Usability Requirements for Improving the Infection Module of a Hospital Intensive Care Unit Information System

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Abstract. The Intensive Care Unit (ICU) of Hospitals deals with patients in life critical conditions. The Intensive Care Information System (ICS) can therefore provide extremely important information to support medical doctors' (MDs) decisions. For instance, it is critical to manage well information about the evolution of a large amount of infections over time, about the antibiotics administered to each patient, and the impact on his/her life condition. Good quality information and interaction in such an extreme environment is therefore critical for helping MDs target well medicines to patients. This paper describes the initial stages of a project aiming at improving a real ICS, in particular from the interaction point of view, taking into account the stringent usability requirements from the MDs. Through a validated low definition prototype of the infection module of ICS, the paper proposes innovative active ways of providing suggestions to MDs on what actions to take.

Keywords: Human Computer Interaction, Requirements Engineering, Medical Information Systems.

1 Introduction

The Intensive Care Information System (ICS) used in four major hospitals in the North of Portugal is called *intensive.care*. It is being developed at the Biostatistics and Medical Informatics Service (SBIM) in the Medicine School of Universidade do Porto (FMUP) [1].

ICS' main functions are to register patients' admission and discharge notes, to register electronic clinical data such as patients' antecedents, diary, therapy data, procedures, diagnosis, complications and infection management, and to calculate ICU prognostic scoring indicators (see Fig. 1). These scoring techniques are used to obtain quantitative statements about the patients' health condition. They include APACHE II

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(Acute Physiology and Chronic Health Evaluation System), SAPS II (Simplified Acute Physiology Score), SOFA (Sequential Organ Failure Assessment) and TISS-28 (Therapeutic Intervention Scoring System-28) [2]. TISS-28 is registered by Nurses, while all other indicators are registered by MDs.

Intensive.care is composed of several modules, which vary in complexity as there are some basic ones, such as the patients' admission and discharge notes, and others that are more complex, such as the infection or complications management.

Intensive.care works with large amounts of data and amongst its stakeholders are the ICU patients, people that are in a very critical health condition, and the ICU MDs for whom time is extremely valuable. So there is the need for very high quality data, good system performance and lack of errors.

