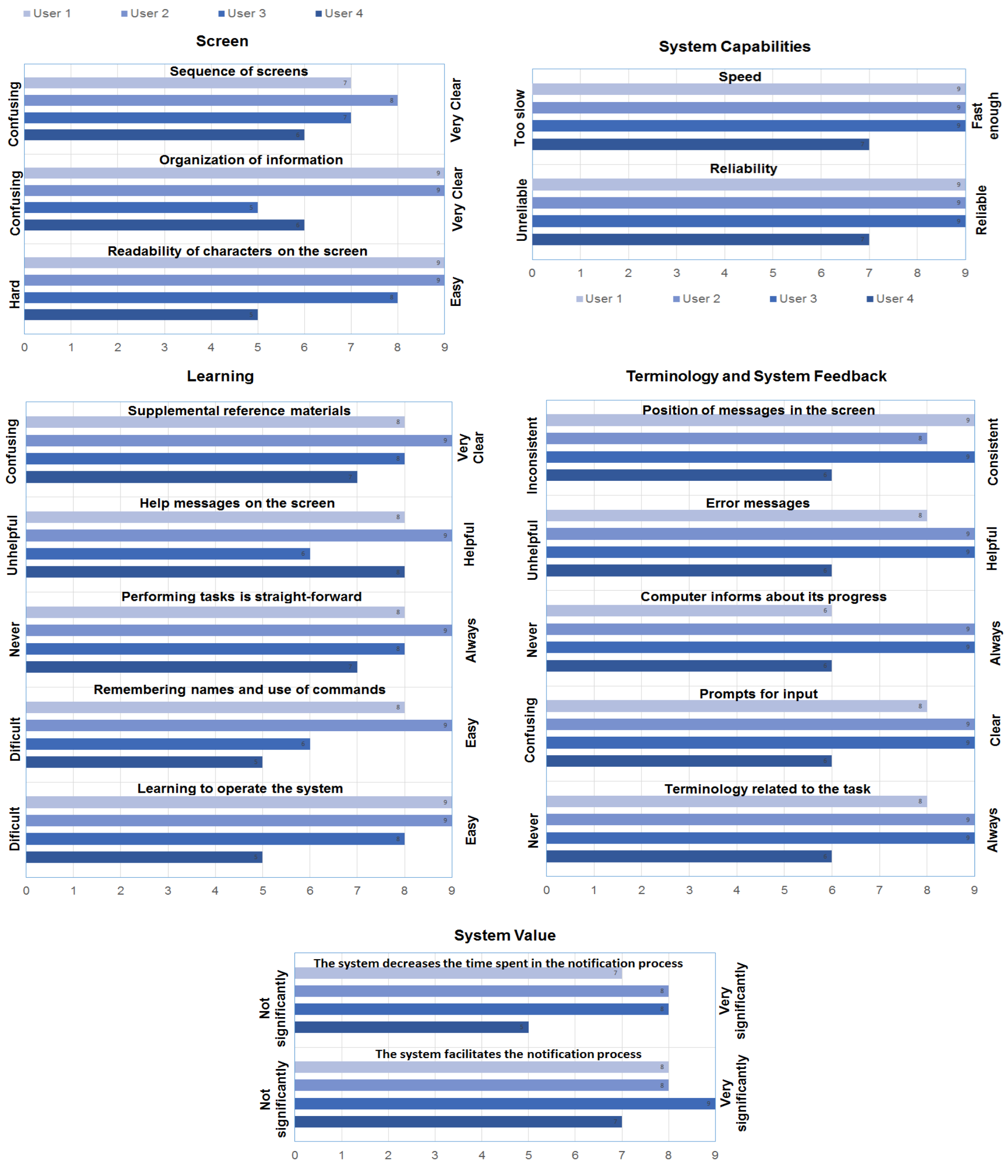

Figure 8: User evaluation results.

through an HTTP POST request. Response times averaged 57,75ms. This test was performed for the extraction of 10 cases from the EHR system. Further testing allowed to determine that this response time was not significantly affected by the number of cases extracted. Additionally, I observed how the requests affected MedicineOne server.

CPU usage raises from 1-2 % to values up to 8%, as can be seen in Figure 10. Although not negligible, this values allow the server to perform in good condition. Thus, Sentinela+ requests shall not affect the performance of the EHR system significantly.

