User Centred Evaluation, Requirements and Prototyping

application to the design of an infection module in a Critical Medicine information system

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Resumo

As Unidades de Cuidados Intensivos (UCIs) hospitalares lidam com pacientes que se encontram em condições de saúde muito graves e em muitos casos, em risco de vida. O ambiente das UCIs é favorável à propagação de agentes infecciosos que afectam os pacientes internados. Como tal, é muito importante monitorizar e gerir a informação relativa às infecções nas UCIs.

Diversos sistemas estão a ser desenvolvidos para tentar resolver este problema. Em Portugal, o sistema *intensive.care* tem sido usado em vários hospitais e contém um módulo de infecção simples, que é usado para registar e gerir informação sobre pacientes e infecções.

Esta tese dedica-se ao problema do melhoramento do módulo de gestão de infecção em UCIs, particularmente no que se refere à proposta de requisitos para um módulo avançado, focado nas necessidades de Interacção Pessoa-Computador dos *stakeholders*-chave, tais como os *intensivistas* (médicos especializados na UCI) e os investigadores.

Uma nova interface gráfica e requisitos para o módulo são propostos, após a passagem por várias fases iterativas de desenvolvimento, e trabalhando sempre com a colaboração próxima de investigadores e médicos de cuidados intensivos.

Apesar de o módulo não ser operacional, espera-se que venha a melhorar a gestão de informação e que isso, em conjunto com uma interacção amigável possa fazer diferença na melhoria das taxas de sobrevivência nas UCIs.

Abstract

Intensive care units (ICUs) of hospitals deal with patients in critical life situations. The environment of ICUs is favourable to the spread of infectious agents that affect patients. It is therefore very important to monitor and manage all information regarding infections in ICUs.

Several systems are being developed to address this problem. In Portugal, the *intensive.care* system has been in use in several hospitals and offers a simple infection module to register and manage information on patients and infections.

This thesis addresses the problem of improving the infection management module for ICUs, in particular aiming at proposing the requirements for an advanced module, focusing on the user interaction needs of key stakeholders, such as ICU medical doctors and researchers.

A new graphical user interface and module requirements are proposed, after going through several iterative development phases in close work with intensive care medical staff and researchers. Although the module is not operational, it is expected that improved information management and friendly interaction could make the difference for improving the survival rates at ICUs.

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Acronyms and Abbreviations

ACSS	Administração Central do Sistema de Saúde (*Central Administration of the Health System*)
APACHE II	Acute Physiology and Chronic Health Evaluation System
CHVNG	Centro Hospitalar de Vila Nova de Gaia
ER	Emergency Room
FMUP	Faculdade de Medicina da Universidade do Porto (*Faculty of Medicine, University of Porto*)
HCI	Human-Computer Interaction
HIS	Health Information Systems
HPH	Hospital Pedro Hispano (Matosinhos)
HSJ	Hospital de São João (Porto)
HSS	Hospital de São Sebastião (Santa Maria da Feira)
ICInf	*Intensive.care*'s Infection Module
ICU	Intensive Care Unit
IGIF	Instituto de Gestão Informática e Financeira da Saúde (*Health Finance and Information Management Institute*)
MD	*Medicinae Doctor*
SAM	Sistema de Apoio ao Médico (*MD Supporting System*)
SAPS II	Simplified Acute Physiology Score
SBIM	Serviço de Bioestatística e Informática Médica (*Bioestatistics and Medical Informatics Service*)
SOFA	Sequential Organ Failure Assessment
SONHO	Sistema Integrado de Informação Hospitalar (*Integrated Hospital Information System*)
TISS-28	Therapeutic Intervention Scoring System-28
UR	Urgency Room

1 Introduction

1.1 Health Information Systems

Information is a fundamental tool for healthcare professionals. It allows them to acquire knowledge about their line of work, to learn from past experiences and to do research.

Decisions on which procedure to adopt or which medication to prescribe to a patient are decided, most of the times based on knowledge about the patient's former clinical history or similar clinical cases.

It is impossible to store information with reliable quality in other ways than computer-based systems. The traditional paper record, although popular among many MDs, causes serious delays in information analysis, and can never be as trustworthy as a computer-based system.

For investigation matters, health care professionals need to have information to work on. Most research cannot be done over empirical knowledge as it has to be based on substantiated facts.

Quality of care can only be assessed by the analysis of outcomes from clinical and administrative procedures within each hospital service or area (Sarmento and Lencastre, 2005). If each of these procedures is recorded in a reliable system, to analyse quality issues becomes an easy and quick task, as such systems can automatically provide structured information for further analysis.

Health Information Systems (HIS) can provide tools to easily manage and analyse large amounts of data in a reliable way. Having that, HIS are vital for the functioning of health units and to the development of knowledge among health care professionals.

Every health unit, such as, for instance, a hospital or a private clinic, has several information systems to handle clinical and administrative data.

Every hospital in Portugal has an Integrated HIS which is called SONHO (IGIF, 2005b). It manages patients' administrative and demographic information. It was developed by the former *Instituto de Gestão Informática e Financeira da Saúde* (IGIF), now called *Administração Central do Sistema de Saúde* (ACSS), which is a Portuguese governmental institution that manages finance and information issues in healthcare.

Also developed by IGIF and maintained by ACSS is a system intended to support the MDs in their daily tasks in the hospital, the MD's Support System – *Sistema de Apoio ao Médico* (SAM). Among these tasks are the prescription of medicines, clinical diaries and the display of various medical reports (IGIF, 2005a).

Intensive Care Units (ICUs) are a particular case in hospitals as due to the criticism of each of the patient's condition, they are continuously monitored and their vital signs constantly collected. This leads to the collection of enormous amounts of data that need to be stored and processed to provide valuable information to health professionals (Fretschner et al., 2001).

This increasing amount of data, along with the need to save human lives, led to the exponential increase of the use of critical care information systems in the past few years (de-Mul et al., 2004). "These systems provide medical and nursing staff with up-to-date patient data and have the potential to improve quality by reducing errors and supporting evidence-based medicine through their built-in guidelines and protocols" (de-Mul et al., 2004).

In an ICU, besides the administrative or clinical data registering information systems, there are numerous machines, such as equipment to deal with pain management, respiratory and cardiac support and patient monitoring (Senagore and Gale, 2004). These equipments control patients' health status and signal if something unexpected happens.

1.2 Human-Computer Interaction

Human-Computer Interaction (HCI) is a multidisciplinary discipline that is being developed and has been gaining importance over the last few years. This is mostly

due to the fact that at the present time almost everyone has some kind of contact with computers, unlike what happened in the early days of computing, when only skilled professionals knew how to operate a computer. Nowadays the range of knowledge and experience of the different people who use computers is very extensive. So, it is extremely important that interaction between people and computers is intuitive and clear (Preece et al., 1994).

HCI relates subjects such as computer science, psychology, design and ergonomics, among others, and aims at making user interfaces intuitive and easier to use (Preece et al., 2002, Preece et al., 1994).

HCI uses inspection, inquiry and testing techniques to study the interaction between people and computer systems and aims at improving the interaction process.

User interfaces have evolved very rapidly in the recent past and are becoming more and more visual (Rozanski and Haake, 2003). Not so many years ago, users worked in computers using command line instructions, not having colour monitors or the graphical windows' based interfaces. Nowadays it is almost unthinkable to have software without any kind of graphical interface. User interaction with computers is so important it has become a discipline.

Today, interfaces are composed of windows, icons, menus, pointers and buttons but it is expected that in the near future interfaces will become intelligent and be able to dynamically adapt themselves to the context and situation they're built in (Maybury, 2001).

Also, with the evolution in computers, communications, graphics and displays, amongst others, systems will become more and more integrated within the environment and "become much more intimately associated with their users' activities" (ACM-SIGCHI, 2005).

All these lead to the increasing need of having HCI in mind, while developing a software product.

For a product to be successful, its user acceptance is very important, so concern about users' interaction with it should be a main preoccupation for software developers.

1.3 Intensive Care Units

ICUs are the areas of a hospital where Critical Medicine is practised. They provide continuous care for critically ill patients, who can still benefit from treatment. Most patients in an ICU need artificial life support in order to survive.

There are different ICU types, depending on the kind of patients and patients' illness or injuries. The same hospital may have – and usually has – several ICUs. For instance, there might be a Neonatal ICU and a Paediatric ICU for infant patients, and Surgical ICU and Medical ICU for adults.

Patients arrive at the ICU from other services of the same hospital, from other hospitals or from the Emergency Room (ER). In the first two cases, they usually have been medicated in the previous hospital or service, and that must be taken into consideration when choosing the treatment to administer.

Patients in ICUs need to be constantly monitored, analysed and treated. They are admitted to the ICU usually whether they are neither too well nor too sick to benefit from intensive care (Senagore, 2004).

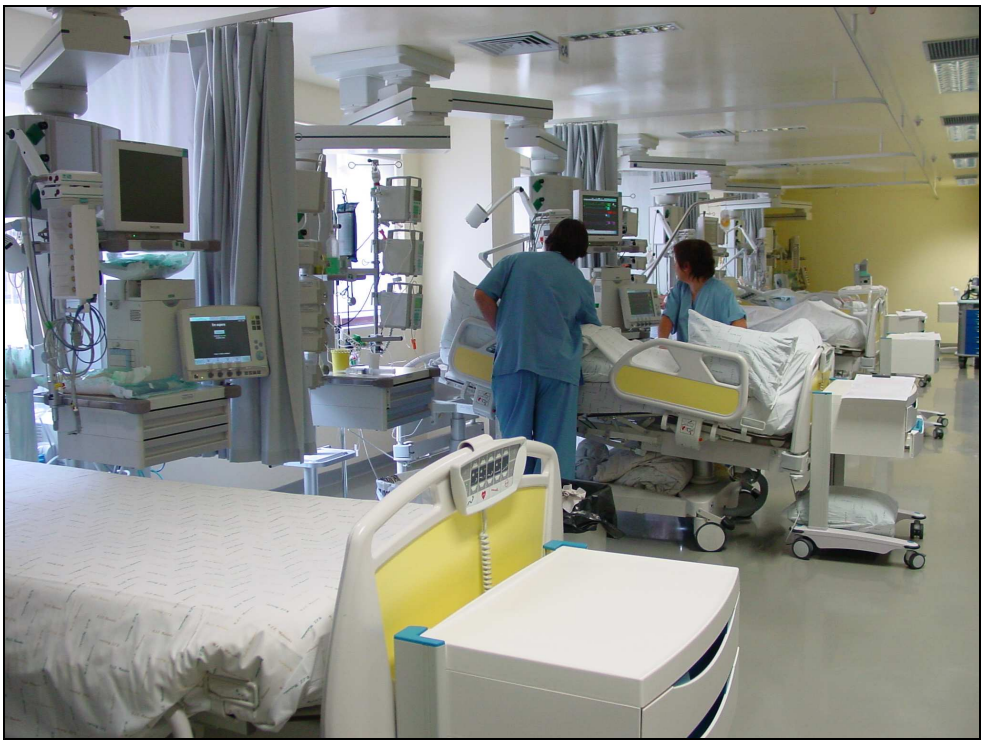


Figure 1 – Intensive Care Unit

Typically, each patient has several monitors attached to his or her body for real-time evaluation of medical stability. The attending Doctor of Medicine (MD) makes

periodic assessments of the patient's cardiac status, breathing rate, urinary output, and blood levels for nutritional and hormonal problems that may arise and require urgent attention or treatment. Most of the times, these patients have catheters placed to detect hemodynamic (blood pressure) changes, and/or require endo-tracheal intubation to help their breathing, with the breathing tube connected to a mechanical ventilator (Senagore, 2004).

Working in an ICU is a set of people who are specialized in different areas of healthcare. There must be, of course, *intensivists*, who are the MDs specialized in intensive care medicine, but also other specialists, such as respiratory care therapists, nurses, physiotherapists, anaesthesiologists, etc.

Since patients need continuous monitoring, beds in an ICU must be displayed in a way that guarantees that the people working there have a visual overview of all of the patients.

1.3.1 Infections

Infections are a major problem in hospitals and even a bigger one when it comes to ICUs. They are a main cause of complications and death. Infections are caused by the entrance of micro-organisms (or microbes) in a human body, causing inflammation and disease. These micro-organisms may be protozoa or fungi, but are mainly bacteria and viruses.

Micro-organisms in ICUs are extremely resistant to antibiotics. This happens because they have survived the previously applied antibiotics, have become immune to them and genetically started spreading ways to become immune to other micro-organisms (Sarmento and Lencastre, 2005).

To make things even harder, antibiotic consumption in an ICU is about ten times greater than in other hospital units, which contributes to micro-organism strengthening. “Hospital epidemics with multi-drug resistant organisms are a major issue, with individual ICUs having their own sensitivity patterns and epidemics with different micro-organisms” (Metha and Niederman, 2001).

1.3.2 Colonizations

Not all micro-organisms present in the human body are infecting it. In fact, the human body is filled with about 10^{14} bacteria which are its flora (Sarmento and Lencastre, 2005). This flora is colonizing the human body.

Colonization occurs when a body has a micro-organism, but has no clinical signs or symptoms of infection.

1.3.3 Nosocomial Infections

Nosocomial infections are those which are not present or incubating when a patient is admitted to a hospital. These infections may be endogenous or exogenous. They are endogenous if they are caused by micro-organisms that belong to the patient's own flora (Sim, 2007). If they are caused by hospital micro-organisms or are a result of hospital procedures or treatments, such as patients' intubation or catheters, which are used to diagnose or treat the patients' initial illness or injury, they are exogenous (Senagore and Gale, 2004, Sim, 2007).

These infections 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. They increase patients' morbidity and make their hospital stay longer, amplifying costs and mortality rates.

Even if a patient arrives without any infection to an ICU, he or she will, almost for sure, get an infection there. This happens because patients that need to be in an ICU are critically ill, which makes them much more vulnerable to being attacked by hospital micro-organisms (Sarmento and Lencastre, 2005, Carneiro, 2006).

Many vital hospital procedures create conditions for nosocomial infections to happen. For instance, if a patient needs to be intubated to get an artificial life support, he or she becomes much more vulnerable to an infection, because a foreign object is placed on his or her trachea. This object, a tube, becomes "a highway for micro-organisms to enter the human body" (Sarmento and Lencastre, 2005).

There are several strategies to control antibiotic resistance in an ICU, but they are sometimes expensive and difficult to enforce. These strategies include frequent hand washing (Saene et al., 2005), as "if all carers cleaned their hands effectively

before touching their patients, the problem of transmitting organisms would be minimal (Scott, 2000)".

The next presented experience (Table 1) was made in The University of Georgia College of Agricultural and Environment and shows the micro-organism differences between unwashed, washed and sanitized hands. The experiment was intended to assess bacteria in human hands in different washing stages, from unwashed to sanitized hands (Reynold, 2000).

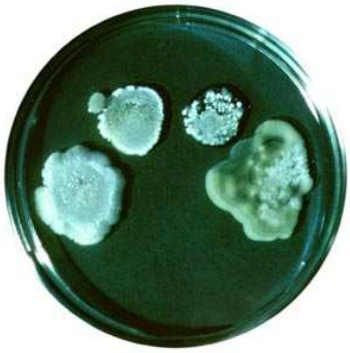
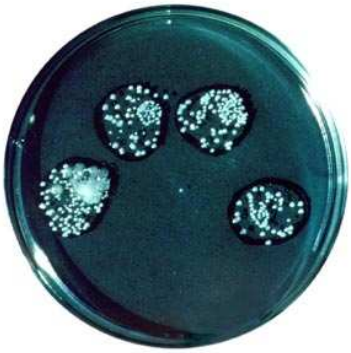
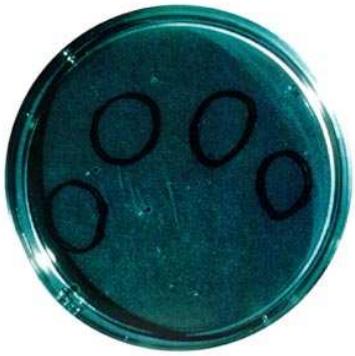
 **Figure 2 – Hand testing**	 **Figure 3 – Unwashed hands' bacteria**	 **Figure 4 – Rinsed hands' bacteria**
 **Figure 5 – Hands washed for 20 seconds' bacteria**	 **Figure 6 – Hands washed for 40 seconds' bacteria**	 **Figure 7 – Sanitized hands' bacteria**

Table 1 – Images from an experiment to assess bacteria in different human hand cleansing states (from http://pubs.caes.uga.edu/caespubs/pubcd/B693.htm)

The figures show the amount of micro-organisms in hands in different cleansing states.

The procedure for the experiment was having a person successively touching agar plates with his/her hands in different cleansing states. In the first stage hands were unwashed (Figure 3), then rinsed with cold water for 20 seconds (Figure 4).

Afterwards they were washed with cold water and soap for 20 seconds (Figure 5). Next the hands were washed with cold water and soap for an additional 20 seconds (Figure 6) and last, they were dipped in a sanitizing solution (Figure 7).

The plates were incubated at 37ºC for 24 hours and the results show the amount of bacteria living in unwashed hands and after different cleaning stages.

The way micro-organisms develop and reproduce themselves in unwashed hands is so clear, that it seems vital to find ways to encourage healthcare professionals working in ICUs to wash hands every time they touch a patient.

Other strategies to control antibiotic resistance in an ICU include "the use of gloves, gowns, facemasks and patient isolation with use of surveillance cultures" (Metha and Niederman, 2001).

1.4 *Intensive.care*

Intensive.care is an ICU Information System that is currently implemented in four hospitals in the North of Portugal. It is being developed and supported by the Biostatistics and Informatics Service of the Faculty of Medicine of the University of Porto – *Serviço de Bioestatística e Informática Médica* (SBIM) of *Faculdade de Medicina da Universidade do Porto* (FMUP).

The hospitals using *intensive.care* are *Hospital Pedro Hispano* (HPH), in Matosinhos, *Hospital de São João* (HSJ), in Porto, *Hospital de São Sebastião* (HSS), in Santa Maria da Feira and *Centro Hospitalar de Vila Nova de Gaia* (CHVNG), in Vila Nova de Gaia (Pereira and Fonseca, 2005). In HPH, *intensive.care* is registering data from two different ICUs.

The *intensive.care* system's 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. These scoring techniques are used to obtain quantitative statements about the patients' health condition. They include APACHE II (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) (Réanimation, 2002, Knaus et al., 1985). TISS-28 is registered by nurses, while

all other indicators are registered by MDs. APACHE II and SAPS II are calculated 24 hours after the patient's admission in the ICU. SOFA is calculated every in-day.