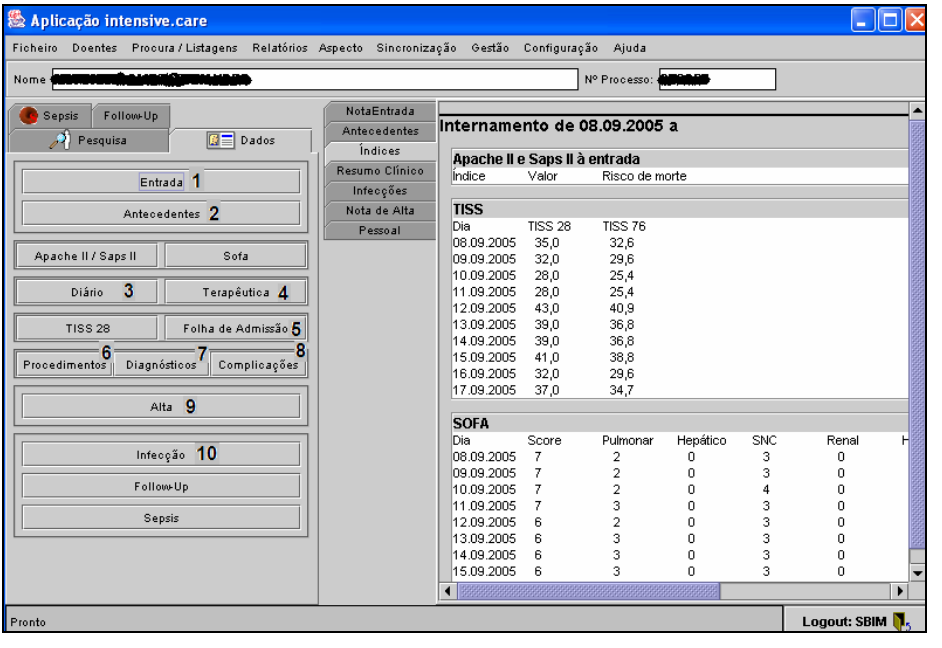

Fig. 1. Starting menu of *intensive.care* (on the left) where users can navigate through the existing modules (1 – admission; 2 – antecedents; 3 – diary; 4 – therapeutics; 5 admission chart; 6 – procedures; 7 – diagnosis; 8 – complications; 9 – release; 10 – infection). On the right there is an overview of prognostic scoring indicators' evolution for a patient, selected by the *Índices* option (central tabs).

Every hospital in Portugal has a central information system that manages patients' information. This system is called SONHO. *Intensive.care* connects to SONHO, automatically getting the patients' demographic data and storing it in the local patient record (whenever the person is already known in the hospital central system). Since every single public hospital in Portugal uses SONHO, *intensive.care* is prepared to easily being introduced into a new ICU, requiring nevertheless some customization.

Intensive.care has never had a Human Computer Interaction (HCI) development plan and has not been developed having usability as a main concern. Its development has always been focused on its functionality rather than its HCI characteristics. Therefore *intensive.care* has some notorious HCI problems and its users feel there are many things about it that could be improved. Moreover, there are some modules of *intensive.care* that have never been used, in particular because of their HCI problems.

Meetings with several *intensive.care* users, reported in the next sections, indicate that it is a successful application, but still with several problems. The current study has identified the modules that most need improvements and aims at defining overall requirements. Since there is an intention of implementing *intensive.care* in other ICUs, usability problems need to be addressed, so a formal HCI evaluation is being conducted in order to propose an improvement plan for *intensive.care*. This improvement plan will produce a document containing a set of usability requirements for the evolution of *intensive.care*.

Currently *intensive.care* is implemented in four hospitals in Portugal, but these units have started using it at different times. Since *intensive.care* has been gradually implemented in different units, it has different kinds of users when it comes to their experience with the application. The users range from those who have three years experience to those who have been using *intensive.care* for only a few months.

The next section presents the methodology of the overall study. Section 3 presents the preliminary results of the interviews with key stakeholders, which led to the choice of the infection module for a more focused HCI evaluation. In section 4 there is the definition of some requirements, supported by a prototype, for the improvement of the infection module. In the final sections there are the proposed future work and the conclusions.

2 Methodology

An HCI study and evaluation is being conducted in order to produce an HCI evolution plan for *intensive.care*. This evolution plan is based on a set of usability requirements that are being defined, based on the results from the application of well-known HCI techniques. At different stages of this evaluation, usability requirements will be specified and evaluated by *intensive.care*'s stakeholders.

The current project started with the study of the ICS tool and of the ICU information management problem. This was made to gain some knowledge about the system and the way it interacts with users' needs. There were some meetings with the development team, including the current project manager and the first project manager of *intensive.care*.

Several interviews were held with users, which can be divided into two sets. The first set was composed by three interviews to key users of *intensive.care* in three different hospitals. These interviews were intended to collect information about the most problematic issues about *intensive.care*. The main objective was to find areas from *intensive.care* that most users felt should be improved, and after that to focus the study in those areas.

After compiling the results of the interviews, there was a qualitative study that resulted in the establishment of the main module from *intensive.care* where the HCI evaluation would be centred. The focus for the evolution was set to be the infection module, as will be seen on section 3.

When the focus area was established, the second set of interviews took place. They happened in two hospitals with experts in infection in ICU. Since the evaluators have no medical background, these interviews aimed to understand the basis of infection, its implications and its management. Knowing work methods are not the same in every hospital, it seemed important to hear what MDs from two different hospitals had to say about infection itself and their needs for an infection module in their ICU software.

