Intelligent Support System for the Provision of Inpatient Care

Sónia Faria, Daniela Oliveira, António Abelha, and José Machado

Algoritmi Center, University of Minho, Campus Gualtar, Braga 4710, Portugal
sonia.faria@algoritmi.uminho.pt,
daniela.oliveira@algoritmi.uminho.pt,
abelha@di.uminho.pt,
jmac@di.uminho.pt

Abstract. Inpatient care is seen as a rigorous healthcare environment, as several daily tasks are performed to provide adequate treatment to inpatients and a minor flaw in these tasks may result in irreversible damage to patients. It is therefore required that the information related to the patient is always updated and available to all health professionals. Thus, comes up the motivation of the project described in this paper, which presents an intelligent system to support the practice of inpatient healthcare through a Web platform that allows the monitoring of patients admitted to a health facility. Thus, the developed system culminates in an application where all relevant information is gathered to monitor the different hospitalization episodes, presenting this information in a simplistic and intuitive way and alerting the professionals to the occurrence of events related to medical exams and analysis, surgical procedures, among others. This paper presents the architecture, the requirements and a SWOT analysis of the solution proposed, the main conclusions and a proposed future work.

Keywords: Inpatient Support System, Multi-Agent System, Clinical Decision Support System, Healthcare.

1 Introduction and Contextualization

Nowadays, the major concern of health institutions is to improve their quality, focusing on the patient security and his health-being and thus providing more efficient and effective health care.

During hospitalization episodes there are several and highly heterogeneous teams of care providers that monitor the patients' evolution. And it's necessary to transmit information about patient treatment at various times, making a correct and assertive communication among the professionals essential. An incorrect or weak communication between professionals can lead to clinical errors and compromise patient safety. What makes hospitalization considered a place conducive to the occurrence of Adverse Events (AE), that is, the occurrence of unwanted, unforeseen and unintentional complications resulting from the care provided to the patient [1].

Worldwide, it is estimated that 1 in 10 patients is affected by one or more AE and 50.3% of the AE occurred were considered avoidable [2]. In Portugal, one or more AE occur in public hospitalizations, which results in a consequent increase of hospital death risk from 5% to 7% [3]. Communication failures are pointed as one of the main contributing factors for the occurrence of AE, jeopardizing the continuity of the patient's treatment [4].

In order to overcome these events, Medical Informatics focus on the development and implementation of Hospital Information Systems (HIS). HIS aim to facilitate and improve the performance of all functions conducted by the hospital in patient care, taking into account human resources, technological resources, economic resources and legal requirements such as data security, among others [9][10]. With the increasing improvement of HIS, Clinical Decision Support Systems (CDSS) have emerged, which are computer systems that allow quick access to a set of pertinent information and automatically extract knowledge from a high volume of data and also allow analysis and comparison of the same data [11][12].

To overcome failures in communication, mismanagement of hospitalization episodes and to prevent failures in shift handovers, emerged the motivation to develop an Intelligent Clinical Decision Support System (ICDSS), presented in this paper, intending to assist the professionals during their tasks through an automated process.

This paper is divided in six sections. The first section introduces and contextualizes the work. In the second section are presented the background and related work. Section three presents the methodologies used to conduct the research, namely the Design Science Research methodology. The solution proposed is explained in the fourth section. A proof of concept is accomplished in the fifth section. Finally, in the last section the conclusions are drawn and future work is suggested.

2 Background and Related Work

In hospitalisation episodes, failures occur that are often caused by the difficulty in accessing the patient's current clinical record and by the lack of recorded information. Thus, communication failures or failures in the transmission of information at the shift handover are constantly reported and demonstrated to be factors that influence the delivery of health care, which can endanger the life of a patient and thus reduce the quality of care delivery.

At the most health institutions the relevant information related to the hospitalization episodes is decentralized, dispersed by several HIS and several databases, making its access and consequent interpretation difficult. It is therefore important to consider the concept of interoperability, which can be broadly defined as the ability of two or more systems to exchange and use data efficiently [5][6].