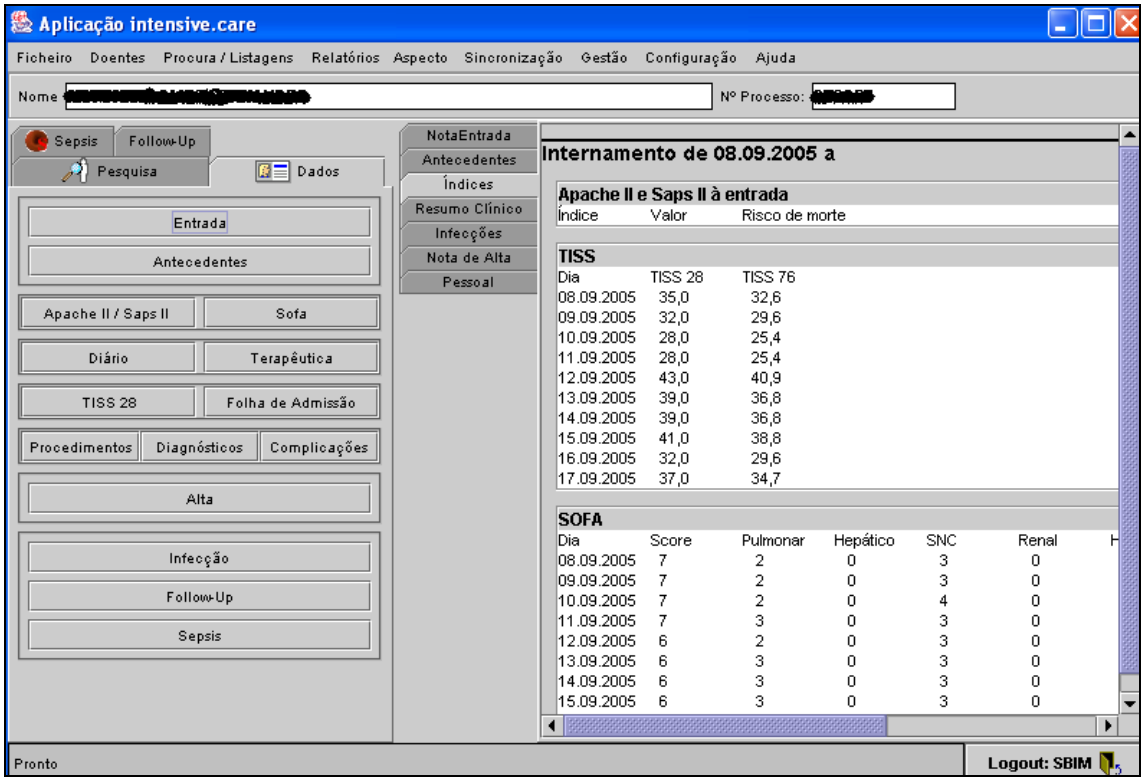


Figure 8 – Main window of *intensive.care*

Intensive.care has a set of modules. Some of the modules are basic and used to register essential ICU information, such as the patients' admission and discharge notes, and others are more complex, such as the infection or complications management.

It 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.

Intensive.care has never had an 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.

Intensive.care connects to SONHO (the integrated HIS referred to in 1.1), automatically retrieving the patients' data and storing it in the local patient record (whenever the patient is already registered in SONHO). 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.

It also uses input data from other hospital information systems, such as the ones used to register results from microbiological exams. Unlike the interaction with SONHO, data from other hospital systems need to be inserted manually in *intensive.care* by its users.

Intensive.care is developed in Java and uses an Oracle database. It is based on a three-tier structure, as it is intended to process large amounts of data. The intermediate tier is located in the server and permits the interaction between the Oracle database and the user interface. *Intensive.care* connects to SONHO through their Oracle databases (Figure 9).

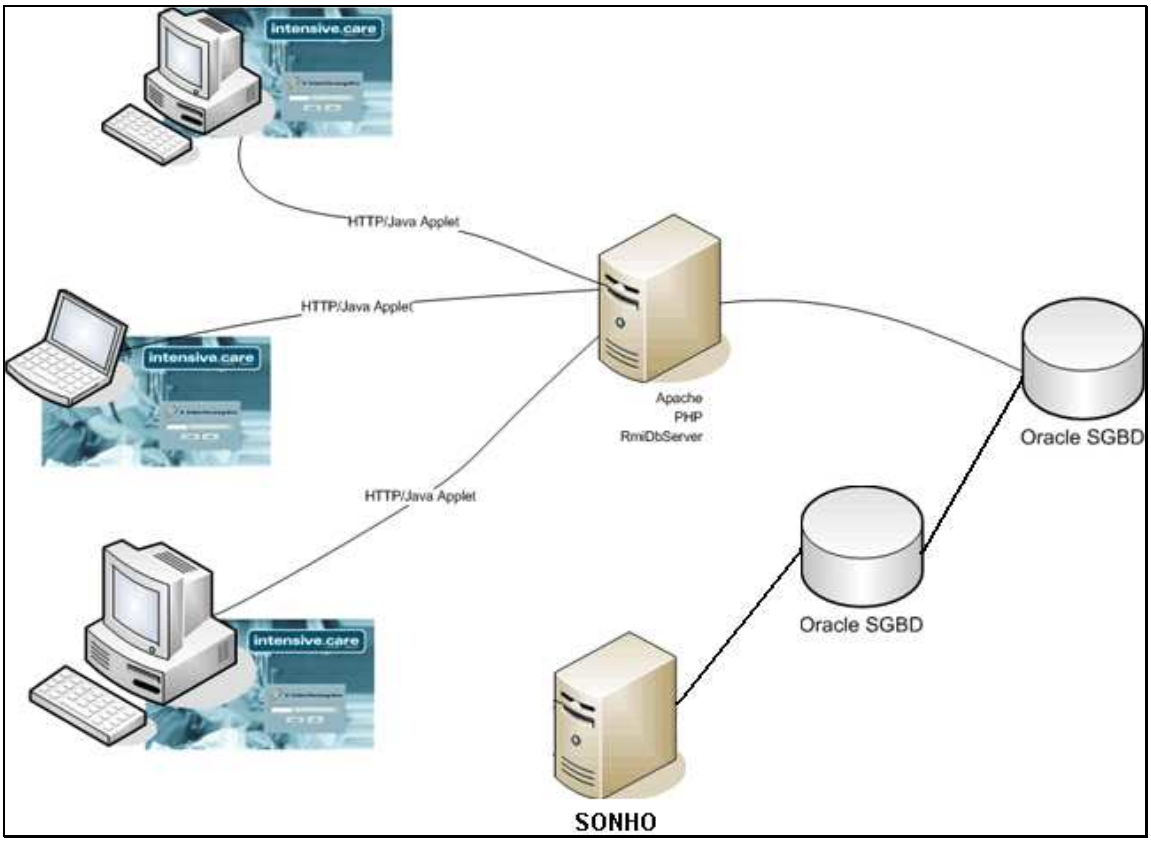


Figure 9 – Architecture of *intensive.care*

Meetings with several *intensive.care* users, reported in the next sections, indicate that it is a successful system, but still has several problems.

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 system.

1.5 Infection Module

Infection modules of ICUs are used to register all the available data and to provide information about infection. They can be used as a tool to register data that will be presented as valuable infection related information. This information can be used for many purposes, being the most common ones the medical research, the support of medical decisions and the quality control of ICU procedures.

Quality control of infections in an ICU can be done with the aid of infection modules. When all infection data is registered, it is relatively easy for these systems to yield information that relates nosocomial infections and hospital procedures. These systems may even find recurring patterns of nosocomial infections happening after specific procedures and help improving or changing those infection-enabling procedures.

Micro-organisms are not static through time. Some die and some evolve. When a micro-organism evolves, it gets stronger and stronger and controlling it becomes a major problem for MDs. These micro-organisms become immune to almost every solution (Sarmento and Lencastre, 2005, Carneiro, 2006). Many times MDs have to make empirical decisions on which antibiotic to apply to a patient – as if they waited three to four days for the analyses' results from the laboratory, the patient would die from the untreated unknown infection. This empirical choice of what antibiotic to prescribe to the patient is based both on the MDs experience in ICU and their knowledge of their ICU's micro-organisms (Sarmento and Lencastre, 2005).

So, infection modules can efficiently provide MDs with information about micro-organisms' evolution through time in a specific ICU.

Intensive.care has a module that registers and manages infection data, but it is not used as an interface for quick access to relevant information, because it is not prepared to do it.

In *intensive.care* the infection module is used to register data about collected biological products and all the analysis that occur after that action. Whenever a biological product is collected, it needs to be furthermore analysed by different service of the hospital and afterwards the results must be introduced in *intensive.care*. This works only as a registering tool, and only in one ICU.

1.6 Motivation

HIS are able to improve healthcare and sometimes help saving lives, which makes them a very important and motivating field of study.

Knowing that infection is one of the main causes of complications and death in ICUs, it is exceptionally important to register data about infections, in order to have a knowledge and control over micro-organisms based on real information, rather than empirical decisions.

Nosocomial infections are a healthcare field that still needs to be researched into and the addition of this thesis provides ways for studies to be made over this field.

MDs have the need for software that will help them to register data, have scientific studies about happenings in infections in the ICU and have a way to control the quality of intensive care procedures that might lead to infection (Sarmento and Lencastre, 2005, Carneiro, 2006).

Since infection is such an important matter in ICUs, all information that is registered is valuable and usable to perform scientific studies. But this information can only be used as long as it is structured and organized, in a way that it can be analysed. These studies are relevant in order to expand the current knowledge about the local ICU micro-organisms, their sensitivity and ways to fight them. Without them, microbe fighting is less accurate and mistakes can recurrently be made without being even noticed. As infection is such a major cause of death in ICUs, creating ways to help MDs control it is imperative.

Death risk in patients in ICUs is much higher than in other hospital units, because these patients are extremely vulnerable. 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 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.

Not having registered information that will show the need for these strategies, they are even more difficult to implement.

Nosocomial infection rates are a clinical indicator of quality of care (Appelgren et al., 2001). Results from hospitals with effective programmes for nosocomial infection surveillance and control indicate that infection rates can be reduced by about 32% (Haley et al., 1985, Misset et al., 2004). Thus, the infection module needs some functionality that will study procedures while using and not using control strategies. This might help to establish control policies, justified by quality control studies.

The main motivation for this thesis's work is to create an infection module that will be used by all MDs using *intensive.care*, helping to achieve higher quality in critical care and to diminish the above stated problems.

Also there is the will to increase the user acceptance of *intensive.care* and helping it to be introduced to new ICUs.

1.7 Objectives

This thesis objective is to have an HCI evaluation of the existing *intensive.care*'s infection module that will lead to the proposal of a new infection module, based on HCI guidelines and on *intensive.care*'s users' real needs.

For the proposal of the new infection module, there should be a complete set of specified and validated requirements and a prototype.

1.8 Contribution of this Thesis

As a result of this thesis's work, a new infection module for *intensive.care* is proposed – ICInf. This new module is defined by a prototype and a set of additional

requirements. This module is going to be implemented by *intensive.care*'s development team and integrated in *intensive.care*.

It is expected that after this new addition to *intensive.care* all of its users will start using the ICInf module to take even better care of the ICU patients. With the visual aid allowed by the new module, some decisions will be easier and quicker to make, which can improve the quality of care, with a positive impact in life conditions of patients at ICUs.

Also, as the new infection module will provide the MDs with visual aid about ICU patients and their micro-organisms, infections, collected biological products and administered antibiotics, it is expected that they will start using it as a basis for their scientific research.

The MDs who are responsible for an ICU can use the new infection module to quality control of their unit and to create surveillance control programmes.

Furthermore, SBIM's intentions to expand *intensive.care* to other hospital ICUs might be facilitated as the ICInf module may work as a preview of the future changes to other modules in *intensive.care*. As *intensive.care* was already a well accepted system, having an easy to use and visual infection module, may help to increase the use of intensive.care in other hospitals.

1.9 Thesis Organization

Until this point, an introduction to the whole thesis has been made, giving an overview about ICUs and nosocomial infections, health information systems and human-computer interaction, which are this thesis's main research areas. The first chapter also comprises a review of the studied system – *intensive.care*, ICUs' systems' infection modules, the contribution of the thesis's work and the motivation for this project.

The remainder of the thesis explains how the project was developed, shows the obtained results and establishes some conclusions.

Chapter 2 focuses on the methodology used while developing this project. It gives an overview about the used techniques. These techniques' usage while working on this thesis is explained in later sections.

Chapter 3 explains the Intensive Care Infection Module case. It presents the current infection module, its functions and functionality, its users and the problems they find while using it. It also presents *intensive.care*'s stakeholders and the ICU environment, in which *intensive.care* is integrated. Afterwards it goes through the used methodology, explaining how it was used and the results obtained.

Chapters 4 and 5 contain the main results of this work: the proposed ICInf module prototype, its evaluation by MDs and stakeholders, and a summary of the corresponding requirements.

In chapter 4 the developed prototypes for ICInf are presented. There is an explanation of the low-fidelity prototypes' construction and their evaluation and validation. Afterwards the final prototype is presented. This is a Flash built prototype that includes some interaction. Its screens are shown and fully described. Chapter 5 describes the evaluation of the ICInf final prototype by a user and a stakeholder. It presents the evaluators' feedback on the prototype functionality and possible changes. In this chapter there is also an overview and explanation of the specified requirements, both for ICInf and for further improvements to ICInf. Requirements for the definition of ICInf were obtained by the application of the thesis methodology and by the initial evaluations of the low-fidelity prototypes. The requirements for ICInf's further improvement were elicited from the evaluations of the final prototype. The complete set of requirements for ICInf is presented later, in Appendix A.

In the final chapter there are the specific and general conclusions gathered from the project and the ideas for the future work.

2 Methodology and Process for Developing HCI Components of Health Information Systems

This chapter presents an overview of the methodology used throughout the development of this thesis. Each of the used techniques is explained in a sub-chapter. The way they were used while working on this project will be explained in later sections.

2.1 Interviews

Interviews are used in order to gather some quantitative information, but mostly, qualitative information. There are three kinds of interviews – structured, semi-structured and unstructured.

Structured interviews are based on a strict agenda and work more as an interrogation, where the interviewer sticks to the previously prepared outline and asks all the questions to the user.

Unstructured interviews are more like a conversation than an interrogation. The interviewer does not have a pre-prepared agenda and is interested in gathering the largest possible amount of information about the users' experience with the interface in question.

Semi-structured interviews have a combination of structured and unstructured interviews' characteristics, as they may have an agenda, but not a strict one. This agenda is more like a list of topics to be debated and the interview is more like a guided conversation through the topics in the list. Also the interviewed user may talk about issues that are not specifically in the topic list (Ghiglione and Matalon, 1997, Preece et al., 2002).

While interviewing a user one can use or not an audio recorder. There are some advantages and some disadvantages in recording the interviews. The main disadvantage is that interviewed people may feel constrained when talking to a recorder and may not say everything they would if the interview was not recorded. The main difficulty in not using an audio recorder is that the interviewer will spend most of the time looking at his or her notebook and may not be able to write down complete answers. Consequently he or she will cut some eventually important issues and may have the tendency to write down the issues they already know and leave out new information.

"A common aspect of both questionnaires and interviews is that one cannot necessarily trust all the users' answers." (Nielsen, 1993). This happens because many times users tend to answer what they think they ought to, instead of answering the true facts. "Response bias in favour of socially acceptable answers is more pronounced for interviews conducted in person and less pronounced for questionnaires administered by a computer where people seem to be less anxious to avoid embarrassment" (Nielsen, 1993).

Interviews are difficult to conduct because it is very easy to inadvertently bias the users' answers by asking the right questions, but with a wrong formulation.

2.2 Field Observation

Field Observation is a simple technique as it merely consists of visiting users and observing them while they execute their everyday work. While observing users, the observer must try to become as "invisible" as possible, in order not to interfere with the users' work. Notes can be taken during observation and even videotaping is possible, although the last one can interfere with the users' actions, as they may feel constrained.

Although being a simple method, field observation is a very important one, as it allows for the person conducting the study, to become aware of the users' real difficulties or even unexpected easiness with parts of the interface. And 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. "Data about people's actual behaviour should have precedence over people's claims of what they *think* they do" (Nielsen, 1993). As nothing is interfering with the user and he or she is in their own environment, that is, their everyday work place, there is a high probability that users will perform their tasks as they would normally perform them.

This technique's main difficulty is for the observer to be able not to influence the users in any way while they are being tested, so that results are accurate. In this particular case, users' levels of concentration in their work are expected to be very high and it may become easier for the observer to seem invisible.

2.3 Focus Groups

A Focus Group is a kind of group interview where three to nine users are involved. These users must be of the same type, that is, they all must use the system in the same way, so they can discuss the same issues.

The main advantage of this technique is that many questions arise from the group discussion, which would probably be missed with other techniques. There is an agenda for the meeting and the facilitator conducts the focus group so that every topic in the agenda is debated, quieter users give their opinions and more intervenient ones stop for a while and listen to others. Also, the facilitator should encourage the discussion of topics that may arise from the debate and that were not previously scheduled.

In this project, all users are MDs, so in order to gather about five of them in the same room for about two hours, it may be necessary to schedule the focus group to a late hour of the day or for the weekend. Also there is always the risk of losing one or more users during the focus group due to an emergency in their ICU.

2.4 Prototypes

"It is often said that users can't tell you what they want, but when they see something and get to use it, they soon know what they don't want" (Preece et al., 2002).

A prototype is a product representation that can be explored and interacted with. Prototypes do not all have the same level of completeness and complexity. They can vary from the simplest prototypes, such as paper or cardboard mock-ups, to complex and almost functional ones, such as almost completely functional systems.

Prototyping is a very useful technique because when using prototypes it is easier to have a closest idea to what the interface will look like and in what way users can interact with it.

Most of the common literature about prototypes refers the existence of two types of prototypes: low-fidelity and high-fidelity prototypes. Each of these types has both advantages and disadvantages associated with it (Preece et al., 2002, Rudd et al., 1996).

Low-fidelity prototypes are not very similar to the final interface they are representing. They are built with low-cost materials, such as paper or cardboard and are intended to be simple, quick and cheap to create and modify. They are very useful because they encourage new ideas and changes to the interface, due to their characteristics of being cheap and quick to change. They are only intended to give a general perspective of what the interface will look like, the amount and kind of information displayed and the way the users can interact with it. There can be some iteration between the first low-fidelity prototype to be created and the last one, because when stakeholders interact with and evaluate them, new ideas and suggestions arise and new versions of the prototype might be created. The main disadvantages associated with this kind of prototyping are their low functionality and the impossibility of having user tests performed in them.

Unlike low-fidelity prototypes, high-fidelity prototypes are very similar to the final interface they represent. They are completely functional and allow user testing. The main difficulties in using these prototypes are that they are expensive and time-consuming to build and discourage changes because of the effort needed to make the changes.

Some authors, like Engelberg and Seffah, defend there are prototypes that are in a middle level between low and high fidelity, which are the mid-fidelity prototypes. These prototypes are relatively detailed and complete, but objects in them are represented in an approximate or schematic form and not a final one. This allows for quicker development of the prototypes, with ability to evaluate functionality, even if it is a simulated one (Engelberg and Seffah, 2002).

2.5 Requirements Elicitation, Specification and Validation

The development of a software system's requirements is believed, by many professionals, to be the most important part of the software engineering process. The specified requirements for the development of a software system ought to be "a complete, detailed, unambiguous description of what the system is supposed to do" (Leach, 1999).