One of the hospitals where MDs were interviewed has *intensive.care* installed, so they are experienced with *intensive.care*. The other interviewed MD does not work with *intensive.care* at all, as it is not installed at his hospital. Since the current expectations about the improvement of the infection module are that it will suit every MD that deals with infection, it is important to elicit requirements from different MDs, even those who are used to working with other applications and not *intensive.care*. Only this way can a proposal be reached that will suit all users.

Intensive.care's users are mainly MDs and it is very difficult to elicit requirements from them, as they have such tight and unpredictable schedules. This happens because they work at ICUs and deal with critically ill patients that might need attention at any time [3].

Previous to the field observation, there was a quick visit to two ICUs in two different hospitals. This was intended to provide an overview of the environment and the existing machines in such units. Later, there was some field observations intended to understand the users' real difficulties with *intensive.care* in general and with the infection module in particular. As most of the times users do not really know what they want or even what they think about an interface, observing them is one of the best ways of finding that out [4]. "Data about people's actual behaviour should have precedence over people's claims of what they think they do" [5].

A prototype was used to create the first proposal for the evolution of the infection module. Since this is a preliminary requirements specification stage, a low-fidelity prototype was used, as these prototypes are cheap, simple and quick to create and modify [4], [6]. This prototype was evaluated and validated by some stakeholders, including two of the previously interviewed MDs who are experts in infection, and by several other MDs specialized in Intensive Care.

3 Analysis of Stakeholders' Preliminary Interviews' Results

After understanding the overall *intensive.care* current characteristics, including functionality and architecture, the study concentrated on understanding the evolution requirements of the main user stakeholders.

The interviews were semi-structured, having only few questions intended to obtain an overview of the current usage of *intensive.care* and its users' satisfaction [7]. The questions were:

1. For how long have you been using *intensive.care*?
2. What are its most important modules?
3. What are the most problematic modules?
4. What modules would you like to see improved?
5. What modules are never used and why?
6. What are your favourite modules?
7. Have you got any knowledge of or experience with similar systems?
8. Have you got any suggestion?

The interviewed users are MDs specialized in intensive care, with many years of experience in ICUs, who are the key users of *intensive.care* in their unit. They are also ICU managers, so they manage all the MDs in their unit and they have inside knowledge about their real usage of *intensive.care*.

One of the interviewed users has been using *intensive.care* since its beginning and is the main consultant for its further development. She works with it everyday and started using it even before every single patient's data in her ICU started being registered in *intensive.care*, which happened in January 2003. One of the other interviewed users has been using *intensive.care* since November 2003 and the remaining one since May 2005.

It is very interesting to have available users that have such different degrees of experience with *intensive.care*. More experienced users are expected to have more ideas of how *intensive.care* can evolve, because they have been using the system daily for a few years and have had the time to explore all of its potential. On the other hand, more recent users are expected to have a different perspective about *intensive.care*. This happens because as they have been using it only for a few months, they probably have only explored its basic functionality. Besides, their memory is fresher to remember their initial contact with the system and the difficulties they felt when first using it.

It is also interesting to have users from different ICUs because these units do not all have the same work methods. Given that, these users' usage of *intensive.care* is not exactly equal from an ICU to another.

After this first set of interviews, there were some coinciding responses about parts of *intensive.care* that should be improved.

In a general way its users enjoy working with *intensive.care* and feel the application eases their everyday work. Most ICU tasks are covered by *intensive.care*'s functionality set. But when it comes to the more complex tasks, such as infection and complications, users have some resistance in switching from the traditional paper reports to the electronic version presented in *intensive.care*. This happens both for cultural reasons and because of the difficulty for the development team to map the procedures in *intensive.care* exactly as they are made on paper. Also, for some of the most complex tasks there is the need for adjustment in work methods, in order to make *intensive.care* a simple and standard system.

Table 1. Overview of *intensive.care*'s modules usage in each hospital where *intensive.care* is installed. The check sign means the module is used in the respective hospital. The cross sign means the module is never used in the respective hospital.