In order to focus data on a single source, a manual mechanism for inserting information into a static prototype was introduced into Centro Hospitalar Universitario do Porto (CHUP). In some health units of CHUP the prototype is

developed on a white board, while in other health units it is developed on Excel sheets, however, in both cases, entering the required data is based on a manual process. Therefore, the information held in this prototype is daily recorded manually by the professionals of each health unit and should be updated whenever there is any change in patient' data, whether administrative or clinical.

The mechanism mentioned above has serious limitations and failures, one of the main being that it requires time for healthcare professionals, which would be fundamental for the effective delivery of patient care. In addition, this system presents failures due to the dynamism of hospitalization, since, in this context, there is a great flow of tasks and a constant alteration of patients' condition. It is, therefore, necessary to update the information contained in the prototype several times a day, what doesn't always happen and may mislead other professionals. Also, subjectivity in completing the data may lead to ambiguities and misinterpretations of the information included in the prototype. At last, this mechanism still presents another flaw that results from the deletion of information or the filling of erroneous information, although by mistake, that when omitted may compromise the safety and well-being of patients. For these reasons, this system was considered an obsolete system and does not correspond to the needs of the professionals.

Thus arises the need to automate the prototype mentioned before and thereby the need to create a computerized board for monitoring inpatients. The automation of services within this institution has already proved to be an asset, and is achieved through increased interoperability between systems [7]. For this purpose, Agency for Integration, Diffusion and Archive of Medical Information (AIDA), was created, which is a Multi-Agent System (MAS) developed by a group of researchers from the University of Minho, which is implemented in several portuguese health institutions, such as CHUP [10]. AIDA is an agency that provides software agents that exhibit proactive behavior and are responsible for certain tasks, namely, communication between different systems [5] [6].

Therefore, the objective of the project presented in this paper is to automate the services present in the inpatient environment, joining all the pertinent information to the patient, such as their location (bed number), scheduled medical exams, medical analysis and surgical procedures and associated alerts, in one platform. For this purpose a web platform was created to allow the consultation and facilitate the visualization of this information and thus reducing the need to access multiple data sources, which would be more time consuming.

3 Methodology Design Science Research

The methodology used to conduct the research was problem oriented, which means that it was intended to develop a solution to a given problem. The research was developed according to the needs and emerging problems of CHUP and taking into account the information systems present in it, as well as the results obtained by the static prototype mentioned above. The resulting system was inserted in a real context, so the research was carried out cyclically and

continuously, and not through a linear method, since this system has to meet the needs of professionals and therefore has to overcome challenges or consequent problems that may arise. That said, the methodology adopted was Design Science Research, whose main objective is to support the development and evaluation of information technologies artifacts [8].

A schematic of the Design Science Research (DSR) methodology is presented in Figure 1, where the essential steps for building scientific IT artifacts are specified.

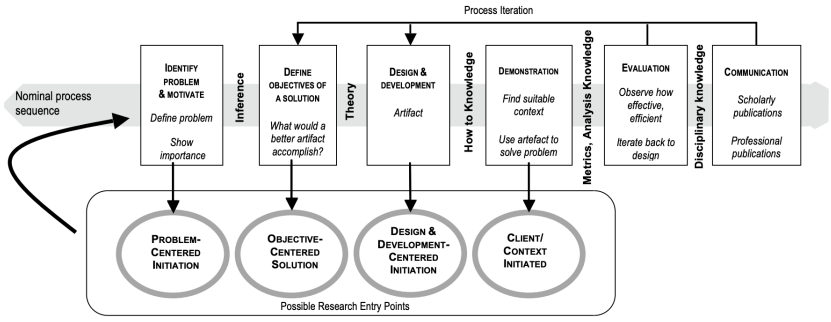

Fig. 1. DSR methodology and its essential steps 1.