Requirements can be elicited from various sources. They are the basis for the creation of systems and it is fundamental that they are specified as correctly as possible, so no delays and rearrangements are needed in the final developed solution. The success of developed products is dependent on effective requirements management (Leffingwell and Widrig, 2003).

Before starting the requirements elicitation, there should be a previous knowledge about the environment in which the system will be used, eventual constraints to the system's performance, the users and their objectives, capabilities and tasks, and the overall goals the organization the system is going to be integrated in has for the system (Leach, 1999, Preece et al., 2002).

Possible sources of requirements are users' needs, similar systems, systems that will interact with the developing system, constraints, etc.

Requirements can be elicited by the combination of several techniques, such as interviews, questionnaires, focus groups, field observations and the studying of documentation, such as manuals or legislation (Preece et al., 2002).

2.6 Evaluation

Evaluating interactive systems is fundamental to assess the systems' success and to know which directions to take when users do not approve of it. Without evaluation of a system, its developers can never be sure that it is usable or that it gives users what they want (Preece et al., 2002).

The evaluation of health information systems is not a simple thing to do, as health is such a complex study area. There are many variables that can difficult the whole evaluation process. For instance, health is not a predictable area, as it deals with people and peoples' illnesses and data from these people have many ethical and legal issues (Gosbee and Ritchie, 1997, Friedman and Wyatt, 1997). Examples of such issues are the need to maintain confidentiality about patients' clinical records and the concern on whether it is ethical to use patients' data for evaluations without patient's approval or knowledge (Friedman and Wyatt, 1997).

While evaluating HIS and due to the complexity described before, one needs to be careful not to subvert the evaluation results. When performing evaluations, useful data should be collected in order to make relevant decisions. The evaluators should have open minds so they can look not just for intended effects of the evaluation, but also for unintended ones. By doing so, unexpected outcomes can be found and resolved. The system should be studied both in the developers' laboratory and in the field (Friedman and Wyatt, 1997). While studying a system in its development environment, technical problems might be easily found and while in the field, the users' usage of the system can be evaluated.

Although complex, evaluation is imperative, as "without evaluation, medical informatics becomes an impressionistic, anecdotal, multidisciplinary subject, with little professional identity or chance of making progress toward greater scientific understanding and more effective clinical systems" (Friedman and Wyatt, 1997).

2.7 Final Remarks

This chapter provided an overview of the methodology adopted to develop this project. The methodology comprehends a set of well-known usability and software

engineering techniques. It shows in what way these techniques can be used for general purposes and in the HIS field.

In the next chapters there will be further detail on how this methodology was applied throughout this project.

3 The Critical Medicine Infection Module Case

In this chapter the Critical Medicine Infection Module case will be presented. The current *intensive.care*'s infection module will be fully described, in terms of its functions and functionality, its users and stakeholders and the problems they find while using it. There is also a presentation of the environment in which the module is integrated, which is the ICU.

Afterwards there is an explanation on how the methodology was used and the presentation of the obtained results.

3.1 The Infection Module

Intensive.care has a module that registers and manages infection data and information. Information about infection is complex and, as the current infection module was designed at the image of the infection process in the ICU, it has inherited complexity from the process itself. This results in its infrequent usage and loss of important information, which is never registered, as records on paper cannot maintain all the amount of data a computer-based record can provide.

The infection module's functions, functionality and evaluation are explained in detail in the next sub-sections.

3.1.1 The infection module's functions

The current infection module is mainly used for registering data about patient's infections and seldom used as a source of information.

Every time there is a suspicion of infection in a patient, one or some biological products are collected from him or her and they are sent for further analysis in a laboratory outside the ICU. All information about the biological product's collection and further analysis' results is registered in the infection module, including information on how micro-organisms are affected by the antibiotics available in the ICU.

3.1.2 The infection module's functionality

To fill in data related to infection for a patient, there are three different screens. One of these screens is the main infection interface (Figure 10) and is accessed much more often than the other two screens (represented in Figure 12 and in Figure 15).

There is a composed screen shot of the whole main screen in Figure 10, intended to provide an overview of the current infection module's main screen.

From this screen shot it is easily noticeable that an MD never has complete information about the patient's infections without having to scroll right and left, as this screen does not fit, in width, the whole computer screen. Also, apart from the right section of the screen, which is related to microbes' sensitivity to antibiotics, the whole interface is presented as a listing of infection data.

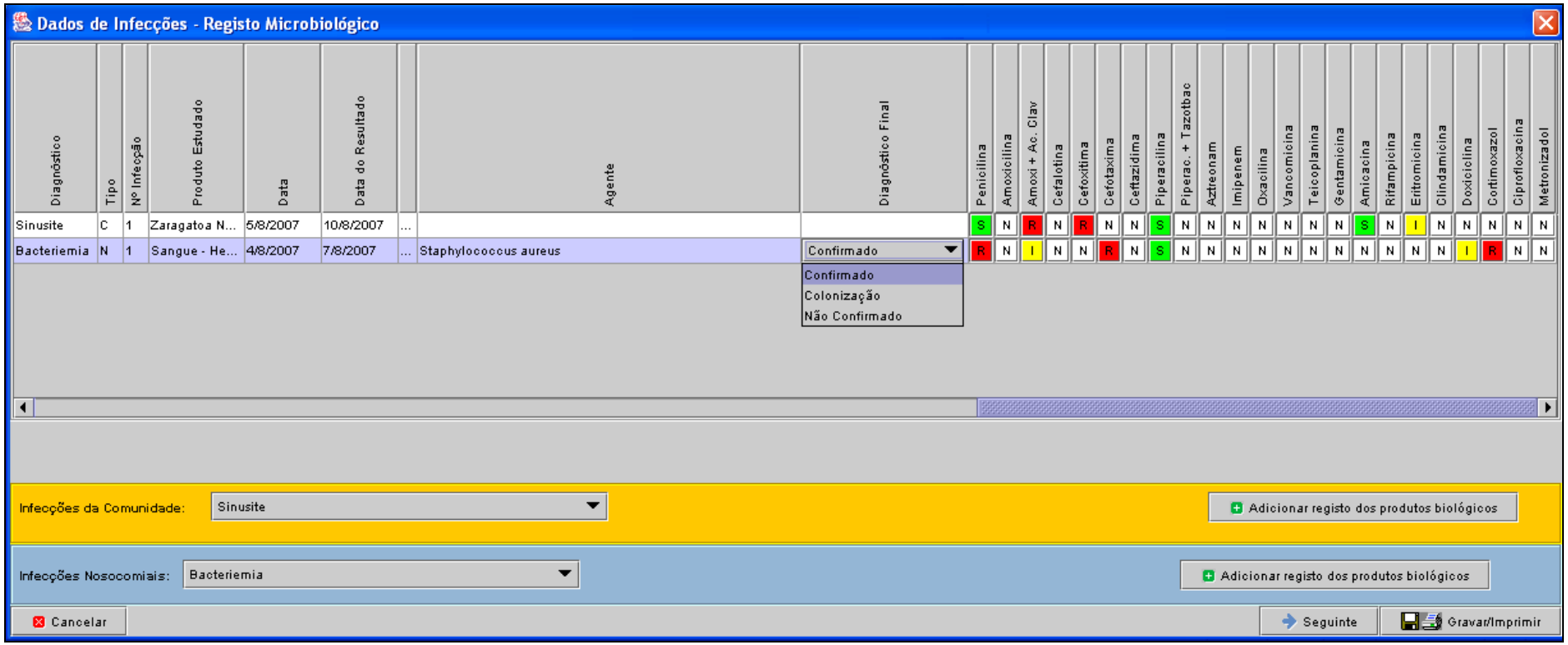


Figure 10 – Main window of the current *intensive.care* infection module

The first step in the registration of infection data for a selected patient is to fill in information about a collected biological product (Figure 11).

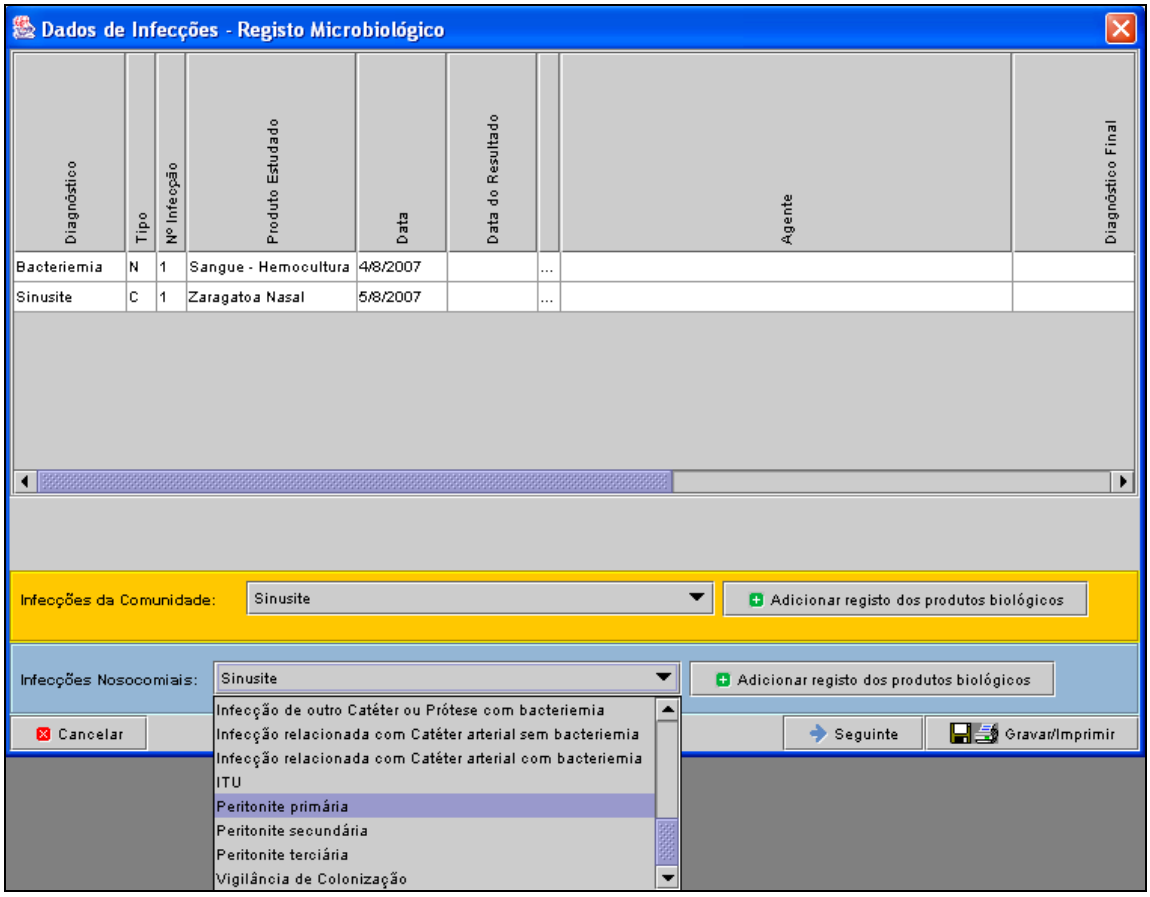


Figure 11 – First step of the infection registration – filling in of collected biological products

To do so, users must choose the suspected diagnosis, from a drop down list of community (yellow) or nosocomial infections (blue). This list is wide and is ordered alphabetically.

After that they have to add the biological product associated with the suspected infection. That is done by clicking the button ***+ Adicionar registo dos produtos biológicos*** in front of the selected infection.

After clicking the button to add a biological product collection registry, a second screen opens, where the user chooses the product, collection date and analysis number (see Figure 12).

If the registration of an infection (or suspicion of infection) is made in the same day it was collected, it is not possible to add a result date. Depending on the required analysis for the collected product, the result date may vary.

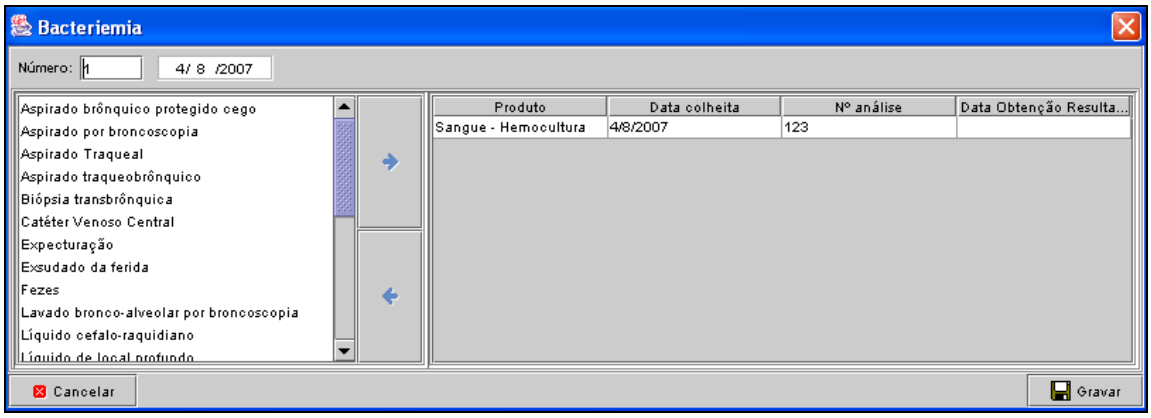


Figure 12 – Infection screen to register the collected biological product and its details

After the ***Gravar*** button is pressed, this screen switches to the previous screen (Figure 11).

When results come back from the analysing laboratories, the rest of the main screen (Figure 13) can be completed with this new information.

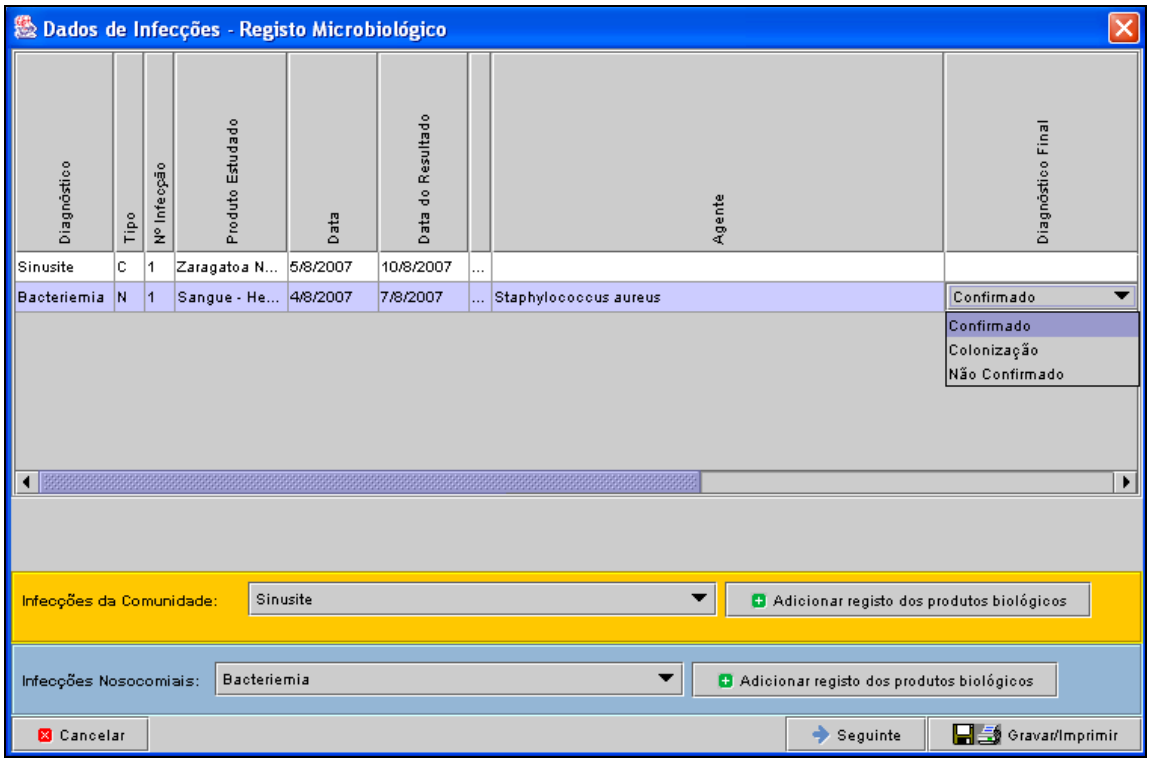


Figure 13 – Completion of the infection registration

The infecting agent, that is, the microbe, is selected from a drop down list in the section ***Agente***. This list is ordered alphabetically. At this time, MDs can state the final diagnosis, which is whether this infection is confirmed, a colonization, or not confirmed.

At last they can fill in the microbe's sensitivity to antibiotics (Figure 14).

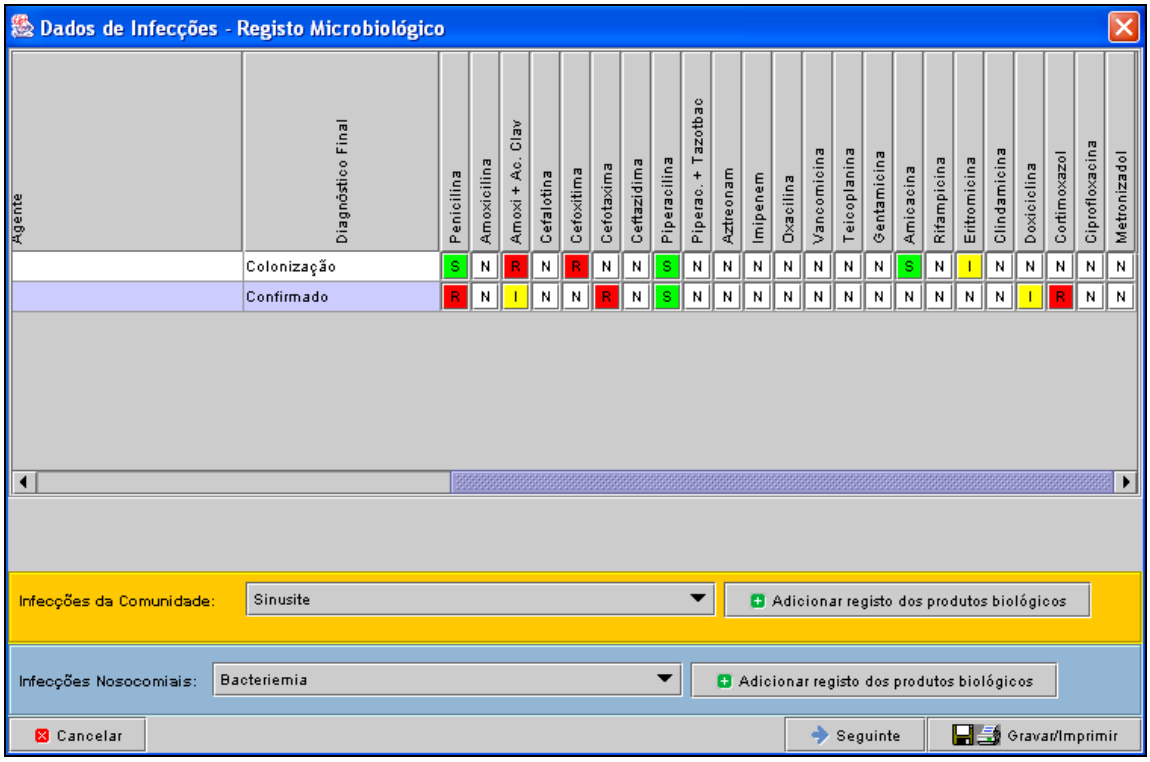


Figure 14 – Microbes' sensitivity to antibiotics fill-in screen

This is done by successively clicking the square below the antibiotic, which changes from the initial state, which is N – neutral into S – sensitive, R – resistant or I – intermediate. These sensitivity statuses are colour coded in white, green, red and yellow, for the neutral, sensitive, resistant and intermediate status.