	H1	H2	H3
Module 1 **Entrance, Admission, Antecedents and Release**	✓	✓	✓
Module 2 **Diary and Therapeutics**	✓	✓	✗
Module 3 **Prognostic Score Indicators**	✓	✓	✓
Module 4 **Procedures**	✓	✓	✗
Module 5 **Diagnosis**	✓	✓	✗
Module 6 **Complications**	✗	✗	✗
Module 7 **Infection**	✓	✗	✗

Table 1 reflects an overview of the usage of *intensive.care*'s modules in each of the three analysed ICU hospitals. We'll call these hospitals H1, H2 and H3. *intensive.care*'s modules are grouped here into modules, 1 to 7.

Patients' entrance, admission and release data, and prognostic scoring indicators are referred to as being easy to register, navigate and use.

When it comes to more intricate tasks, such as registering and managing of infections, complications, diagnosis, procedures and surgery, the users feel *intensive.care* does not provide the best solution, as these tasks are difficult to use in the system.

In a general way, most of the previously referred to complex tasks are registered in *intensive.care*, that is, users find these tasks should be improved, but still use them. When it comes to infection and complications, things change. The infection module is being used in only one of the hospitals, the one that has been using *intensive.care* for the longest time. The complications are not being registered in any other ICU. In all cases, users believe these modules are important and should be improved because they are difficult to use. One of the users who do not register infection data in *intensive.care* said, in the interview, that the infection process is complex and that in his opinion, in *intensive.care* it is particularly difficult to use.

When questioned about their favourite parts of *intensive.care* users referred to the prognostic scoring indicators functionality (see Fig. 2) and the interaction with SONHO. The prognostic scoring indicators functionality is said to be very easy and intuitive to use. It is also said to provide very useful information, as it gives a general perspective of the patients' health condition evolution since their arrival into the ICU. *intensive.care*'s interaction with SONHO is pointed out as being very helpful because when a new patient arrives into the ICU his demographic data is automatically imported from SONHO, which saves a lot of time and guarantees the integrity of this data.

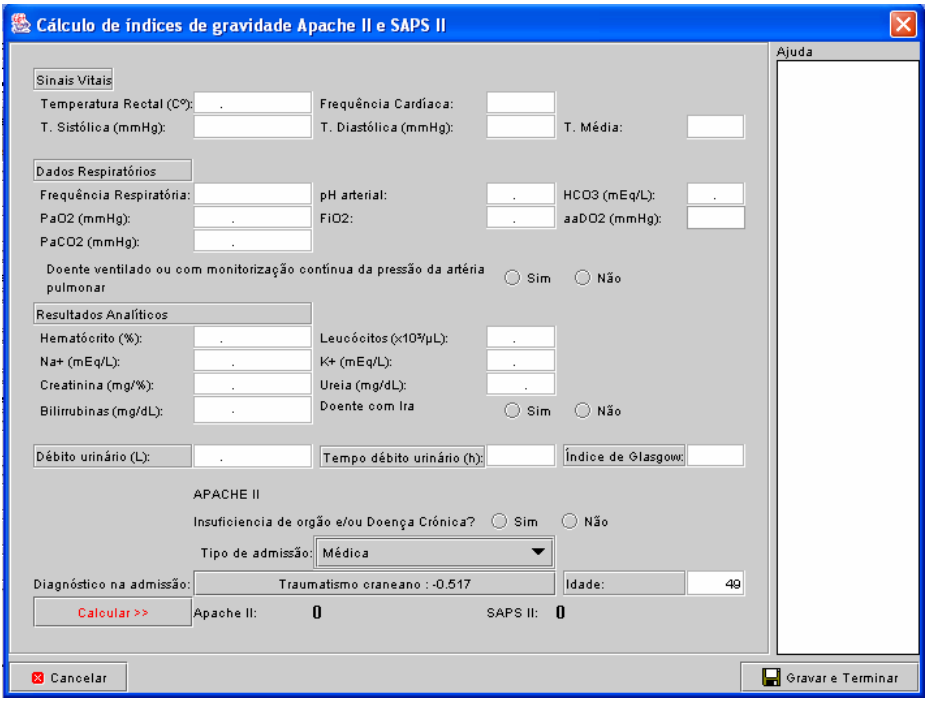

Fig. 2. The APACHE II /SAPS II prognostic scoring indicators module

From this preliminary analysis, we can gather that the usability requirements to be specified will cover some different areas of interaction.