5 Conclusion

The main goals of this project were achieved. I was able to develop a fully functional system, Sentinela+, which extracts data from a clinical system used in primary care in Portugal, MedicineOne, for automated filling of notification forms of Médicos Sentinela. The project focused primarily on the development and implementation of all the system components: the client application for automated form filling, the MedicineOne-Sentinela web service for data extraction from the MedicineOne database and the Sentinela+ server for generating datasets for analysis.

Sentinela+ was able to extract most of the

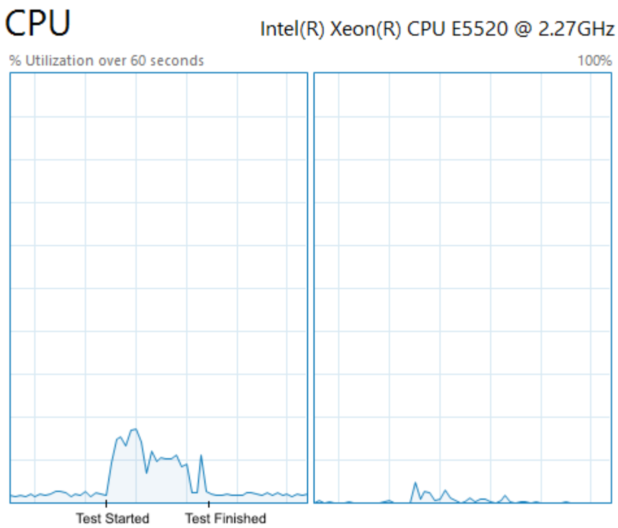

Figure 10: CPU utilization in the MedicineOne server during the extraction process.

data regarding the cases of MS-notifiable events. Sentinela+ was tested by a sample of MS sentinel physicians, who evaluated the system through a user satisfaction questionnaire. Analysis of the responses allowed to conclude that:

1. 3 out of the 4 users reported an overall high general satisfaction with the system and its interface; the other user rated the system with a positive, yet more neutral evaluation.
2. All users agree Sentinela+ substantially facilitates the notification process.
3. 3 out of the 4 users agree that Sentinela+ can reduce the time spent in notification process significantly.
4. All users would adopt Sentinela+ as their reporting tool instead of the current available ones, when possible.

Performance evaluation proved that the system configuration used to develop Sentinela+ has an adequate performance to support MS notification process.

For all the aforementioned results, I can say that Sentinela+ achieved the successful integration of a sentinel network and an EHR system, and proved that this integration is indeed viable and beneficial. The system conceptualization and implementation can provide useful insights for the integration of other sentinel and EHR systems.

The development and deployment of Sentinela+ is not complete. I propose its integration with SAM, the other major EHR system in the NHS. This integration would be extremely useful, since most GPs in national primary care centres use this clinical system.

Additionally, I propose the implementation of Sentinela+ in primary care centres using the MedicineOne EHR system, which implies installing the developed Web service for data extraction in the servers of those primary care centres. However, logistical issues represent an obstacle to this process, given that installing new software requires the approval from the respective regulatory authorities. Furthermore, Sentinela+ deals with extremely sensitive data, which raises concerns regarding data privacy and security. Even though data extraction can only be performed with the login credentials to access the EHR, it would be necessary to review protocol privacy and security policies and procedures in a real case scenario, such as the use of Secure Sockets Layers (SSL) for communication between the client application and the EHR.

Once deployed in primary care centres, Sentinela+ should be subjected to a long-term evaluation. This evaluation should measure the proportion of notifiable cases that are detected as such. Additionally, a study on the impact of the system in MS is also relevant. This study should answer questions such as: 1) Was the adherence to Sentinela+ as a notification tool high or low? 2) Did Sentinela+ increased the average number of weekly notifications? 3) Did the system attract new physicians to join MS?

I had the opportunity to observe that computers in some primary care centres use outdated and discontinued Java technology, which prevents Sentinela+ client application to run in these computers. Thus, in some primary care centres updates to the base software of desktop office computers would be necessary.

The Sentinela+ client was designed to run in the sentinels personal laptops, connected to the private networks of the primary care centres. However, with the increasing adoption of mobile tehcnology, such as smarthphones and tablets, a mobile version of the application could provide a more user-friendly alternative to this reporting method. Thus, the development of a mobile application as an extension for Sentinela+ system would be a great addition. The design of the Sentinela+ desktop application could serve as the basis for the GUI of the mobile application. Moreover, the desktop application code could easily be recycled for an Android application, since applications written for this operating system also use Java-based code. By adhering to standard formats and protocols, the rest of the system adopted for Sentinela+ developed in this project would remain unchanged.

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