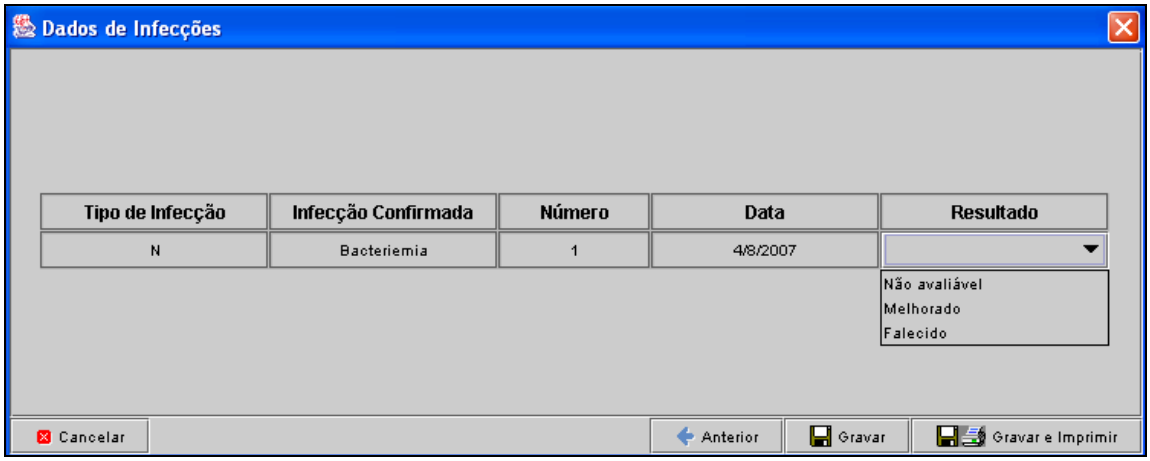


Figure 15 – Update of patient status, regarding his/her nosocomial infections

Figure 15 is the last one of the infection module screens. It has only one editable field, which is the results derived from the respective nosocomial infection:

Resultado. The result can be one of these three choices: unable to evaluate, improved or deceased.

3.1.3 Evaluation of the infection module functionality and characteristics

The current infection module is hardly used by *intensive.care*'s users. From all of the ICUs that use *intensive.care*, only one registers infection data.

This happens because most users find it hard to use as we will see below, and so they prefer registering infection data on paper.

The main overall problems with this module are that it does not provide MDs with an overview of patients' conditions when it comes to infection and it does not provide any information on the way infection affects the ICU as a whole, which makes the infection management an even harder task.

Patient's infection data is displayed as a list of collected biological products, the results of their analysis, the infecting agent and its resistance to antibiotics. MDs do not have a view of the patients' infections evolution, the administered antibiotics and even patient's basic data that might be useful while assessing their condition and possible treatments. Apart from the microbe sensitivity to antibiotics section, the module does not have any graphical display of information.

Another characteristic that makes the interpretation of the displayed data difficult to make is that the main screen does not fit in width in the computer screen (as seen on Figure 10), so it is impossible to see the whole information about patients' infections with just one look at the interface.

There are also some specific issues that difficult MDs' interaction with the infection module. The infections' drop down list is organized alphabetically. This is a wide list, so users have to go through the whole list until finding the infection they want to select. Users say that there is a small set of infections that happen a lot more than the remaining ones. As an alternative to the present configuration, the drop down list could be kept, but with the set of frequent infections on the top of the selection and the remaining infections below, ordered alphabetically. The same thing happens with the biological products and the micro-organisms, so the same alternative could be used in these drop down lists.

There is only a small set of antibiotics that a micro-organism is sensitive or resistant to, so there is not the need to always have the complete list of antibiotics, as it occupies a wide width making scrolling impossible not to happen. If antibiotics not interacting with the present infecting agents were hidden, the interface would occupy much less horizontal space.

There is no indication about an infecting micro-oganism's criticism. MDs could have a visual aid while assessing the criticism of the selected patient's infections, if the micro-organisms were colour coded in terms of difficulty to control and damage they cause. Just by looking at the interface, the MDs would have an immediate overview of the microbes currently affecting the selected patient.

To fill in the analyses' results on the infection module, MDs have to log in to SAM and search for the analyses' results they want, by searching for each analysis' ID. As there is a somewhat large amount of information regarding each analysis, MDs usually print these results. This leads to unnecessary waste of time and money and risk of errors. If *intensive.care* was directly connected to SAM, data regarding analyses' results would be automatically inserted in the respective infection record of *intensive.care*. This would avoid the time MDs spend retrieving the data from a system, printing it and then inserting it into *intensive.care*. It would also reduce costs associated with printing this information and avoid possible errors of data registration.

3.2 ICU Environment

The ICUs are particular units in a hospital, as the patients in it are in very critical health conditions and so, they need a special environment. "The care of the critically ill patient is complex and, at times, overwhelming. Many organ systems may be affected simultaneously." (Apostolakos and Papadakos, 2001).

There are a limited number of beds, as each of the patients needs a lot of attention. There are isolation areas for patients infected with multi-resistant micro-organisms, which are easily spread and very hard to control. A multi-resistant micro-organism is resistant to antibiotics it usually should be sensitive to, so it represents grave danger and is very difficult to control. The isolation areas are intended to avoid the propagation of these micro-organisms. To

access each isolated area, there is an antechamber, in which everyone going in or out of the isolated area, must go through and wash their hands.

Attached to each patient are a number of different machines intended to measure vital signs, to apply treatment and to signal if something unexpected happens with the patient. Whenever there is an unexpected change in a patient condition, a machine beeps. This happens very frequently.

There is a large amount of people working in an ICU, so there is constant movement and rush. These people are different kinds of health care workers, such as MDs from many specialties, nurses, physiotherapists and auxiliary personnel.

Also in ICUs, patients' visitors are not restrained to regular visiting schedules, so they can come in and out at any time during the day, one visitor per patient at the time.

3.3 *Intensive.care*'s Users and Stakeholders

Intensive.care's users are mainly MDs who are specialized in critical medicine – the *intensivists*. Nurses fill in a single screen of the system, but the usage of all of other screens is done by MDs. The users of the infection module are all MDs.

MDs are difficult users when it comes to availability. They are extremely busy, they work for many hours at a time and they can be called at any time if an emergency occurs. This means that it is hard to schedule appointments with them and even if a meeting is scheduled, it might be delayed, interrupted or even cancelled.

Different users have been consulted throughout the project. Since the focus of the work was the infection module and only MDs use it, no nurses were interviewed, as they only use a small part of *intensive.care*.

For the first part of the project, some users from three different hospitals were interviewed. 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 every day 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. Having such differences in experience with *intensive.care* is very enriching.

At the time of the interview some users were recent users and still remembered the difficulties they experienced when they had first started working with *intensive.care*. Also they were still exploring the system. Others were experienced users, who had already explored the whole system and had a wider knowledge about it.

In the field observation just one of the previously interviewed users was observed. This user is the one who has been working with *intensive.care* since its beginning and is responsible for the Medical ICU in HPH. The observed MDs team was working under her supervision. Some of the observed MDs are *intensivists* and some others were interns – MDs doing a specialization, who spend a few months in each department of the hospital, and were working in the ICU at the time.

Intensive.care's most important stakeholders are the ICU in-patients. They are the ones who can benefit greatly if the quality of care improves. Obviously, due to their health condition, they cannot be interviewed.

Other important stakeholders are its developers which are affected by *intensive.care*'s acceptance by its users. During the development of the project there were a few meetings with *intensive.care*'s developers, in order to discuss ideas about the way the prototyping was evolving, so that the final prototype would be feasible.

Finally SBIM is the remaining stakeholder. SBIM is very interested that *intensive.care* becomes more and more successful, as its success is directly related to its expansion to other clients.

3.4 Interviews to ICU MDs

The first step of this study was to analyse *intensive.care* to gain some knowledge about its overall characteristics, namely its architecture and functionality. Only after this initial study could the interviews produce effective results, as they were prepared having internal knowledge on *intensive.care*'s characteristics.

3.4.1 Interviews to establish the thesis' study focus

The first set of interviews was intended to determine the general usage, opinion and problems of *intensive.care*. These interviews were semi-structured (Ghiglione

and Matalon, 1997) and were composed of only few questions intended to obtain an overview of the current usage of *intensive.care* and its users' satisfaction. 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?

In these interviews, three key users, at three different hospitals were interviewed. These users are MDs who are responsible for their ICU, so they are perfectly informed about other MDs' usage of *intensive.care* in their units and the difficulties they experience.

There are 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 system eases their everyday work. The main ICU tasks are covered by *intensive.care*'s functionality set.

When it comes to more complex tasks, as will be seen below, users have some resistance in switching from the traditional paper reports to the electronic version provided by *intensive.care*. This happens both for a cultural reason – since MDs are used to doing procedures their way; and a difficulty for the development team to map the procedures in *intensive.care* exactly as they are made on paper.

Table 2 reflects an overview of the usage of *intensive.care*'s modules in each of the three hospitals where users were interviewed, HPH, HSJ and HSS. ✓ means the module is used and ✗ means the module is never used in the respective hospital.

	HPH	HSJ	HSS
Module 1 Entrance, Admissions, Antecedents and Release	✓	✓	✓
Module 2 Diary and Therapeutics	✓	✓	✗
Module 3 Prognostic Scoring Indicators	✓	✓	✓
Module 4 Procedures	✓	✓	✗
Module 5 Diagnosis	✓	✓	✗
Module 6 Complications	✗	✗	✗
Module 7 Infections	✓	✗	✗

Table 2 – Overview of *intensive.care*'s modules' usage in 3 different hospitals.

Procedures like patients' admission and release information, and prognostic scoring indicators are referred to as being easy to register, navigate in and use.

When it comes to more intricate functionality, such as the 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 as complex tasks are registered in *intensive.care*, that is, users find they should be improved, but still use them. As for infections 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 at all. In either of these cases, users believe these modules should be improved because they are difficult to use.

From these interviews it was decided that this study's focus would be the infection module, because of both the importance of infection control in ICU and of the

difficulty in the usage of this module. The infection module was only being used at one of the ICUs because of the existing difficulty in using it.

3.4.2 Interviews about Infection

After the decision in focusing in the infection module was made, it was necessary to gain some knowledge about infection in general and infection in ICU in particular. It was vital to understand basis of infection, its implications and its management, so that users' real needs and the *intensive.care*'s infection processes would be known and clear. The second set of interviews was intended to provide that knowledge.

This set of interviews happened in two hospitals with experts in infection in ICU. Knowing that 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 expectations about the improvement of the infection module were that it would suit every MD that deals with infection, it was important to elicit requirements from different MDs, even those who were used to working with other systems and not *intensive.care*. Only this way could a proposal be reached that would suit all users.

3.5 Field Observation

The field observations took place at the Medical ICU of HPH. This is the hospital which has been using *intensive.care* for the longest time and the only one that uses the existing infection module.

Several MDs were observed while performing everyday tasks, such as the ICU round and the mid-day gathering and passing of information about all patients to all MDs in the ICU.

Also patient specific tasks were observed, that is, actions taken upon specific needs by each patient. Examples of those kinds of actions are blood collection for further analysis and measurement of several indicators such as blood pressure or body temperature.

In HPH the emergency room (ER) is managed by the ICU. The ER acts as a triage room to decide which patients go to the ICU and to prepare them to the ICU, if that is the case. The ER is the part of the Urgency Room (UR) to where the most critical patients are conducted.

Even though *intensive.care* does not directly deal with the ER data, it was important to understand the whole emergency process as it is part of the daily ICU reality. MDs attending the ER are the same as the ones attending the ICU. So each MD that at a moment is at the ICU might be called to the ER at any time.

From this observation some conclusions were gathered related to both the way users use *intensive.care* and to the functioning of the ICU as a whole.

As for the ICU, each of the attending MDs has knowledge about all the in-patients, as they have, more than once a day, a gathering to share information about each of the patients. Because of this procedure, it is possible for each of the MDs to attend to a patient at any time, which due to the critical condition of the patients, is fundamental. If a patient has some kind of crisis, any MD can take care of him/her, as he/she is familiar with their condition.

At any time there can be a call from the ER, which must be attended immediately. So some MDs leave the ICU for a while to attend to the patient that has just arrived to the ER. There they must provide immediate care to the patient and then assess his/her condition and decide whether this patient is eligible to be interned in the ICU.

Although the data and information contained in *intensive.care* are fundamental to the functioning of the ICU, it is not imperative to write data in *intensive.care* as soon as it is available, as it is not an immediately urgent need. As MDs have a set of critically ill patients to attend to, filling in data in *intensive.care* is not their first priority and so they do it whenever they have the time to.

When it comes to infection data, MDs write down on paper the list of collected products, collection date and the respective ordered analysis reference number. Sometimes some days go by until they fill this information in *intensive.care*.

After they order an analysis on a product, they have to wait for the analysis result, which is usually available on another information system, the previously referred SAM. SAM is the system that supports MDs in their daily tasks. MDs have to access

SAM, gather information about the ordered analysis and then print it. After printing it, they have to type in the data in *intensive.care*. So this is not an immediate process and sometimes MDs prefer to wait for the whole analysis process to be complete to fill it in on *intensive.care*.

As this is an everyday procedure, the infection information registering process would be largely improved if SAM could be directly connected with *intensive.care*. This would save time and money and reduce the risk of errors. With just a mouse click, data about analyses' results could be imported to *intensive.care*. This would save the amount of time MDs spend logging into SAM, searching for the analyses they want to know the results of, then printing the results on paper and after that, inserting the results in *intensive.care*. Also, no money would be spent unnecessarily in printing the results. There would also be less probability of human errors that might arise from the number of steps needed before inserting analyses' results in *intensive.care*.

As the current *intensive.care*'s infection module is not graphical, MDs generally merely use it as a registering tool. There is a large amount of data that just goes to waste, as it is not used as a basis for information that could help MDs in their everyday decisions and ultimately help saving lives.

Every internist has an office with a personal computer. In the ICU room there are two personal computers. Each of these computers, the MDs' and the ICU's, have *intensive.care* installed. If there were tablet PCs or PDAs having intensive.care installed, it would be possible for an MD to be consulting infection information in *intensive.care* while being next to the patient.

Mobility improvements along with graphical interface addition to the infection module could dramatically change the way MDs interact with *intensive.care* and drive forward the usage of the infection module by the large amount of users that do not use it these days.

3.6 Final Remarks

This chapter has shown the current *intensive.care*'s infection module is seldom used by its users, mostly due to the difficulties they encounter while working with

it and the fact that the module does not provide them with much information about the way infection affects their ICU.

Due to time and availability restrictions of relevant MDs during this study period it was not possible to organize a focus group. It would have been a valuable addition to improve the results of this thesis work, and it is suggested that such procedure should be used in the future for further improvements. Therefore the final prototype and the requirements for the new infection module – ICInf – used the remaining parts of the initially proposed methodology (chapter 2).

The next chapter presents the proposed prototype for ICInf and explains its definition and construction.

4 Prototyping of ICInf – an improved Infection Management Module for ICUs

The proposed new infection module for *intensive.care*, which is called ICInf was specified based, among other things, on three prototypes. The first one was very different to what the final proposed interface looks like. After some evaluation and feedback from stakeholders, the second prototype was created. These two prototypes are explained on the next sub-section. They were created in Microsoft PowerPoint and are low-fidelity, as they only represent graphically the interface of the first window of ICInf.

The second prototype was also evaluated, but this time by MDs in the ICU. After that, the third prototype was created using all inputs obtained from this evaluation. This prototype, which will be explained afterwards, was created in Adobe Flash and can be considered to be mid-fidelity (Engelberg and Seffah, 2002), as it is very similar to the final interface, but all functionality it provides is simulated.

4.1 Low-Fidelity Prototypes – iterative construction, evaluation and validation

Two low-fidelity prototypes were created in Microsoft PowerPoint.

The first one looks nothing like its successors (see Figure 16). It has some of the concepts used in the next prototypes, such as colour coding and graphics about

infection, but the next versions are a great deal more complete and provide much more information in just one screen.

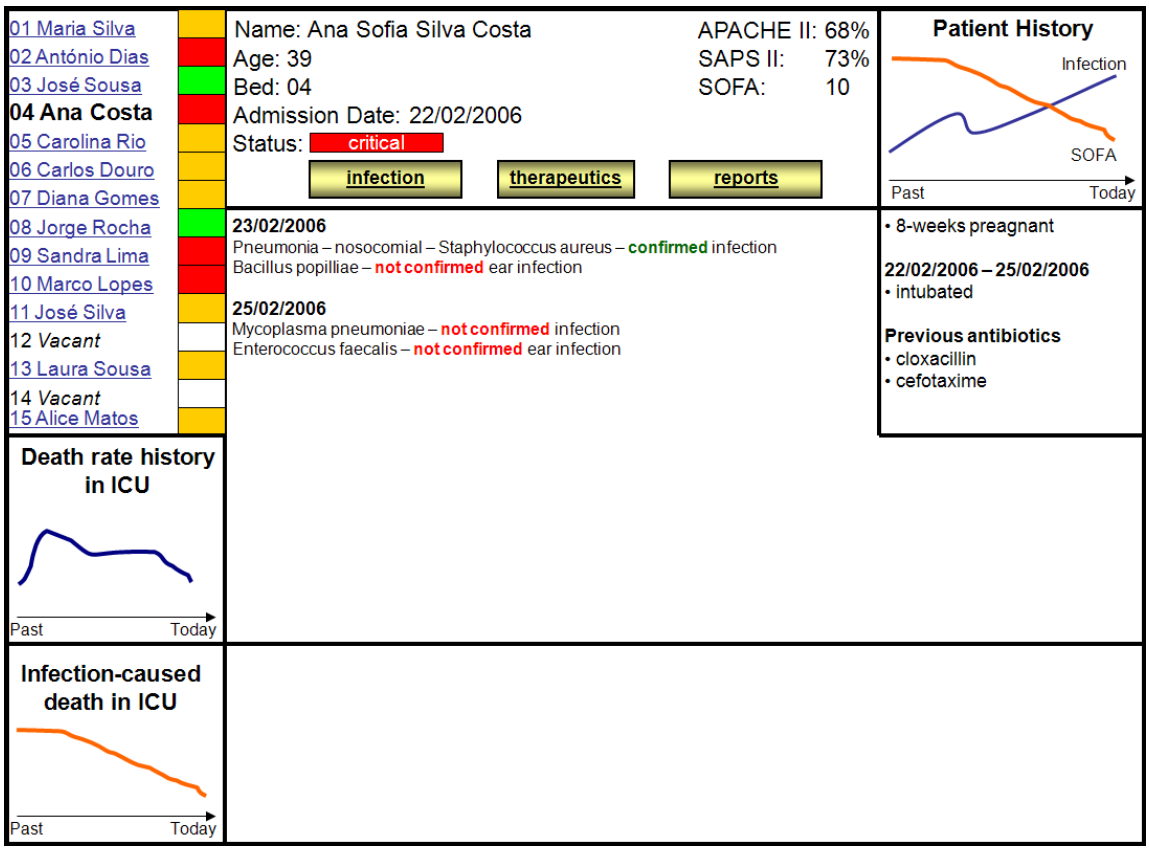


Figure 16 – First ICInf low-fidelity prototype

The left part of the screen presents information regarding the whole ICU. The remaining window is all related to a single patient.