Requirements related to the usability of *intensive.care*'s modules are being specified, as some ICU tasks are difficult to perform in *intensive.care*, and therefore do not have the acceptance they could have otherwise.

Requirements related to mobility might, too, be specified, as usually there are only two computer terminals with *intensive.care* in each ICU and a terminal in each MD's office. It might be interesting to have a mobility study to determine whether it would be reasonable to have mobile devices to register patients' data.

From the first set of interviews, a study focus was established. Due to its importance to the ICUs and its complexity, the infection module was selected to be the object of the current HCI evaluation. This is a complex module as infection is not a simple matter in intensive care. On the contrary, it is one of the main and more complicated issues in ICUs.

4 User Interface Requirements from the ICU for the New Infection Module

As referred to on the previous section, a study focus for this HCI evaluation was settled and the infection module was chosen to be the main object of study.

There were two interviews with MDs who are experts in infection in ICU, with the objective of gaining some knowledge about the basis of infection and its implications in patients. Also there was the need to elicit requirements for the new infection module.

Microbes in ICUs are extremely resistant to antibiotics, which happens because they have survived the previously applied antibiotics, have become immune to them and genetically started spreading ways to become immune to other microbes [8], [9]. To make things even harder, antibiotic consumption in an ICU is about ten times greater than in other hospital units, which contributes to microbe strengthening [10].

Nosocomial infections are those which are caused by hospital microbes or are a result of hospital procedures, such as patients' intubation or catheters. They are a main problem in an ICU, as they are one of the major death causes and one of the main sources of complications in patients in ICUs [8], [9].

Nosocomial infection rates are a clinical indicator of quality of care [11]. Results from hospitals with effective programmes for nosocomial infection surveillance and control indicate that infection rates can be reduced by about 32% [12], [13].

Death risk in patients in ICUs is much higher than in other hospital units, because these patients are extremely sick. ICUs' MDs frequently struggle to keep patients alive. Helping them achieving this objective should be a main concern of an ICU Information System. Not only should such a system help MDs to register data, it should also provide them with knowledge about everything that happens with their patients. Only that way could a control and surveillance programme be implemented in an ICU.

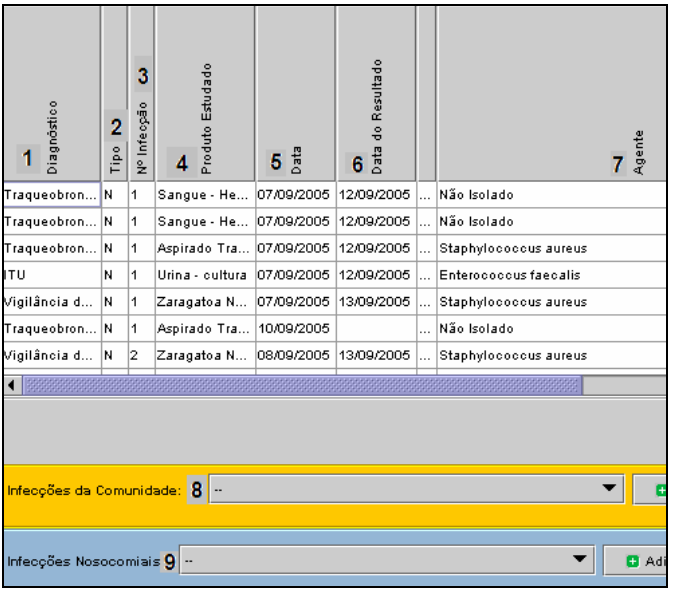

Fig. 3. Partial screen from the infection module in *intensive.care* (1 – diagnosis; 2 – type of infection: N for nosocomial or C for community-acquired; 3 – number of infection; 4 – analysed product: blood, urine, etc.; 5 – exam date; 6 – results date; 7 – microbe; 8 – community-acquired infections; 9 – nosocomial infections)