That said, the first step in this project development was the identification of the problem, which translates into the lack of a single platform for monitoring hospitalization. Thus, in CHUP, health professionals who monitor hospitalization episodes, encounter difficulties when accessing information. This information is scattered across several IS and in multiple formats. The main objective of this research proposal is to find a solution that allows health professionals to access relevant and unambiguous clinical information quickly and intuitively. Thus, the artifact developed is an ICDSS that gathers all the information considered crucial for the episodes of hospitalization and presents it to health professionals, using a web platform. Throughout the development of the solution, its practical demonstration in CHUP and its performance is evaluated through an analysis and an usability study with the elaboration of interviews and questionnaires to the target users. Depending on the assessment, adjustments are made and new objectives are defined. In the last phase the artifact obtained is communicated and produced in the different health units of CHUP.

4 Intelligent Support System for the Provision of Hospitalization Care

For the development of the resultant ICDSS it was first necessary to evaluate and define its clinical and technical requirements, using the help of physicians, nurses and health technicians.

Therefore, at a technical level it is intended that the system has the following characteristics:

- **Interoperable** Interoperable with all HIS present in the health organization that contain the relevant information for this platform.
- **Automated** Works automatically, with the minimum input of data by users. Thus, information regarding patient hospitalization episodes is collected through an automated mechanism and through cycles programmed with predefined time periods.
- **User-friendly** Intuitive, user-friendly, unambiguous user interface that enables simplified access to key patient information.
- **Distributed and Concurrent** Simultaneous access for multiple users and on multiple devices.
- **Integrable** Its implementation and production needs to integrate into the CHUP information systems without compromising their performance.
- **Data Confidentiality** Ensuring access to data by authorized professionals only.
- **Adaptable** Adaptable at different data sources and at various health units.
- **Ubiquitous Access** Access can be done anytime and anywhere. System needs to operate in any operating system or any type of device.

As for the clinical requirements, it was necessary to evaluate the main needs, once multiple and different data is generated during hospitalization episodes, such as therapeutic attitudes, examinations, medical devices, among many others. Therefore, the following clinical requirements were considered:

- **Bed, Unit and Patient Identification** "Bed Number", "Unit Description", "Patient Name", "Episode Number" and "Responsible Relative"
- **Physician and Nurse Responsible**
- **Medical Analysis and Exams**
- **Medical Devices** Device type identifier and change need alert.
- **Medical/Clinical Alerts** "Fasting", "Risk of Fall", "Physical Containment", among others.
- **Allergies and Isolation**
- **Medical/Clinical Notes**

Throughout the development of the system, the authors of this article were granted CHUP approval to extract the information needed in order to test the system and thus meeting the clinical requirements.

4.1 System Architecture

The resultant Intelligent System to Support Inpatient Healthcare, presented in Figure 2, displays an architecture based on three essential components: Web Platform, Database and MAS.

The web platform is based on client–server model. The Client refers to the User Interface (UI), that is, the web application where user interacts with the

platform. Therefore, the Client communicates with the Server through *HTTP Requests*, which sends requests to a secondary Web Service (used only to manage access to multiple databases present in the institution), which in turn, queries the databases, receives the data in *JSON* format and returns it. The Server receives the data and sends the *HTTP Responses* to the Client.

The database created to support the new system, stores the data needed for the application in related tables through a specific key, in this case the episode number. In order to have the tables always filled with updated information, a cyclical mechanism based on MAS was implemented. The MAS is fundamental to the synchronization between the system Database and the different data sources regarding different HIS. Thus, agents were developed to query the different hospital databases, collect the data, process and transmit it and fill the new system database, repeating this process in certain periods of time. This process is essentially the Extract, Transform and Load (ETL) process, a type of data integration used to combine data from multiple sources. [14]

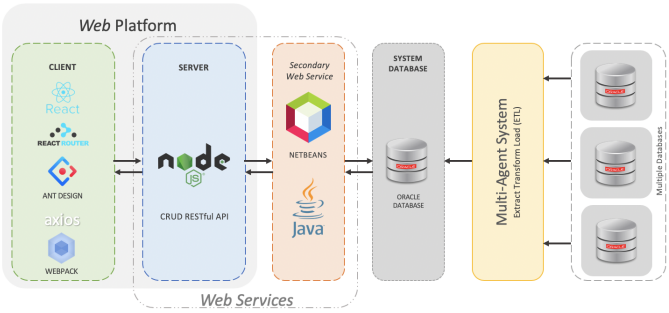

Fig. 2. Intelligent System to Support Inpatient Healthcare architecture and the technologies used.