The left part of the window is divided in three horizontal sections. In the first one there is a listing of all in-patients. Their bed numbers and names are clickable to switch from a selected patient to another. When a patient is selected his or her information is presented on the right sections of the window. In front of each patient's name there is a rectangle representing the patient's health condition.

The other two ICU related area sections represent two graphics, which show the death rate history in the ICU and the infection-caused death in the ICU.

The largest area of the window is composed by patient's specific information. His or her basic data, prognostic scoring indicators, a graphical display of the evolution of SOFA and the patient's infection condition throughout his/her stay in the ICU and three buttons, one for infection, one other for therapeutics and a final one for reports.

Below there is a listing of infections for each in-day and to the right of this section are the patient's special conditions and the previously administered antibiotics.

This prototype was evaluated by experts in infection and stakeholders. It was still an incomplete prototype by the time it was evaluated, as there were parts of the window that still did not display any information. This evaluation was also intended to ask the stakeholders which kind of information they thought would be relevant to the remaining section of the prototype.

After this evaluation, the second prototype was created. The objective of this new prototype was to create a fast and easy way for the stakeholders to evaluate the new ICInf interface and interaction. The second version of ICInf's main window became much more approximate to what users really need (see Figure 17).

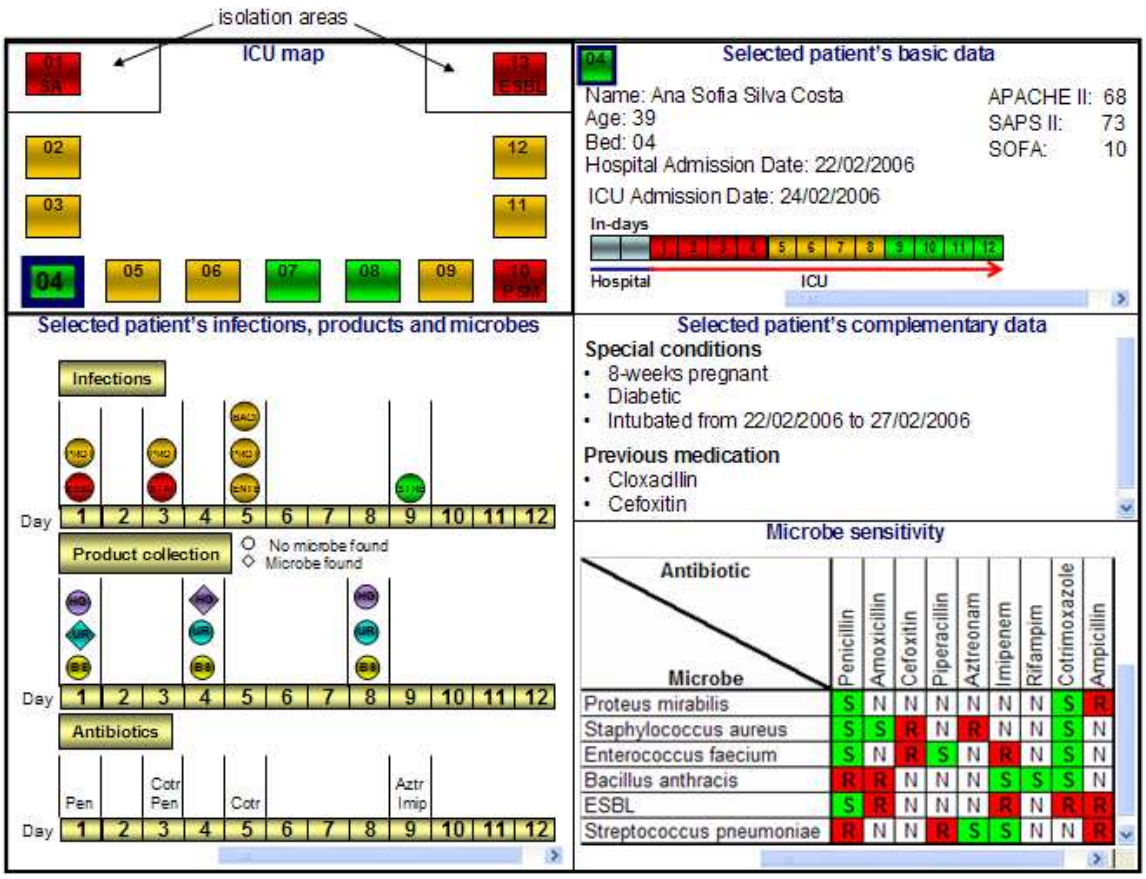


Figure 17 – Second ICInf low-fidelity prototype

This second prototype was created with close help from an MD who is expert in infection.

The use of colour provides a fundamental visual aid, so this prototype is based on colour-coding for quick identification of different situations.

On the upper left part of the prototype (Figure 17) 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, yellow or green.

If a bed is painted red it means the patient standing in it has an infection by a very hard to control micro-organism and this, along with the remaining patient's conditions, such as the result of his/her prognostic scoring indicators, makes this patient's health condition very critical. This patient's condition might even demand isolation and/or particular care. If a bed is yellow, the infection is easier to control, but it is still problematic. If it is green, then the patient has no infection, or his/her infection condition is completely under 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 selected 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 selected 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, but still represented in the screen, marked in light-blue. In this axis the evolution of the alert levels for the selected patient for each in-day 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 collection 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 micro-organism, product collections, such as blood or bronchial secretions and the administration of antibiotics. Micro-organisms, products and antibiotics are easily identifiable by abbreviations.

In the infections representation, detected micro-organisms 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 collected 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 micro-organism's isolation or a negative result. Many times – about 50% 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 lozenge; if not, it remains a circle. This way, by just looking at the screen, infected products are immediately identified.

These circles and lozenges that represent infections and products are clickable for details, as are the days and the buttons tagged "Infections", "Product collection" 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. MDs have to choose antibiotics that will kill the microbes causing the infection, but if the patient was already taking some antibiotics before entering the ICU, MDs have to know which antibiotics are those, as they might interact with the antibiotics they want to prescribe for the given infection.

In the bottom there is the patient's micro-organisms' 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 micro-organism with an antibiotic, there is always a result: N – neutral, S – sensitive, I – intermediate or R – resistant. The intermediate result happens when a micro-organism is neither completely resistant nor completely sensitive to an antibiotic. This means that if this antibiotic's normal dosage is applied, the micro-organism will not die, but if the dosage is increased, the antibiotic might kill the micro-organism.

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 (Carneiro, 2006), and for that case, the window space is typically sufficient.

This second low-fidelity prototype only represents part of the ICInf module, as whenever there is the need to add information about infection, a new screen must be opened. Also this screen has an overview of the infection information for each of the selected patients and allows MDs to rapidly and easily navigate from a patient to another, but if they want more detailed information, there are other screens that provide the required detail.

4.2 Final Prototype

Based on the evaluation of the second prototype (Figure 17), the third and final prototype was developed. It was created in Flash and has some interaction, but it is not fully functional. The decision in choosing flash to develop the prototype was based on its graphical and interactive potential.

The users' evaluation of the second prototype led to some changes on this final prototype's main window. The complementary patient data was grouped on the top of the interface and the ICU map was reduced, so in the centre of the interface are the graphic displays of results about micro-organisms, antibiotics and collected products.

This prototype aims to provide a wider perspective of the ICU's current status and each patient's overview in terms of infection. Having that, it is not possible to provide much detail in the first overview screen. Figure 18 shows the initial screen of the low-fidelity prototype. It represents an overview of the ICU current status in terms of infections.

Whenever an MD needs more detail, he or she can click on the interface buttons that lead them to a different screen with more detailed information about the infection data they need to consult. Clickable objects in the interface are represented with a roundish look. These are the interface buttons, and when clicked, they open new screens.

4.2.1 ICInf overview screen

Figure 18 shows the overview screen of the final ICInf prototype. This prototype was created in Flash and although not being fully functional, it provides some interaction.

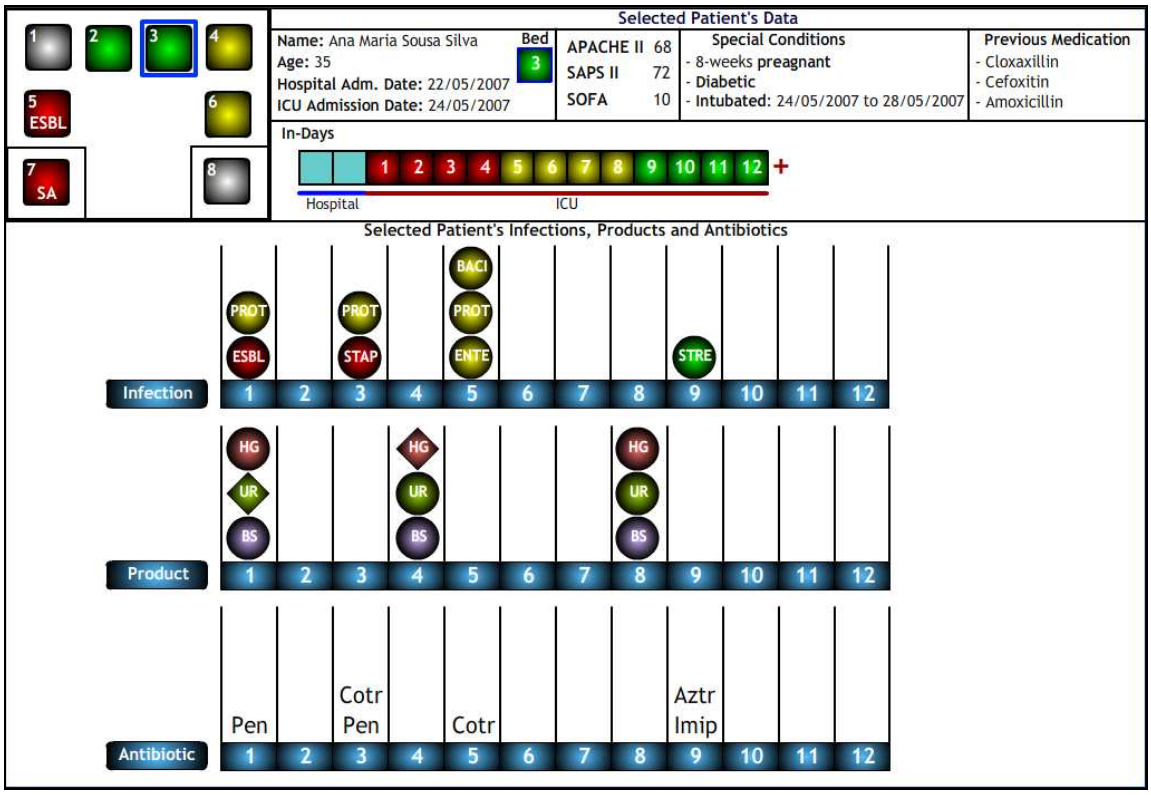


Figure 18 – Overview screen of the ICInf final prototype

As happened in the second prototype (Figure 17), the upper left side of the interface is occupied by the ICU bed map. Each square represents an ICU bed. These beds are displayed exactly as in the real ICU and they are marked with a bed number. All beds are colour coded to provide direct information about the severity of the respective patient's health condition. Colour coding is based on the same presupposition as stated in section 4.1, with one addition: grey coloured beds, which are unoccupied.

In the map of Figure 18 there are two isolation areas (around beds 7 and 8). Whenever a patient is affected by a multi-resistant micro-organism, he or she needs to be isolated in order not to contaminate the other ICU patients. As explained on section 3.2, these areas isolate the patient from the remaining ICU, avoiding the propagation of the multi-resistant micro-organism.

The ICU map area is the only part of the interface that shows some information about the whole set of patients that are in the ICU at the moment. The remaining screen is dedicated to the selected patient.

Patient selection is made by clicking a bed. Clicking beds in the ICU map switches the remaining screen information from one patient to another.

To the right of the ICU map there are two sections related to the selected patient – the Selected Patient's Data section and the In-Days section.

In the top there is the Selected Patient's Data area. This section is composed of four sub-sections. In the leftmost sub-section is data about patient's name, age, health condition (only by colour coding) and bed number. This sub-section also comprises the dates of the hospital admission – only if the patient has arrived to the ICU from a different department of the hospital; and ICU admission date, which is compulsory.

The next sub-section is composed of the three prognostic scoring indicators data. These are APACHE II, SAPS II and SOFA. These indicators provide a quantitative evaluation of the patient's health condition and are based on specific physiological measurements (Ridley, 1998). APACHE II and SAPS II are calculated only once, 24 hours after the patient's admission in the ICU and SOFA is calculated daily, and gives a perspective on the patient's general health condition throughout his/her stay on the ICU. Depending on the selected in-day, SOFA's value changes to the value calculated for the respective day. APACHE II and SAPS II values always remain the same.

To the right of this sub-section are the Special Conditions and the Previous Medication sub-sections.

The special conditions are data about the patient that is relevant in the assessment of their condition and in helping MDs to decide what treatments to apply to the selected patient. Here is registered information such as pregnancy, chronicle diseases, habits (for example drinking or smoking), momentary illnesses at the time of arrival in the ICU and medical procedures the patient has been subject to within the ICU, such as intubation, catheters, etc.

On the previous medication sub-section there is a listing of all the antibiotics the patient was medicated with before his or her arrival at the ICU. Many times this

information is unknown, but if it is available, it is fundamental that it is shown, because of possible side effects or interaction with other antibiotics.

The second section is the one where the in-days for the selected patient are graphically displayed (Figure 19). Here there are two sets of in-days: days spent in a different hospital or a different hospital service and days in the ICU.

Figure 19 – Patient's in-days display section (part of Figure 18)

Information about the number of days a patient has spent interned in a hospital service other than an ICU is very relevant, because if a patient has arrived the ICU from another hospital or hospital service, he or she, almost for sure, has already been medicated and it is possible for the ICU MDs to retrieve information about treatments and/or medication from the previous hospital service. These days are only represented graphically by light blue non-clickable squares, one for each day.

The ICU in-days have more available information. They are also represented by squares, but these are clickable to access different screens with detailed information about the respectively clicked in-day. Also, they are colour coded, according to the previously established colour codes for the patient's health condition. Days are numbered with sequential numbers, starting in 1, regardless of the actual day of the month. The relevant information is the amount of days the patient has spent in the ICU and the evolution of his/her health condition.

Whenever there is the need to add another day to the patient's in-days, it can be done by clicking the plus sign (+) in front of the in-days graphic.

The remaining part of the interface is occupied by the graphical representation of infections, collected biological products and antibiotics. For each of these items there is a horizontal set of buttons, one for each in-day the patient has spent in the ICU. These buttons are clickable for more detailed views of the days' contents. To the left of each of these sets of buttons there are three buttons, one for each of the sets.

The first set of in-days is preceded by a button named Infection (see Figure 20), which, when clicked opens a new screen with details about infection for the selected patient.

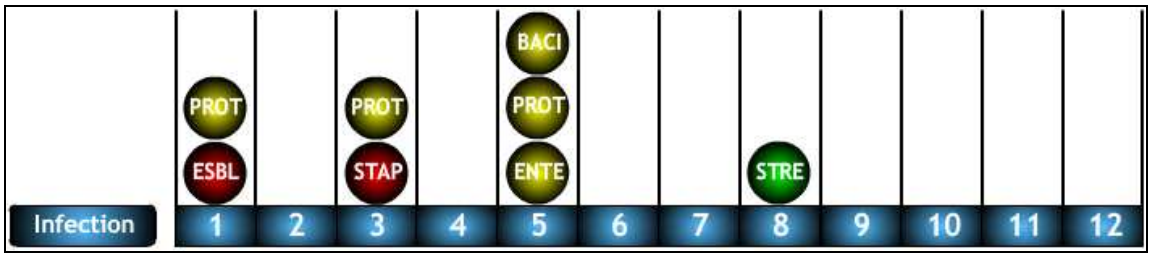


Figure 20 – Patient's infections overview display (part of Figure 18)

Above each of the days there might be, or not, buttons. If there is a micro-organism infecting the selected patient in a given day, that day has a round button above it, marked with the infection's abbreviation. The button is also coloured with the severity of the infection's colour. There is no limit to the number of infection buttons associated with a day.

Below the infection information, there is the collected biological products information (see Figure 21).

Figure 21 – Patient's collected products overview display (part of Figure 18)

The in-days for biological products are preceded by the Product button. This button leads to a new screen with detailed information about collected biological products. As with the infection information, for each of the in-days, there might be, or not, buttons. These buttons may be lozenges or circles, depending on which the biological product is infected, or not, respectively. Every collected biological product button starts off as a circle and may change its shape, if results about its analysis arrive to the ICU and they reveal a microbe infecting the product. Biological products are also colour coded, but not in terms of severity. Their colour coding is merely related to the product itself. Each of the possible biological products has a different colour. That way, just by looking at the set of product

buttons, the listing of collected products can be immediately assessed. Besides that, it is immediate to evaluate whether a product is infected, or not, by looking at the product's button's shape. Besides this colour coding, the buttons also have the collected products initials. For instance, HG is haemoglobin and UR is urea.

The final set of in-days is related to the prescribed antibiotics. Like the previous two sets of in-days, to the left of the days listing is the Antibiotics button, which can be clicked for extended information on antibiotics prescribed to the selected patient. Above each of the in-days there are the abbreviations for the prescribed antibiotics.

With the display of infections, collected biological products and antibiotics in this horizontal way, it is possible to have an overview of each of the three fundamental variables that affect infections, and the way they evolve through the patients' stay in the ICU.

These three essential infection variables cannot be dissociated from each other, as they are intertwined. This interface allows having a daily (vertical) perspective of the three variables and the possible interactions between them. For instance, if a collected biological product is infected, its button becomes a lozenge and above it, in the infection area, there is, for sure, at least one button indicating the micro-organism affecting the patient.