Intensive.care has an infection module that is being used in only one of the four hospitals that currently use the ICS tool (see Fig. 3). Users find it difficult and time-costly to use, so they prefer to use paper to register infection data. Taking into account what has been said before, this seems like an issue that needs to be addressed immediately, so a preliminary version of interaction requirements for this module was created.

A brief summary of the specified requirements will be presented next. A scale was used to classify each requirement. This scale is composed of three alphabetic values, L – Low, M – Medium and H – High, that will characterize each requirement in terms of its importance and its difficulty of implementation.

Table 2. Overview of the specified HCI requirements for the infection module

ID	Requirement	Imp.	Dif.
1	**Classification of microbes** – microbes should be classified according to their alert level, using colour coding; red for the ones defined as being the most problematic, orange for the ones defined as having an average alert level and green for those which are easy to control.	H	L
2	**Overview of the ICU** – a map of the ICU should be represented with colour coding for each bed, indicating alert levels according to patients' microbes.	H	M
3	**View of patients' in-days[1] in ICU** – there should be a graphical way to quickly identify the number of days each patient has been in the ICU.	H	L
4	**View of each patient's infections, harvested products[2] and antibiotics.**	H	H
5	**View of microbes' sensitivity** – for each isolated microbe in a patient's organism, there should be a list of the antibiotics that the microbe is sensitive and resistant to.	H	L
6	**Registering of product harvest** – each time there is a harvest of a product in a patient, it should be registered in *intensive.care* and automatically sent to the analysis laboratory; the id of the analysis should be stored in *intensive.care*.	H	H
7	**Registering of exam results** – for each harvested product there should be an exam result that should, automatically, be retrieved from the exams laboratories applications and inserted in *intensive.care*.	H	H

To evaluate and validate these requirements, a low-fidelity prototype was created in Microsoft PowerPoint (see Fig. 4) [6]. This prototype was analysed by some stakeholders, including two MDs who are experts in infection in ICU. After this evaluation, some changes were made to the initial prototype, so that it became much approximate to what users really need.

[1] In-days in the ICU are days patients remain hospitalized at the ICU.
[2] E.g.: blood, urine, gastric juice.