4.2 MAS and Interoperability

The MAS plays a key role in updating the data and increasing interoperability between different information systems. That's because its agents work accordingly to collect and transform data from different data sources, loading the resultant data into the system database tables, allowing it to be permanently updated [13]. For this purpose, some agents were created, which sequentially execute their cycles.

The MAS process is initialized by Agent number 1, as shown in Figure 3, that performs the ETL process to the general episode information, such as bed, unit and patient identification. Also, this agent provides variables, such as patient episode and sequential numbers, used as parameters in the next agents.

Each next agent will sequentially perform its ETL process, inserting at last the information in the intended table.

The process, outlined in the Figure 3, is sequential, each agent runs sequentially and its actions are performed in a chain, eliminating the possibility to occur

a lock in the process and eliminating the possibility of its actions jeopardize the actions of the following.

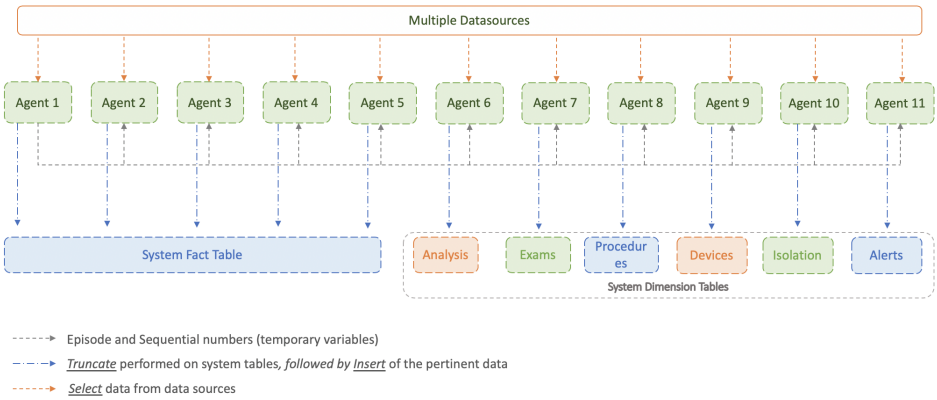

Fig. 3. Multi-Agent System schema developed and representation of tables created to support the intelligent system.

4.3 Web Application

The developed web application consists of a computerized internment board. This platform displays all the relevant information referent to patients admitted at a given moment in one of the CHUP health units. Figure 4 shows the resultant hospitalization chart of the Surgery health unit and it's possible to verify the different information represented by graphic elements, namely icons, which allows to gather a large number of information in a small space, still allowing its interpretation.

Fig. 4. Web application presenting the inpatient board of the Surgery health unit.

5 Proof of Concept

A project developed must be evaluated before making it available to its target users. So the application was subjected to a proof of concept, through a SWOT analysis, in order to prove the viability and usability of the solution proposed in this project. A technology acceptance study using questionnaires was also developed.

The Strengths, Weaknesses, Opportunities and Treats (SWOT) analysis, as the name implies, is an analysis that evaluates the strengths (advantages and qualities), weaknesses (disadvantages that prevent a particular artifact from achieving its objectives), opportunities (conditions of the implementation environment that positively influence the success of the artifact), and threats (conditions of the implementation environment that may compromise or negatively influence the success of a given product). Strengths and Weaknesses correspond to factors internal to the developed artifact, while Opportunities and Threats relate to external factors [7].

The Table 1 presents the SWOT analysis performed on the product under study in this article.