So, to sum this first screen up, it provides graphical information about infection severities in the whole ICU, and in a more detailed way, it shows basic data about a selected patient, ICU indicators, his or her infection evolution throughout the in-days and the evolution of the three fundamental variables of infection – infections, products and antibiotics.

4.2.2 Detailed in-day screen

Whenever an in-day is clicked on the infection overview screen (Figure 18), a different screen opens. This screen presents an infection data registering interface and detailed information about all of the selected day's infections.

Figure 22 shows the detailed in-day screen.

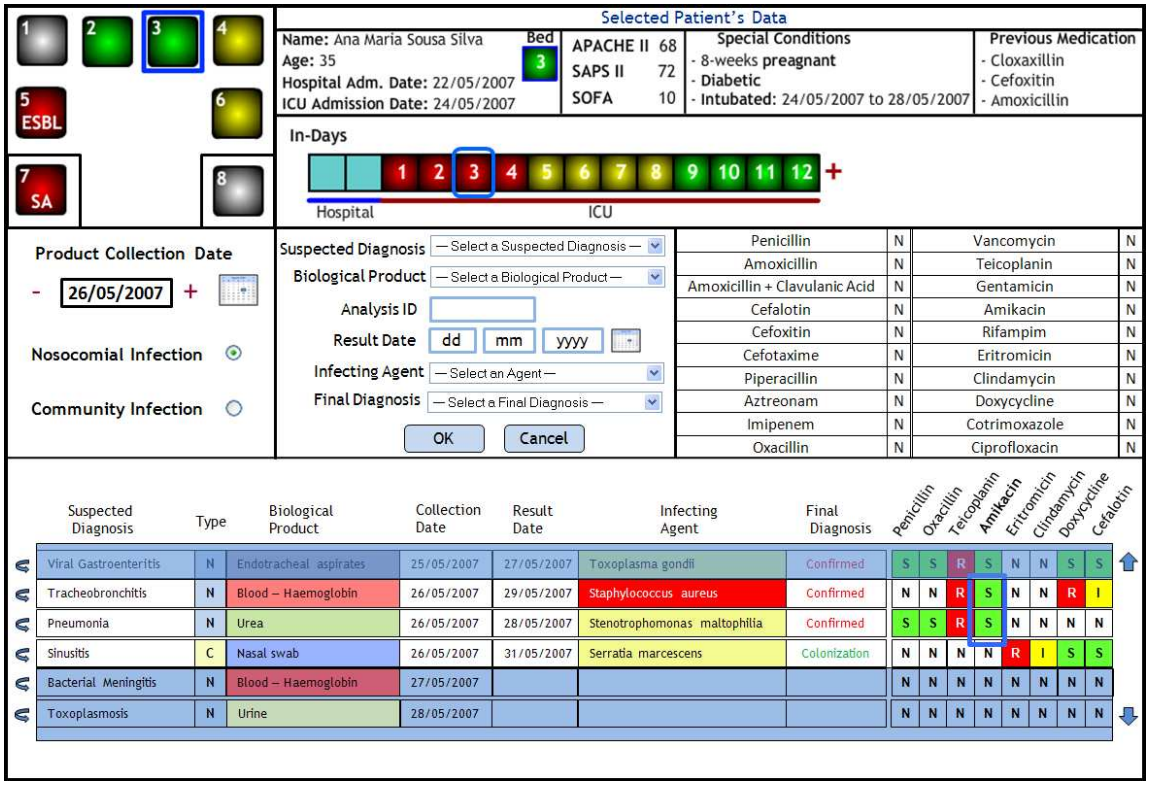


Figure 22 – Detailed view of a selected in-day's infection screen

This screen allows both registering and visualization of information about infections affecting the selected patient. The registering of data is only made for the selected in-day. The information section has data about all infection information for the selected patient, although with special focus on the selected in-day.

The ICU bed map, patient's data and in-days display sections are maintained and navigable in this screen, so easy access to basic information, along with the choice of navigation to other patients or other in-days is maintained. However there is a difference in the in-days section, as the selected in-day is clearly marked, signalling it is the currently selected day.

On the example in Figure 22, day 3 is chosen, so on the in-days display section it is marked with a blue selector around it.

The remaining screen (below the other sections) is divided in two horizontal parts. The first part is where new or updated data about infections on the selected day is inserted. This part is divided into three vertical components. The second part, below, is filled with information about infections affecting the patient throughout his or her stay in the ICU.

As said before, the first part, intended to register new infection data or to update existing one, is divided in three pieces. The first, on the left, has the selected in-days' date. This is the date of collection of all the biological products inserted in this screen. Also, infection information presented on the bottom of the screen, although covering all information about infection for the selected patient, is highlighted when the biological product collection was made on the selected date.

If the user wants to select a different date, he or she has three different options that lead to the same result. They can choose the day number from the in-days section, above; or they can navigate with the minus (**-**) and plus (**+**) signs buttons to change the current date to go one day back or forward for each click; or, they can click the calendar button, to the right of the **+** button, which will open a calendar that can be clicked, being the chosen date automatically inserted in the Product Collection Date box.

If a date is changed, it will produce modifications on the remaining parts of the screen that are related to the selected in-day. The in-days selector (on the in-days display section, above) will move to the in-day that corresponds to the new selected date and the information part of this screen will change its highlight to information related to the new selected date.

Below the biological product collection date there are two radio buttons that allow the user to choose which type of infection he or she is about to register – nosocomial or community infection. Since nosocomial infections are much more frequent than community ones, by default the radio button is selected on the nosocomial infections option.

To the right of this part of the screen is the form to register infection data, which is related to both the date and the type of infection chosen on the left of the form. In this form users fill in information about collected biological products and their infection information. This form is usually completed in two steps, as when a biological product is collected, results from further analysis are never known, and they are only identified a variable number of days later.

Users can press the OK button only when the suspected diagnosis, the biological product and the analysis ID are all filled in. These are compulsory fields, as when an infection starts being registered, these are known data. The analysis ID is the field

that connects the current collected biological product, to the respective analysis, in the SAM system. This is the code MDs have to insert in SAM to retrieve information about the biological product's analysis.

On a second phase of registering, typically some days later, the rest of this form can be filled in. The result date can be inserted manually, in the respective fields for day, month and year. Alternatively, the calendar button can be clicked to open a calendar. After a date is clicked on this calendar, the respective values will be automatically inserted in the day, month and year fields of the form.

At this time, MDs also have information about the infecting agent and the final diagnosis, which can be chosen from the respective drop down lists. The infecting agent is the micro-organism affecting the selected patient and the final diagnosis is merely a choice between three options: confirmed infection, colonization, or not confirmed infection. Even thought very often MDs are absolutely certain the selected patient is affected by an infection, most of the times the results returned by the microbiological laboratory are negative or inconclusive. This does not mean the patient is not infected, it just means the micro-organism died or did not evolve on the microbiological analysis made at the laboratory.

After choosing an infecting micro-organism, MDs can choose the micro-organism's sensitivity interaction with the list of available antibiotics (Figure 23).

Penicillin	N	Vancomycin	N
Amoxicillin	N	Teicoplanin	N
Amoxicillin + Clavulanic Acid	N	Gentamicin	N
Cefalotin	N	Amikacin	N
Cefoxitin	N	Rifampim	N
Cefotaxime	N	Eritromicin	N
Piperacillin	N	Clindamycin	N
Aztreonam	N	Doxycycline	N
Imipenem	N	Cotrimoxazole	N
Oxacillin	N	Ciprofloxacin	N

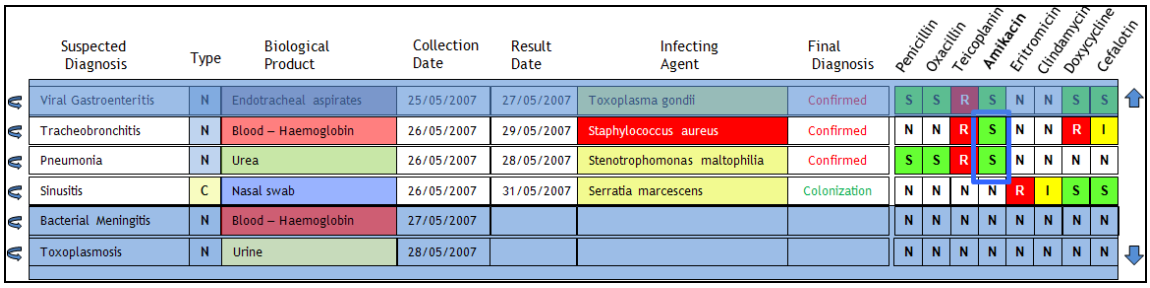
Figure 23 – Grid for micro-organism/antibiotic interaction choice (part of Figure 22)

As the micro-organism is already selected, to register the interaction with the antibiotics, the user just needs to click on the N buttons next to the each of the antibiotic's names. If the N button is selected, it means the micro-organism is neutral to the respective antibiotic. When an N button is clicked, it changes its colour and letter, from N – neutral (white), to S – sensitive (green), to R – resistant (red), then I – intermediate (yellow) and back to N.

All these changes will be automatically reflected on the information part of this screen, below the registration part.

If there was a connection between *intensive.care* and SAM, this second part of information filling in would be simplified, as with only a mouse click, *intensive.care* would import this information from SAM.

The second part of this horizontally split screen is the information area. This part has a listing of the infections and suspected infections affecting the selected patient (see Figure 24).



Suspected Diagnosis	Type	Biological Product	Collection Date	Result Date	Infecting Agent	Final Diagnosis	Penicillin	Oxacillin	Teicoplanin	Amikacin	Eritromicin	Clindamycin	Doxycycline	Cefalotin
Viral Gastroenteritis	N	Endotracheal aspirates	25/05/2007	27/05/2007	Toxoplasma gondii	Confirmed	S	S	R	S	N	N	S	S
Tracheobronchitis	N	Blood – Haemoglobin	26/05/2007	29/05/2007	Staphylococcus aureus	Confirmed	N	N	R	S	N	N	R	I
Pneumonia	N	Urea	26/05/2007	28/05/2007	Stenotrophomonas maltophilia	Confirmed	S	S	R	S	N	N	N	N
Sinusitis	C	Nasal swab	26/05/2007	31/05/2007	Serratia marcescens	Colonization	N	N	N	N	R	I	S	S
Bacterial Meningitis	N	Blood – Haemoglobin	27/05/2007				N	N	N	N	N	N	N	N
Toxoplasmosis	N	Urine	28/05/2007				N	N	N	N	N	N	N	N

Figure 24 – Listing of infections affecting the selected patient (part of Figure 22)

The selected in-day's information is fully visible, but information about the other in-days is also available for quick navigation between recorded infections information. This information has a blue shaded box over it, so that information about the selected in-day is fully visible and well distinguishable from the remaining in-days' information.

The list always displays the suspected diagnosis, the type of infection – nosocomial (N) or community (C), the collected biological product and the collection date. Depending on the status of completeness of each infection record, the list may also display the result date; the infecting agent – that is the micro-organism; the final diagnosis, which is a choice between one of the three – colonization, confirmed or not confirmed infection; and the interaction patterns table between each of the registered micro-organisms and antibiotics existing in the ICU.

To the left of each line of the list is a ↪ button which, when clicked, allows MDs to update information about the selected line's infection record. This update is done on the above section, where data about infection is registered. Fields that already contain data are filled in with the respective values, which can, nevertheless, be altered.

Some items of this part of the screen are colour coded. If the infection is nosocomial, its square presents an N and is coloured blue. If instead, it is community-acquired, the respective square will show a C and will be coloured yellow.

Each product has an identifying colour, so the rectangle that shows the collected product's name is colour coded accordingly.

The micro-organism is colour coded according to its severity. So, the rectangle showing the infecting agent is red, yellow or green, whether the micro-organism represents a critical, medium or easy to control threat.

The final diagnosis text is coloured red if the diagnosis is confirmed, green if it is a colonization and black if it is not confirmed.

A micro-organism has interaction with only a small set of antibiotics. That interaction represents sensitivity relationships between the micro-organisms and the antibiotics. On the micro-organism/antibiotic interaction grid, these relationships are graphically displayed. Only antibiotics that have some interaction with at least one of the micro-organisms affecting the selected patient are shown on the top of the grid, so that this list of antibiotics is not too extensive. Each grid square represents crossed information between the micro-organism of its line and the antibiotic of its column. These squares, as explained for the registering area of this screen, are colour coded according to the existing type of interaction. When the selected patient is taking one of the displayed antibiotics, this is signalled on the grid. The name of the antibiotic is printed in bold and a blue rectangle – the selector, is around the respective grid squares.

To the right of the interaction grid there are two arrow buttons. These buttons only appear next to the grid if there is more information above or below the shown records, respectively. Whenever the ⬆ button is clicked, there are more infection records on the top of the displayed ones and the list shifts one position up. Every time the ⬆ button is clicked, the list shifts one position up. The same thing happens when it comes to the ⬇ button. It only appears on the screen when there is more information below, and it slides one position down, one click at the time. If any of these buttons are continuously clicked, the display lines slide until the beginning or

the end of the list. This is particularly useful with long term in-patients, which most probably have many infection records associated with them.

4.2.3 Detailed specific patient's infection screen

Whenever a specific infection button is clicked, the detailed specific infection window is opened. A specific infection button is any infection round button associated with an in-day on the **Selected Patient's Infections, Products and Antibiotics** section of the overview window (Figure 18).

In this screen, such as on the detailed in-day screen, the above sections – ICU map, basic patient data and in-days – are maintained to allow quick navigation and contextualization on the selected patient.

The remaining screen is composed of information about the selected infection relative to the selected patient. This information is divided in two horizontal sections.

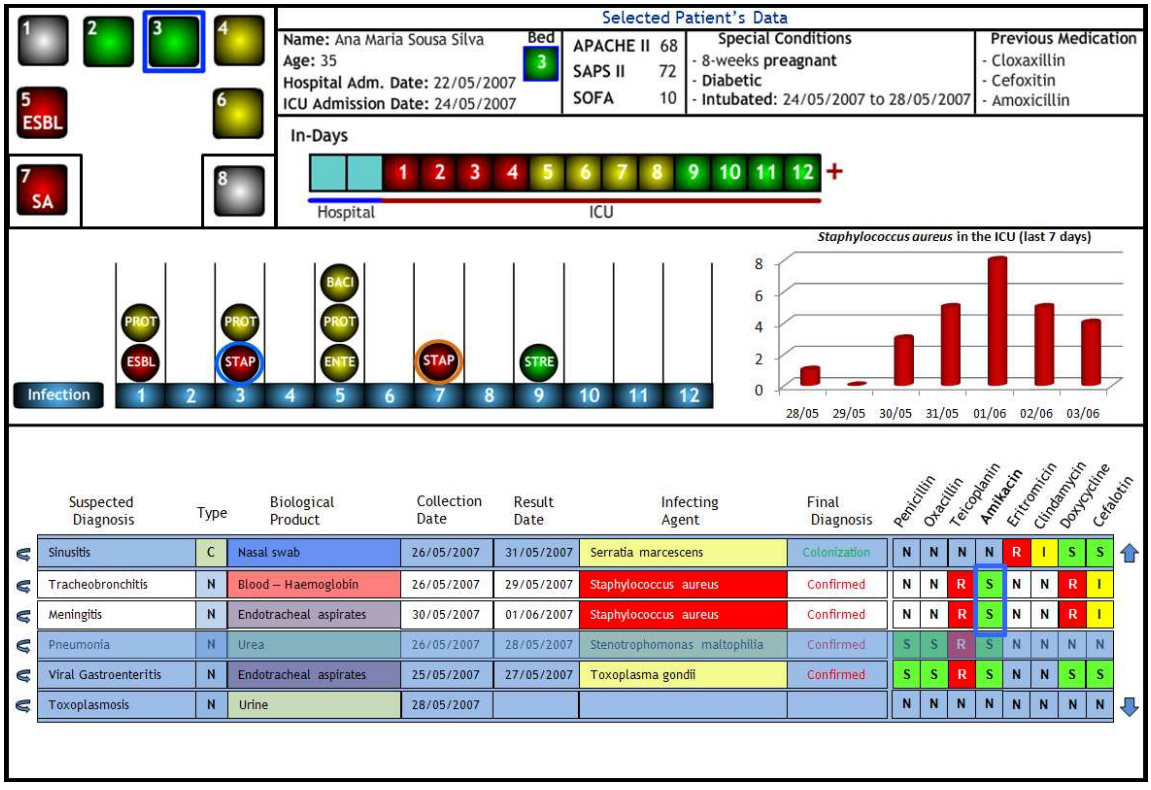


Figure 25 – Specific patient's infection detail window

The top section is composed of the horizontal display of infections affecting the selected patient throughout his/her stay in the ICU and a graphic showing the

evolution of the micro-organism's type in the whole ICU in the current date and the previous 6 days.

The infection part works exactly the same way it worked on the overview window (Figure 20) with clickable infection button, in-days' buttons and infections' buttons to open the respective windows. All occurrences of the same micro-organism are signalled on the infections' display with a blue selector (for the clicked button) and an orange selector for the remaining occurrences.

All micro-organisms are divided by types. To the right of the infection part is a graphic that represents the incidence in the ICU of the type of micro-organisms that the selected micro-organism belongs to. This incidence is relative to the current date and the previous six days, that is, a week. The vertical axis has the number of patients and the horizontal axis, the date of occurrence.

The bottom section has a listing of the patient's infection that is similar to the one in the detailed view of a selected in-day's infection window (Figure 24). It has the same type of navigation, by the ↵ the ⬆ and the ⬇ buttons, as explained on 4.2.2, but has a different display order.

Here, instead of being ordered by product collection date, the list is ordered by the infecting agent. Other records of infection by a different agent than the selected one have a blue shaded box over them, so that information about other infecting agents is fully visible and well distinguishable from the remaining infecting agents' information.

4.2.4 Detailed infection screen

When the infection button on the overview window (Figure 18) is clicked, a new window is opened (see Figure 26). Unlike the previous cases, this window is not associated with any patient. All information in it is details of infection in the ICU, as a whole.