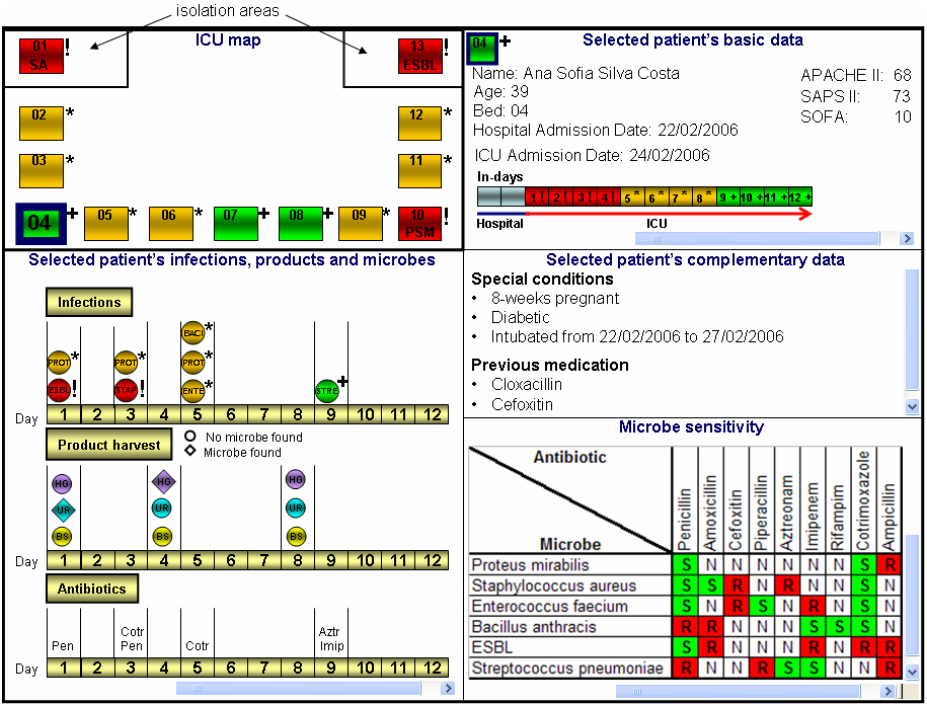

Fig. 4. Low-fidelity prototype for the patient screen of the new infection module. (**!** Represents the red colour; ***** represents orange and **+** represents green).

The use of colour provides a fundamental visual aid, so this prototype is based on colour-coding for quick identification of different situations. For the purpose of this paper, additional signs have been added to the prototype, because when printed in black and white, some colours are too similar to be distinguished one from another.

On the upper left part of the prototype (Fig. 4) there is a schematic drawing of the ICU. Beds are displayed as they are located in the real ICU, they have a number (the bed number) and a colour coding – red (!), orange (*) or green (+). If a bed is painted red it means the patient standing in it has an infection by a very hard to control microbe and might demand isolation and/or particular care. If a bed is orange, the infection is easier to control but still problematic. If it is green, then the patient has no infection, or has an infection by a microbe that is easy to control. Each bed is clickable to switch from a patient to another on this screen, as every other parts of the screen are related to the chosen patient. According to the ICU MDs, it is very important to have this global perspective of the unit, as patients' location is many times switched as determined by the alert levels.

All other parts of this screen are related to the chosen patient. The upper right part has patient's basic data as his/her name, age, admission dates in the hospital and in the ICU and the latest measure of the prognostic scoring indicators (APACHE II, SAPS II and SOFA). There is also a graphical view of the in-days, with in-days in the hospital

not accounted and marked in light-blue. In this axis the evolution of the alert levels in the patient is represented with the same colours as explained before.

On the lower left part of the screen is a graphical view of three fundamental issues in infection in the ICU – infection, product harvest and antibiotics. The in-days are represented in the same way as explained before and for each day there might be the diagnosis of an infection by a microbe, product harvests, such as haemoglobin or bronchial secretions and the administration of antibiotics. Microbes, products and antibiotics are easily identifiable by abbreviations.

In the infections representation, microbes found are characterized by a colour, which is related to their alert level. Every time a new microbe is found, there is a new entry in the respective day.

The harvested products are represented by an abbreviation and a colour coding. Each product has a different colour code and is examined by the respective laboratory. The result of this exam might be a microbe isolation or a negative result. Many times – up to 60% of the times, even though the patient is infected, the results are negative, as microbes do not always survive through the complete product analysis process. In this prototype, if a microbe is isolated, the representation of the product becomes a rhombus; if not, it remains a circle. This way, by just looking at the screen, infected products are immediately identified.

This circles and rhombuses that represent infections and products are clickable for details, as are the days and the buttons tagged “Infections”, “Product harvest” and “Antibiotics”.

The last quadrant is split in two parts. The top is composed by the patient’s complementary data, such as special conditions and previous medication, which is fundamental information for the MDs when choosing the antibiotics for each patient.

In the bottom there is the patient’s microbes’ sensitivity to antibiotics. This is represented by a grid, so the optimal combination of antibiotics can be chosen. Microbes are represented on the bottom left and antibiotics on the top. When crossing a microbe with an antibiotic, there is always a result: N – neutral, S – sensitive or R – resistant.