Parameter	**Analysis**
Strengths	– Centralization and gathering of information dispersed in different HIS; – Appropriate and timely sharing of vital clinical information; – Provision of better information and evidence, thus increasing the quality of decision making; – Increased security and protection of data; – High usability, scalability and adaptability to various health units, multiple users and multiple devices.
Weaknesses	– The data obtained from the different information systems may be incorrect, due to its incorrect fulfillment by the professionals; – Synchronization of data is not immediate.
Opportunities	– Improvement of the quality and effectiveness of the services provided in the context of hospitalization; – Decrease in associated clinical errors; – Continuous increase of the interoperability of the HIS present in the health organization.
Treats	– Changes and failures in the structure of the databases that constitute the data source system may jeopardize the operation and purpose of the proposed system; – Low level of acceptance of professionals regarding a new technology, since the implementation of new technologies requires them to change their habits and to adapt to a new tool.

Table 1. SWOT Analysis

In order to understand the level of acceptance of health professionals regarding the use of the tool presented in this dissertation, a questionnaire was developed and interviews were conducted, following the methodology and con-

structs of TAM, a model that evaluates a number of factors that influence their decision to use, how to use and when to use this technology [15].

The questions evaluated were the follow:

1 Do you consider important to use new technologies to support health care?
1 How much do you attribute to the need for an interactive platform that replaces the manual completion tables in each service?
3 Do you think this table optimizes your search for patient information?
4 The application is user friendly and intuitive.
5 The clinical terms used are correct and are used appropriately.
6 The icons illustrating the various clinical conditions are appropriate and easy to interpret.
7 The information contained in the table is that necessary to the context of hospitalization.
8 Inpatient information is now easier to consult and is always up to date.
9 The application improves communication and assists daily actions in the health unit.
10 Overall rate the developed application.

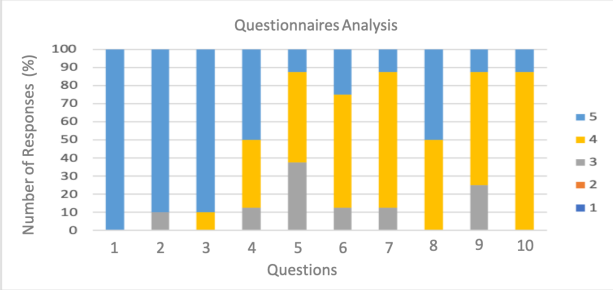

Fig. 5. Analysis of results obtained from questionnaires based on TAM.

The results obtained for the questionnaires are presented in the graph in Figure 5. These results are presented as a percentage and the answers are in accordance with the *Likert* scale, where number 5 represents a very positive degree in relation to the statement or question and number 1 represents a negative degree, while the rest are intermediate degrees. To date, it has only been possible to collect the responses from a small sample of the target audience, since the application, although already functional in the institution, is not yet inserted in the daily lives of professionals. Thus, the answers obtained were given by professionals who already had contact with the application during training.

6 Conclusions and Future Work

This project had as main initial motivations the existence of communication failures, among professionals and between the different shifts, the occurrence of clinical errors due to incorrect information or the complexity of access to

information. Also was motivated by the lack of interoperability among several HIS that contain inpatient relevant information and the lack of computer tools to support the practice of health care, specific to the context of hospitalization.

The main contribution of this application is the effective support to health professionals when providing health care, providing them with better real-time evidence for the accomplishment of their tasks and decisions, which results in the reduction of errors, better clinical outcomes, increased patient safety, reduced costs associated with clinical errors, and increased quality of care.

Also, the development of this project also improved the interoperability of the CHUP HIS, as it opened the door for the transmission and grouping of information crucial to the treatment of patients, which until now were stored in isolated IS, which makes access to this information harder.

As future work can be pointed out the need to insert a new functionality to normalize the exchange of information from shift to shift. Thus, it is intended to develop a module in the application where professionals can fill in the specific information regarding the episode of hospitalization, noting throughout the day the tasks performed, the tasks to be done and filling in more detailed observations. Thus obtaining a complete daily report of the patient's condition, presenting in detail examinations, analyzes, diagnoses and care, thus facilitating shift handovers. It is also intended to develop different profiles depending on the different types of health professionals. And finally, the implementation of sockets is also intended, which allows immediate synchronization.

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