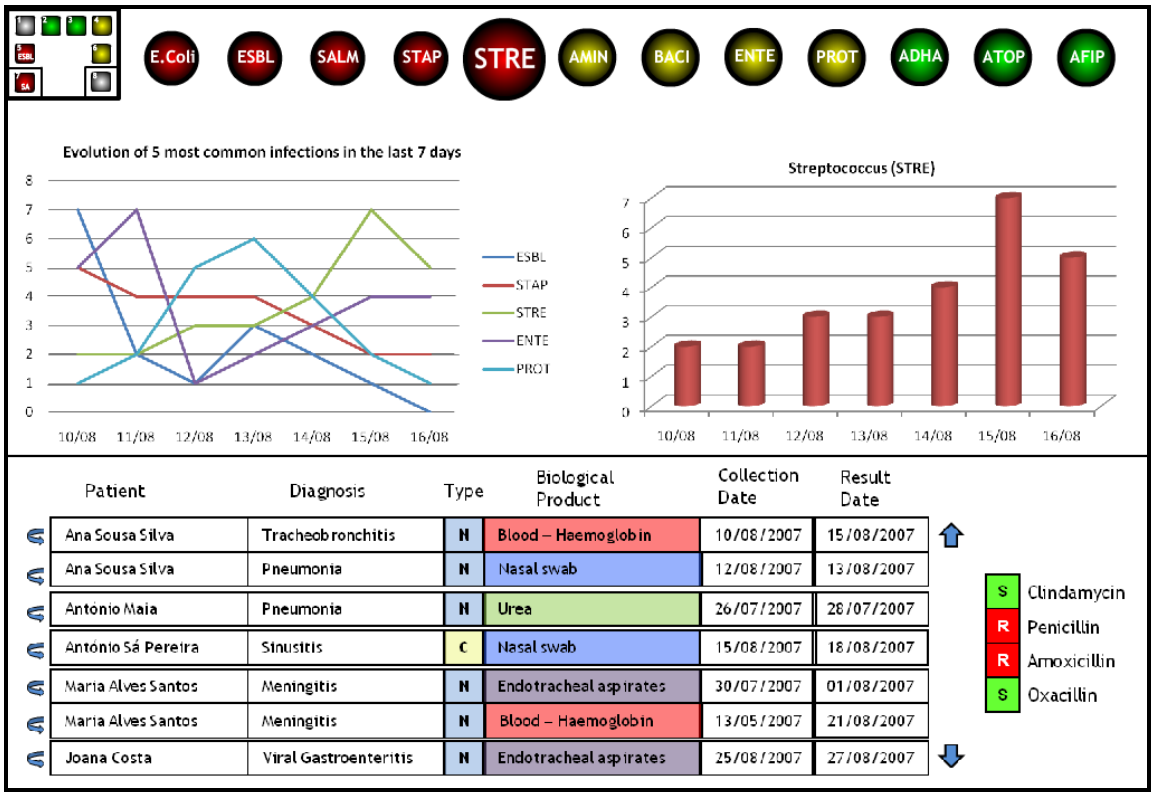


Figure 26 – Window of the display of details about infection affecting the ICU

On the top left part of the screen there is the ICU map in a smaller size than on the previous windows, but still navigable. Each bed button is clickable, opening the respective bed's overview screen (as in Figure 18). Since this window respects infection in the ICU as a whole, the ICU map is the only set of buttons that lead to single patients' information screens. Having the ICU map overview is very important for this particular window, as this information is very significant for the infection management of the ICU.

To the right of the ICU map there are a set of round buttons that represent each of the micro-organisms that are affecting or have affected the ICU. These buttons are colour coded by the micro-organism's severity, as explained in previous sections. When clicked, the information below changes, being referent to the selected micro-organism. The selected button becomes larger, so that the micro-organism the remaining screen is referring to becomes obvious. These buttons are ordered first by their colour and then alphabetically.

The remaining screen is divided in two horizontal sections. In the first section there are two graphics. The first one represents an evolution of the five micro-organisms that infected the ICU patients more frequently during the last week, taking into

account the current date. The second graphic shows the incidence of a type of micro-organism in the ICU patients during the last week. The type of micro-organism is the one to which the selected micro-organism belongs to.

The second horizontal section has a listing of all infections by the selected micro-organism, ordered by patient. The colour coding associated with each line is the same as explained before. The ↪, ⬆, and ⬇ buttons function in the same way as explained in the previous section. When ↪is clicked, the respective infection record's update screen is opened. ⬆ and ⬇ are used to navigate vertically in the current listing of infections. To the right of this listing is the display of interaction the selected micro-organism has with antibiotics. Here there are only three possibilities, red R (resistant), green S (sensitive) or yellow I (intermediate). If the micro-organism is neutral to an antibiotic, this interaction is not represented.

4.2.5 Conclusions about the final prototype

This prototype is based on the display and introduction of information about the ICU and its patients, mainly in the infection related area.

It uses colour and shape coding in order to provide easy and quick assessment of situations and assist MDs' decision making.

As infection management cannot be done effectively without full understanding of global happenings in the ICU, as well as detailed patients' information, this prototype offers different levels of detail from overviews to detailed information. It provides information about the three main variables of infection – micro-organisms, products and antibiotics in a single overview window, so that MDs can assess the situation as a whole and understand more quickly and more effectively the way infection is affecting a single patient or the whole ICU.

When it comes to a single patient's micro-organisms, products and antibiotics, MDs can have both a horizontal and a vertical perspective of information. Horizontally they can evaluate the way each of these variables is affecting a patient throughout his/her stay in the ICU. Vertically they can analyse the patient's situation day by day, as the graphical representation of the overview screen of a single patient's in-days represents these variables with similar structures and in-days are aligned for easy reading.

4.3 Final Remarks

Throughout this thesis there was the definition of three different prototypes for the development of ICInf.

The first two prototypes were created in Microsoft PowerPoint and represent two very different views of the main overview windows of ICInf. The first one (Figure 16) was evaluated by stakeholders, among which there were some infection expert MDs. Its evaluations led to the second prototype (Figure 17), which is much more like the final prototype than like the first one.

Even though these two prototypes are very dissimilar, they have common concepts, like having a display of information for each patient, having colour coding to help visualization and quick understanding of the situation and quick navigation between each patient record.

The second prototype was evaluated by MDs who work in an ICU and led to some changes which can be seen in the third, and final, prototype (Figure 18). This prototype was developed in Flash and presents some interaction. Several windows of this prototype were presented in section 4.2.

Whenever possible, all information is presented in a single screen, so all information is visible in a single window. This way, MDs can have overviews of the ways infection affects single patients or the whole ICU. This facilitates the tasks of decision making and assessment of problematic situations.

There are three fundamental variables that influence infection: the biological product, the micro-organism and the antibiotic. ICInf shows graphic information about the three variables in a single interface, so that MDs can assess the way these variables affect their patients throughout their stay in the ICU.

Also there is always easy navigation between ICU patients, by the use of the ICU bed map and between single patients' in-days' detail, by the use of the in-days display section. Moreover, there is the possibility of getting to a window through different paths. For instance, in the overview window (Figure 18) clicking on an in-day on the in-days display section, or in the same in-day number on each of the horizontal sets for infections, products and antibiotics, will lead to the in-day's detailed window (Figure 22).

The specified requirements are intended to define the creation of the new infection module, at the image of the final prototype's user interface and proposed interaction. The requirements are explained in the next chapter.

5 Requirements for ICInf

Each of the three created prototypes for ICInf was evaluated at different times. Each of the evaluations led to improvements in the evaluated prototype, which led to the creation of the next one. The third and final prototype was evaluated by a user and a stakeholder of *intensive.care*. These evaluations and their results are explained in the first sub-section of this chapter.

There was the specification and validation of a complete set of requirements for ICInf, which will define how ICInf will be implemented in *intensive.care*. These requirements describe the interface and interaction defined in the final prototype.

Also new requirements to the improvement of ICInf were elicited and they are presented in the last sub-section of this chapter.

5.1 Evaluation of the ICInf Prototype

The evaluation of the ICInf prototype was made by a user and stakeholder of *intensive.care*.

The user that evaluated ICInf is a very important one where this project is regarded. This was the director of the Medical ICU of HPH and has dealt with *intensive.care* since before its first implementation. She also is an *intensivist*, that is, an MD specialized in ICU.

It was impossible to show the prototype to other users to evaluate it, because this evaluation was made at the end of this thesis and there were few available MDs at HPH's Medical ICU.

In a general way, the feedback was positive and this user would like to have ICInf in her ICU, but there are some details that should be changed in order to improve ICInf.

The graphical displays of information showing overviews of an isolated patient or of the ICU as a whole were considered very interesting and useful. Infection management cannot be effectively done without considering all information about patients and the ICU and this proposed module provides that kind of information. Besides, information is displayed having colour and shape codes which facilitates and quickens the analysis of infection information.

The details that should be improved are presented next.

Although not all patients arrive at the ICU from a different hospital or a different hospital service, whenever this happens, information about the past infections, collected products and antibiotics is very useful. Other than the number of days in a different place and the prescribed antibiotics, this information is not available in ICInf. It was suggested that there could be a similar graphical display to the one there is for the in-days for each of the days spent in the hospital. This display would be represented in the overview window, to the left of the ICU in-days' details, and should be clearly marked as being information gathered and relative to the time before the patient's admission to the ICU.

When a product is collected, its micro-biological analysis results are only available some days later, but there is a microscope analysis' result, which is available immediately. This analysis is called Gram staining and identifies whether the micro-organism is Gram-positive or Gram-negative. Although not being able to identify the micro-organism affecting the patient, this is particularly important when there is the need to prescribe antibiotics to the patients before knowing which micro-organism is affecting them, because it provides some indications on the type of infecting micro-organism (Søgaard et al., 2007). Neither *intensive.care* nor ICInf have data about Gram staining. This should be a primary addition to ICInf, and can be inserted in the patient's infection record whenever this record is being created.

The current overview shows prescribed antibiotics but it is not very clear when the patient started taking an antibiotic and stopped taking it. This should be more

obvious, by numbering the antibiotics associated with each day. When there is a first taking of the antibiotic it should appear over the respective day in the format <antibiotic abbreviation><antibiotic's count day>. For instance, is Penicillin is prescribed in in-day 2 and continues to be administered to the patient until day 6, instead of "Pen" over an in-day, there should be "Pen1" in in-day 2, "Pen2" in in-day 3 and so on until "Pen5" in in-day 6.

The prototype shows graphics of occurrences of specific infections, always for the current date and the previous six days. Besides this weekly overview, there should be the possibility of showing other time spans, such as graphics for a whole month or year.

The stakeholder who evaluated ICInf is the director of SBIM, so he is very interested in the success of *intensive.care*, in order to expand its use to other ICUs and to have approval and positive feedback from the current clients.

Although being an MD, this stakeholder is not an *intensivist*. This means he knows the infection process in the ICU, but obviously not as deeply as an *intensivist* would. So, he was able to evaluate the prototype and give feedback about it, but he didn't get to the level of detail the user did.

His evaluation was very positive and he considered this new proposed module would help MDs in their ICU infection management in a way the current module is not able to. He considered that the most important aspects of the prototype are the way it graphically displays information about infection, using colour and shape to differentiate diverse infection variables. He also liked the fact that this prototype provides information on both single patients and the ICU as a whole, which he considers fundamental for an effective infection management.

5.2 Requirements for ICInf

A complete set of requirements for the new infection module – ICInf was specified and validated. These requirements were elicited throughout the whole process of this thesis's work. They are based on the application of the methodology used for the project. They were gathered from interviews and meetings with users, field observations, the study of the infection process and the development and evaluation of the prototypes.

The requirements were separated into ten different areas which are presented in Table 3. Each requirement's ID is associated with the area the requirement belongs to. They are composed by the area identifier followed by a sequential number.

M	ICU bed map
P	Patient information
ID	In-days' display
IPA	Infections, products and antibiotics overview
MO	Main overview window
IR	Infection registration
PDII	Detailed information about a single patient's infection
IDD	In-days detailed window
SPID	Specific patient's infection details
DGI	Detailed general infection display

Table 3 – Areas into which requirements are divided

The complete list of specified requirements is available in Appendix A.

Requirements for the ICU bed map are identified by M. They are related to the graphical display of the ICU map in all of ICInf windows (as shown on Figure 18, among others). It refers the way the map should be displayed and its characteristics, such as colour coding and critical infections' abbreviation display.

The specified requirements for patient information specify the way information that is related to single patients is presented in all ICInf's windows (as shown on Figure 18, among others). This is personal patient's information, their prognostic scoring indicators' values, their eventual special conditions and previous medication. These requirements are defined by P.

The in-days's display section exists in every ICInf window that has single patient's information (as seen on Figure 19). Its requirements are identified by ID and specify requirements such as the graphical in-days' display as clickable buttons and their colour coding according to the severity of the respective patient's health condition.

For the main overview window of ICInf, there is a section where the three infection variables are displayed (two of these displays are shown on Figure 20 and Figure

21). It presents the way each of these variables evolves through a single patient's stay at the ICU. The requirements that specify this section are defined by IPA, for Infection, products and antibiotics overview. These requirements cover all the specification of the display of each of the horizontal sets of information, including colour coding for infections as well as colour and shape coding for products.

The requirements that compose the main overview window are represented by MO. These requirements define the way the window's items are displayed.

Infection registering requirements are represented by IR. They are related to the window that opens when an in-day button is clicked on the main ICInf window or when there is a click on an update button for an infection record. These requirements specify the complete interface, interaction and default values for the form that creates or updates an infection record (as seen on Figure 22 and Figure 23). For instance, when inserting a new infection, the collection date should be already filled in with the previously selected in-days' date and the nosocomial infection radio button should be selected by default.

Still in the window for a specific in-day's detail, there is the display of a listing of infection information regarding the selected patient, which is focused on the selected date (see Figure 24). These requirements are defined by PDII, which stands for patient's detailed infection information. They specify the way the listing of infections should be presented, the existing colour coding and buttons for updating a record and navigation further up or down on the listing.

The requirements identified by IDD are related to the in-days detailed window and specify the way this window is displayed.

SPID requirements are those which are related to specific patient's infection details. These requirements define the way information is presented in the specific patient's infection details window, which includes, among other things, a graphic and a listing of all infection records for the selected patient, as well as all of its colour coding.

Finally the requirements related to the detailed general infection display window are defined by DGI and specify the way the window presenting the general infection information is displayed. They also define the way the graphics and the list of infected patients are built and presented.

5.3 Requirements for further improvements to ICInf

The requirements for further improvement of ICInf were elicited during the evaluations of the final prototype and reflect the required changes. These possible improvements were already described in section 5.1, where the results from the final prototype's evaluation were presented.

These requirements cover some diverse areas of improvement. They are associated with:

- Presentation in the main overview window of infections, products and antibiotics for hospital in-days, whenever the selected patient has arrived to the ICU from a different hospital or a different service in the same hospital.
- Results of Gram staining analyses for every collected product.
- Display of antibiotics on the main overview window showing not only the antibiotics abbreviation, but also the count of days for that antibiotic prescription.
- Adding additional time spans for graphics' displays, such as month, trimester, semester and year.

As a proposal for future work, these requirements should be specified and validated. Before implementing ICInf in *intensive.care*, these requirements should be analysed, as the developing team should prepare ICInf for these planned improvements.

5.4 Final Remarks

The evaluation of ICInf's final prototype has produced very positive feedback. The evaluators showed the will to have it implemented in *intensive.care*, due to the way it is expected to improve infection management in the ICU.

A complete set of requirements has been specified for the new infection module, ICInf. These requirements were elicited throughout the development of this thesis, by the application of the proposed methodology.

In the evaluations of ICInf's final prototype a new set of requirements were elicited. These are intended to improve ICInf as it is currently specified by the requirements and the prototype.

The next chapter has some general conclusions and ideas for future work.

6 Conclusions and Future Work

In this chapter there are some conclusions about the thesis' results and some possibilities of future work are presented.

6.1 Conclusions

This thesis aimed at producing a complete set of requirements and a prototype for the improvement of an existing intensive care information system's infection module. The existing module is barely used due to the difficulties users find while using it and to the little functionality it provides, as compared to what it could offer. The module works almost exclusively as a registering tool for infection data, providing little information about the way infection affects the patients staying at the ICU and about infection influencing the ICU as a whole.

Infection is a very important issue in ICUs, as it is one of the main causes of complications and death. Knowing that, it seemed fundamental to try to create a new infection module that would support MDs in their infection management tasks.

The new proposed infection module, ICInf, provides an interface for both registering infection data and displaying infection information. The proposed module offers graphical presentations of information, with colour and shape codes that provide immediate visual understanding of the current situations. Also, it provides MDs with overviews of infections affecting single patients or the whole ICU.

The methodology used throughout the development of this thesis was appropriate to the projects' needs, as it produced the expected results: a prototype and a

complete set of requirements for a new infection module. The created prototype was evaluated by a user and a stakeholder, who considered it to be a very useful proposal for the new infection module.

In addition to the specified requirements for ICInf, requirements for the evolution of ICInf were also specified, based on the prototype's evaluation.

This thesis' results are not applicable only to *intensive.care*. The requirements and prototype proposing a new infection module were obtained through the application of the selected methodology, which always implicated close contact with MDs from different ICUs. One of these MDs was the director of an ICU that does not even use *intensive.care*. This has produced a conceptual new infection module that can be used generally by MDs working in ICUs. Having inputs from various sources while constructing the ICInf prototypes, led to an infection module that supports general MDs needs while managing infections.

Some of the concepts used for the construction of ICInf can be extensively used, not only in intensive care information systems, but also in a wider range of HIS:

- Having overviews of factors that contribute to the development of a certain health condition might help MDs to take quicker and more correct decisions. This happens because this way they are able to see the whole situation around the health condition they are treating.
- Having colour and shape codes according to different status on a situation enables immediate understanding of circumstances, helping MDs to react faster while making decisions that will affect the current situation.
- Having visualization of different perspectives of the same data can help to achieve higher understanding of a certain situation.
- In some situations, to immediately assess the current status, details are not important. That does not mean they are not necessary in other times. But it means that different levels of detail in different screens of the same module can prove to be useful in different scenarios.

6.2 Future Work

The future developments of this thesis work can go two different, but not exclusive directions. ICInf can be improved and its concepts can be applied to the remaining *intensive.care*'s modules.

6.2.1 Proposed improvements to ICInf

When ICU MDs need to deal with the need to immediately treat and medicate a patient without having any certainty of what micro-organism is infecting the patient, all variables about infection are valuable information to help them in their decision making. In these cases, 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. The Gram group is very valuable information when it comes to determining which antibiotics to prescribe, as it gives an indication on the type of micro-organism affecting the patient. So, MDs' decision on which antibiotic to prescribe is based on several issues such as patient's background, previously taken antibiotics, symptoms and the Gram staining, amongst many others.

In the future ICInf should provide the possibility of inserting data about Gram staining on the infection records and presenting this information on the infection information areas, as it represents such valuable information.

One of the other proposed improvements for ICInf is the creation of a decision-support system, which based on the evaluation of all variables affecting the patient (including the Gram type of the micro-organism), would help MDs in their decision making about treatments or medications to prescribe to the patient.

In the overview window of ICInf, there is only graphical display of information about the days patients spend in the ICU and little information is known about the days the patient spent on a different hospital, or a different service from the same hospital. Although not always being available, this is valuable information to assess the patient's health condition and to decide what medication can be prescribed to him/her. An addition to ICInf should be the creation of a graphical display of infections, products and antibiotics affecting each patient on the days he/she spent on a hospital service other than the ICU, before his/her admission in the ICU.

The current display of antibiotics prescribed to the patient should be improved so that there is no doubt on the amount of days the patient has been taking each antibiotic.

The graphics in ICInf are all about the way infection affects the whole ICU during the last week, starting in the current date. In the future these graphics should allow the selection of different time spans, such as a month or a year.