Whenever all the information in a part of the interface does not fit the screen, scrollbars are provided. In most of the cases they will not be necessary as usually patients stay in the ICU for about a week [9], and for that case, the window space is typically sufficient.

This prototype aims to provide a wider perspective of the ICU’s current status and each patient’s overview in terms of infection.

When a patient first arrives at an ICU he/she might have some infection symptoms and need to be immediately medicated, or else he/she might die. Even though several products are harvested and sent to the analysis laboratories, results from these analysis are never immediate and most of the times, they take a few days to arrive. So, MDs need to make a decision on which antibiotics to administer, based on some information about the patient and their own experience in ICU infection. This decision is based on several issues such as patient’s background, previously taken antibiotics and symptoms, amongst many others.

A system like *intensive.care* should help MDs in their decision making, by not only showing them all the variables that should be thought about, but also having algorithms that could evaluate situations and provide advice about possible decisions.

This prototype is based on the display and introduction of information about the ICU and its patients. In the future there will also be a decision support system, which will help MDs on their decisions, based on the patients' variables and some artificial reasoning, which takes into account previous cases.

This addition is expected to reduce the amount of time MDs spend analysing all the variables about a single patient, by displaying patients' variables in a user-friendly way and making suggestions on the combination of antibiotics that should or could be administered to that patient. Wishfully it will help MDs save lives.

5 Future Work

Next, in this study, there will be an iteration over the current low-fidelity prototype, based on the inputs from several stakeholders. These stakeholders are both from the development team and from *intensive.care*'s users. Several MDs have evaluated and validated the prototype and gave their inputs for its improvement.

Afterwards a focus group will be conducted, that will gather several MDs from different ICUs. The results of this focus group are expected to be one of the most important contributors to the final requirements specification for the evolution of *intensive.care*, in particular in what concerns interaction. Joining together a group of MDs for a focus group might be problematic because of constraints such as medical emergencies or different work schedules [3]. However, such a brainstorming meeting is expected to collect much valuable information about *intensive.care*'s usability problems (and other problems), since MDs are experienced users and their debate of its problems might bring up some new important issues.

In the final stage of the evaluation, a high-fidelity prototype will be constructed to support the requirements specification and validation by *intensive.care*'s main stakeholders. This prototype will be functional and very similar to the new infection module final interface. Since it is such a complete and interactive prototype, users may evaluate and validate it more easily, as they can interact with it and simulate real actions [6], [4].

6 Conclusions

Intensive.care is a product that meets the majority of the ICU needs, but still has some unresolved usability problems that need to be addressed. There is a clear objective from SBIM to expand *intensive.care* to other ICUs in Portugal, but HCI problems need to be eliminated first.

One of the most problematic modules of *intensive.care* is the infection module, as it is hardly ever used, mainly due to its usability problems. Infections in ICU are a very serious problem because patients are critically ill and are prone to dying from several infections. MDs need to be fully supported by an ICS to be able to save more lives, by taking appropriate decisions on medicines and other treatments.

An easy to use infection module will aid MDs on their everyday tasks, by reducing the amount of time they spend in registering and analysing infection data, and

providing them with advice on which decisions they could take when choosing antibiotics and other treatments.

Since *intensive.care* works in such an extreme environment, which deals with life and death in a daily basis, it is imperative that it provides good quality data and interaction, which will be the basis for all the decision support algorithms that might save lives. MDs need to be fully comfortable and confident while working with the system, so they can take full advantage of it.

The specification of HCI requirements and creation of prototypes based on these requirements is essential for user validation. At the end of this project a new infection module will be proposed to substitute the existing one. It is expected to be well accepted by *intensive.care*'s users, as it is being built with their help, based on their real needs. In the end, *intensive.care* will be a much more effective and pleasant application to work with, and therefore, a much more successful product.

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