Ideally each user would have the graphics display customized, so that it would show their chosen time span as default when designing these graphics.

The final suggestion of improvement regards the direct connection between *intensive.care*'s and SAM's databases. This would keep MDs from spending unnecessary time inserting in ICInf the analyses' results they get from SAM. This would save time, money and prevent human errors, which are associated with the fact that currently MDs print a sheet of paper with analyses' results and then they copy it manually to *intensive.care*.

6.2.2 Expansion of ICInf concepts to other *intensive.care*'s modules

The ICInf module has many specific definitions that can only be used in infection management, but has many others that are general and can be used in the remaining *intensive.care* modules, in order to improve them. Nevertheless this cannot be done without due customization to each module.

The ICU map can be used in the other modules, having some colour coding in each bed representation, but this colour coding being specific to the module the map is in. The patient's basic and complementary data is always usable in any other *intensive.care*'s module, as this is information that can be used as a contextualization on the selected patient. The in-days section can also be used in other modules of *intensive.care* provided their colour coding is adjusted to the module the section is inserted in.

There should be an assessment of the main variables and tasks for each module of *intensive.care*. After this assessment, whenever possible, there might be an adaptation of ICInf's concepts to each module's variables and tasks. These concepts are such as colour and shape coding, overviews of important information and different perspectives of relevant information.

These changes to *intensive.care* will improve its functionality and the way they support ICU MDs in their everyday tasks, by providing registering and information interfaces that are intuitive and easy to use.

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Appendix A – Requirements for ICInf

This appendix presents the complete set of specified requirements for the new infection module of *intensive.care* – ICInf.

A.1 ICU Map requirements

ID	Requirement	Description
M1	Display of the ICU bed map	The interface should show a map of the ICU beds exactly as they are displayed on the ICU and with a visible display of each bed number.
M2	Bed map colour coding	According to the infection condition of the patient staying in a bed, the bed should be colour coded in red – highly critical, yellow – medially critical, green – no infection or controlled infection, and gray – empty bed.
M3	Display of critical infection abbreviations	Whenever the patient staying in a bed has a critical infection, besides the red colouring of the bed, there should be a text with the abbreviation for the respective infection.

M4	Clickable ICU map beds	The ICU map beds should be clickable to display more information about the respective patient staying in the clicked bed. Whenever an ICU map bed is clicked, the rest of the interface changes according to the selected patient's information.
M5	Signal of selected bed	When a bed is selected, there should be a blue square around it, signalling the bed is currently active and that the information in the remaining interface belongs to the patient currently in that bed.

Table 4 – ICU map requirements

A.2 Patient's information requirements

ID	Requirement	Description
P1	Selected patient's data section	Whenever a patient is selected from the ICU map, data about him/her and their condition should be presented on the top of the interface.
P2	Display of patient's basic information	When a patient's bed is selected in the ICU map, his/her basic information should be displayed on the patient's data section. This information has the following patient data: name, age, hospital admission date (if available), ICU admission date, bed number with the respective colour coding according to the criticism of the current infection.
P3	Display of patient's prognostic scoring indicators	The prognostic scoring indicators (APACHE II, SAPS II and SOFA) should be presented on the patient's data section.
P4	Display of patient's special conditions	Selected patient's special health condition or hospital procedures he/she's been submitted to should be presented in a list, on the patient's data section.

P5	Display of patient's previous medication	Whenever a patient has been previously medicated and this medication is known, it should be displayed in the patient's data section.

Table 5 – Patient's information display requirements

A.3 In-days' display requirements

ID	Requirement	Description
ID1	Graphical display of patient's in-days in the ICU	For each in-day a patient spends at the ICU there should be a square representing the in-day number (starting in 1).
ID2	Colour coding of patient's in-day	Each numbered square representing an in-day at the ICU should be colour-coded, according to his/her infection criticism level (red – highly critical, yellow – medially critical, green – no infection or controlled infection).
ID3	Clickable in-days for the ID section	Each square representing an in-day should be clickable, to change from the overview screen to a detailed view of the selected in-day.
ID4	Graphical display of patient's in-days in the Hospital (previous to entrance in the ICU)	If the selected patient has been in the hospital for at least one day previous to his/her entrance in the ICU, there should be a graphical representation of it. Each of these days is presented as a light blue square, which is not numbered. These squares are not clickable.
ID5	Adding a day to the in-days	In front of the in-days graphical representation there should be a clickable plus sign (**+**), that whenever clicked, opens a new screen to add another day to that patient's in-days.

Table 6 – In-days display requirements

A.4 Infections, collected biological products and antibiotics overview requirements

ID	Requirement	Description
IPA1	Graphical overview of selected patient's infections, products and antibiotics	In the largest area of the interface, below the map, patient and in-days information, there should be a graphical overview of the selected patient's data about infections, products and antibiotics.
IPA2	Display of in-days for infections	There should be a line of blue rectangles, one for each of the in-days of the selected patient. Above each of the days there must be information about infection related to the respective patient and day.
IPA3	Display of in-days for products	There should be a line of blue rectangles (below the set for the infections), one for each of the in-days of the selected patient. Above each of the days there must be information about selected patient's collected products in the respective day.
IPA4	Display of in-days for antibiotics	There should be a line of blue rectangles (below the set for products), one for each of the in-days of the selected patient. Above each of the days there must be information about antibiotics prescribed to the patient for the respective day.
IPA5	Clickable in-days for the IPA section	Each of the blue rectangles representing in-days for infection, products and antibiotics, should be clickable to provide detailed information about the respective day.
IPA6	Infections button	There should be a button on the left of the in-days display related to infections. When clicked, this button should open a new screen with detailed information about the selected patient's infections throughout his/her stay in the ICU.

IPA7	Products button	There should be a button on the left of the in-days display related to products. When clicked, this button should open a new screen with detailed information about the selected patient's collected biological products throughout his/her stay in the ICU.
IPA8	Antibiotics button	There should be a button on the left of the in-days display related to antibiotics. When clicked, this button should open a new screen with detailed information about the selected patient's prescribed antibiotics throughout his/her stay in the ICU.
IPA9	Graphical representation of each day's infections	For each of the in-days next to the infection button there should be a graphical representation of the infections affecting the selected patient. These infections are represented by a circle with an abbreviation of the infection name and a colour coding: red – highly critical, yellow – medially critical, green – no infection or controlled infection.
IPA10	Graphical representation of each day's collected biological products	For each of the in-days next to the products button there should be a graphical representation of the products. Each different biological product has a different colour associated with it and a text with the product's name abbreviation. The button is shaped as a lozenge or a circle, whether the product is infected, or not infected, respectively.
IPA11	List of each day's prescribed antibiotics	For each of the in-days next to the antibiotics button there should be a list of all the prescribed antibiotics for the respective day. Each antibiotic is represented by an abbreviation.

IPA12	Change of products shape	When a collected biological product is inserted in *intensive.care*, there is still no information whether it is infected or not. As so, every collected product first appears as a circle, and only when its infection status is known, can it change its shape to a lozenge, and only if the product is infected.

Table 7 – Infections, collected biological products and antibiotics overview requirements

A.5 Main overview window requirements

ID	Requirement	Description
MO1	Top interface of main overview window composed of requirements specified in sections A.1, A.2 and A.3	The top sections of the interface of the main overview window of ICInf are composed by the requirements specified in sections A.1, A.2 and A.3. These requirements specify the ICU bed map, the patient's data and the in-days' display sections.
MO2	Bottom interface of main overview window composed of requirements specified in A.4	The bottom section of the interface of the main overview window of ICInf is composed of the requirements specified in section A.4, which defines the way the graphical display of infections, products and antibiotics is built.

Table 8 – Main overview window requirements

A.6 Infection registering requirements

ID	Requirement	Description
IR1	Infection registering in the detailed in-day screen	The registering of infection is always done on the detailed in-day screen. Whenever an action leads to the registering or updating of infection data, the detailed in-day screen should be opened.
IR2	Infection data registering form	There should be a complete form to insert data about infection for the previously selected patient.

IR3	Biological product collection date automatic filling in	The biological product collection date should be automatically filled in when an in-day is clicked on the in-days display section. This is the calendar date corresponding to the selected in-day.
IR4	Type of infection selection by radio button	The type of infection to register should be selected between two options: nosocomial infection or community infection. This selection is made by a radio button that, by default, is selected on the nosocomial infection option.
IR5	Suspected diagnosis drop down list	The suspected diagnosis is chosen from a drop down list, containing the five more frequent diagnosis on the top of the selection and the remaining ones below, ordered alphabetically. This is a mandatory field of the form.
IR6	Collected biological product drop down list	The choice of the collected biological product to register is made by a drop down list. This list is composed of all biological products ordered alphabetically. This is a mandatory field of the form.
IR7	Analysis ID text box	The form should contain a text box to register de analysis ID. This is a mandatory field of the form.
IR8	Result date text boxes	The form should contain a three text boxes to register the result date's day, month and year, respectively. This field can be left blank, while the infecting agent and the final diagnosis fields are blank. If either one of those fields is filled in, this becomes a compulsory field.
IR9	Result date calendar	There should be a calendar button, that when clicked opens a pop-up window with a calendar, in which the user can choose a result date, with a click over the desired date. The selected date is automatically inserted into the result date fields.

IR10	Infecting agent drop down list	The infecting agent is chosen from a drop down list of all existing micro-organisms, ordered alphabetically.
IR11	Final diagnosis drop down list	The choice of the final diagnosis is made by a drop down list. This list is composed of three possible choices: confirmed, colonization or not confirmed.
IR12	OK button	Below the infection registering form there should be an OK button that, when clicked, submits the form data.
IR13	Cancel button	Next to the OK button there should be a Cancel button, which, when clicked, will delete all previously inserted data and will not submit the form.
IR14	Choice of micro-organism sensitivity interaction with existing antibiotics.	To the right of the infection data registering form there should be a section with the grid for choosing the interaction between antibiotics and the chosen micro-organism.
IR15	List of antibiotics in the right section	There should be a complete list of ICU antibiotics in the interaction grid. In front of each of the antibiotics, there should be a square button, which determines the type of interaction between its respective antibiotic and the previously selected micro-organism.
IR16	Colour coding of the micro-organism interaction with an antibiotic button	The buttons determining the type of interaction existing between the previously selected micro-organism and the buttons' respective antibiotic should be colour coded. If the interaction is neutral, the button should be white and should contain the letter N. If the interaction is of sensitivity, the button should be green and contain the letter S. If the micro-organism is resistant to the

		button's antibiotic, the button should become red and display the letter R. If the interaction is intermediate, the button should be yellow and contain the letter I. The initial status for every button is N and when clicked it switched to S, when clicked again, to R, then to I and then back to N.
IR17	Change of the biological product collection date by direct update on the date field	The biological product collection date can be changed by direct update on the collection date text field. The user clicks on the text field and enters the new date.
IR18	Previous date button	To the left of the biological product collection date there should be a button represented by a **-**. When clicked, this button should change the collection date to the date previous to the registered collection date.
IR19	Following date button	To the right of the biological product collection date there should be a button represented by a **+**. When clicked, this button should change the collection date to the date following the registered collection date.
IR20	Change of the biological product collection date by the calendar button	The biological product collection date can be changed by clicking on the calendar button that is located to right of the following date button. When the calendar button is clicked a calendar pop-up window opens and a new date can be chosen by clicking above it. After that the calendar pop-up window should be closed and the selected date should be inserted on the biological product collection date field.

IR21	Validation of the new biological product collection date	When there is an update on the biological product collection date, the new chosen date should be validated so that: ▪ it is a valid calendar date; ▪ the new date is not previous to the selected patient's admission to the ICU.
IR22	Validation of the new result date	When the result date is updated, the new date should be validated so that: ▪ it is a valid calendar date; ▪ the new date is not previous to the product collection date.

Table 9 – Infection registering requirements

A.7 Detailed information about a selected patient's infection requirements

ID	Requirement	Description
PDII1	Display of infection information with one record of infection in each line	All infection information about the selected patient should be displayed linearly, so that each line represents a whole infection process record.
PDII2	Update button	To the left of each infection detailed information line, there should be an update button that, when clicked, allows the users to update the respective line's infection information. This update is made on the infection registering form section of the screen.
PDII3	Suspected diagnosis information	The registered suspected diagnosis should be presented in the box under the suspected diagnosis label.

PDII4	Type of infection information	The infections can be of one of two types: nosocomial or community acquired. When the registered infection is nosocomial, the type field should present an N and should be coloured light blue. If the infection is community acquired, the type field should contain a C and be coloured yellow.
PDII5	Collected biological product information	The collected biological product's box should be coloured with the colour code associated with the respective product. Each product has a different colour associated with it.
PDII6	Biological product collection's date	The biological products' collection date should be displayed in the format dd/mm/yyyy.
PDII7	Analysis result's date	The date in which the results from the biological product arrive at the ICU should be displayed in the format dd/mm/yyyy.
PDII8	Micro-organism information	When the micro-organism affecting the selected patient is identified, it should be displayed on the infecting agent box. This box is colour coded according to the respective micro-organism's severity.
PDII9	Final diagnosis information	According to the final diagnosis – confirmed, colonization or not confirmed, the font in which the final diagnosis is written, should be coloured red, green or black, respectively.
PDII10	Layer over unselected dates infection information	The infection information related to other days than the one selected should be covered with a blue transparent layer, to indicate that information is about a different date than the selected one. This way, the information about the current date is evidenced.

PDII11	Display of prescribed antibiotics	When an antibiotic is prescribed to the selected patient it should be displayed on the interaction grid of micro-organism/antibiotic. The squares relating the micro-organism with that antibiotic should be rounded by a blue rectangle which works as an antibiotic selector. The names of the antibiotics in use should be displayed in bold.
PDII12	Micro-organism/ antibiotic sensitivity interaction grid information	In the end of each infection information display line, there should be a set of squares crossing information about the respective line's micro-organism and the respective column antibiotic. These squares display a letter and are colour coded, according to the type of interaction between the micro-organism and the antibiotic. If the micro-organism is neutral to the antibiotic, the square should display an N and be coloured white. If the micro-organism is resistant, there should be an R and a red colour in the square. If the micro-organism is sensitive, the square should be coloured green and display an S and if the micro-organism's interaction is intermediate, the square should be yellow and show an I.
PDII113	Sliding of lines in the infections list	Infection information regarding the currently selected date should be centred, but consulting information about other dates should also be possible, by the use of scroll down and up buttons, such as these: ⬇⬆, respectively. When the scroll down button is clicked once, the infection information list slides one position down, showing the next available line. When the scroll up button is clicked once, the infection information list slides one position up, showing the previous

		available line. If any of these buttons is continuously clicked, the infection information slides rapidly to the bottom or the top of the list, respectively.

Table 10 – Detailed information about a selected patient's infection requirements

A.8 In-days detailed window requirements

ID	Requirement	Description
IDD1	Top interface of in-days detailed window composed of requirements specified in sections A.1, A.2 and A.3	The top sections of the interface of the in-days detailed window of ICInf are composed by the requirements specified in sections A.1, A.2 and A.3. These requirements specify the ICU bed map, the patient's data and the in-days' display sections.
IDD2	Bottom interface of in-days' detailed window composed of requirements specified in A.6 and A.7	The bottom section of the interface of the in-days detailed section window of ICInf is composed of the requirements specified in sections A.6 and A.7, which define the way information about infection can be inserted, listed and updated in ICInf.

Table 11 – In-days detailed window requirements

A.9 Specific patient's infection details requirements

ID	Requirement	Description
SPID1	The interface for specific patient's infection details should include requirements in sections A.1, A.2 and A.3	The specific patient's infection details section should comprehend the requirements specified in sections A.1, A.2 and A.3, regarding the top section of the screen. These requirements specify the display of the ICU map, patient's details and in-days' display, respectively.

SPID2	Display of patient's infection overview	The requirements for the display of patient's infection overview are the same as requirements IPA2, IPA6 and IPA9
SPID3	Display of blue selector for chosen infection	Around the previously clicked infection button, there should be a blue circumference, indicating that infection is selected.
SPID4	Display of orange selector for other occurrences of chosen infection	For all other occurrences of the same type of infection as the one that was selected, there should be an orange circumference, signalling this is another happening of the same infection.
SPID5	Graphic of the evolution of selected type of infection in the ICU	To the right of the patient's infection overview display there should be a graphic with the incidence in the ICU of the selected type of infection for the previous week. The vertical axis represents the number of patients and the horizontal axis represents the dates.
SPID6	Display of list of infections, with one record of infection in each line	There should be a list of all infections affecting the selected patient, as specified in requirements of section A.7, except requirement PDII10.
SPID7	Layer over unselected micro-organisms	The infection information related to other micro-organisms other than the one selected should be covered with a blue transparent layer, to indicate that information is about a different micro-organism than the selected one. This way, the information about the current micro-organism is evidenced.

Table 12 – Specific patient's infection details requirements

A.10 Detailed general infection display requirements

ID	Requirement	Description
DGI1	Display of ICU map	There should be a display of the ICU map as specified by the requirements of section A.1.
DGI2	List of micro-organism buttons	All micro-organisms that are infecting or have ever infected the ICU, should be displayed as an horizontal list of buttons, to the right of the ICU map.
DGI3	Colour coding and shape of micro-organism buttons	Each micro-organism button should be represented by a circle with an abbreviation of the infection name and a colour coding: red – highly critical, yellow – medially critical, green – no infection or controlled infection.
DGI4	Signalling of the selected micro-organism button	Whenever a micro-organism button is selected, it should become larger that the remaining ones, so that the selected button is clearly noticeable.
DGI5	Graphic for the five most common infections in the ICU	Below the ICU map there should be a graphic displaying the five infections that occurred in a larger amount of patients during the previous week. This graphic has the number of patients in the vertical axis and the dates on the horizontal axis.
DGI6	Graphic of the evolution of selected type of infection in the ICU	To the right of the graphic for the five most common infections in the ICU there should be a graphic showing the evolution of the selected type of infection in the ICU. The specification of this graphic is described in requirements SPID5.
DGI7	Listing of all patients infected with selected	Below the graphics section, there should be a listing of all in-patients who are or where infected with the selected micro-organism. This listing

	micro-organism	should provide detailed information about all the infection variables, such as described in section A.7, except for requirements PDII10 to PDII13. In addition the list should contain names of the infected patients, one for each line.
DGI8	Update buttons	To the left of each infection detailed information line, there should be an update button that, when clicked, allows the users to update the respective line's infection information. This update is made on the infection registering form section of the screen.
DGI9	Display of antibiotics the selected micro-organism has interaction with	If the selected micro-organism's interaction with an antibiotic is not neutral, it should be displayed to the right of the listing of infections. There should be a square with the interaction between the selected micro-organism and an antibiotic, for each of the antibiotics the micro-organism is not neutral to. The square should be colour coded and contain a letter, according to the respective interaction. It should be red and contain an R if the micro-organism is resistant to the antibiotic, it should be green and contain an S, if it is sensitive and it should be yellow and contain an I if the micro-organism is neither resistant neither sensitive to the respective antibiotic.

Table 13 – Detailed infection details window requirements