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An Anesthesia Alert System Based on Dynamic Profiles Inferred through the Medical History of Patients

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Abstract: Anesthesia Information Management Systems (AIMSs) have existed for many decades. However, how to turn patient records into strategic information to improve the anesthesia process is still a research challenge. We did not find systems that use data from previous procedures for issuing alerts. This data can prevent errors during procedures and aid on medical staff evaluation. We propose SaneWatch, an alert system guided by the medical history of patients. SaneWatch uses configurable rules to continuously review the patient's history and automatically generate an anesthesia profile. This dynamic profile allows the emission of strategic alerts during the anesthesia procedures. We have implemented and integrated the system in an AIMS that has been used the past four years by more than 40 anesthesiologists in several hospitals in the city of Porto Alegre in southern Brazil. We applied the integrated system in a practical experiment. Twenty doctors tried it and filled out a questionnaire based on the Technology Acceptance Model (TAM). An overall strong agreement of 96% was obtained in perceived usefulness acceptance assessment. In addition, 86% of users indicated that the system was easy to use. The results were encouraging and demonstrate the potential for implementing SaneWatch in anesthesia procedures. However, 12% of doctors disagreed with regard to ease of use, showing that the system needs improvements in interface related aspects.

Keywords: Anesthesia Information Management System, Trails, Profiles, Alert Systems.
Categories: H.3.3, H.3.4, H.4, M.5

1 Introduction

Anesthesia Information Management Systems (AIMSs) were developed in order to facilitate the job of anesthesiologists, bringing all the benefits of a digital record to a previously paper-only registry. An AIMS allows better control over the use of drugs, the cost of the procedure and patient safety. Most of these systems run on workstations, tying users to a static machine at any time they need to access information [Kadry et al., 2012].

Although AIMSs are available since the 70s, their dissemination has been weak due to factors such as the high cost of implementation. Only 5% of operating rooms in the USA used an AIMS up to 2006. However, a significant increase has not occurred until 2009, when 44% of academic centers in the USA were using or had interest in using an AIMS [Ehrenfeld and Rehman, 2011].

An AIMS can go beyond the functionality of registering data as demonstrated by the Smart Anesthesia Manager (SAM) [Nair et al., 2013]. SAM is coupled into an AIMS and, based on pre-established rules, monitors the database to bring relevant information to the user during a procedure, allowing gains such as improving the integrity of the data recorded and the reduction of medication costs [Nair et al., 2013].

SaneMob is an AIMS developed in 2012 through a partnership between the Anesthesiology Society (SANE) and the DigitalDesk Company, both institutions from Porto Alegre/Brazil. The system digitalizes the paper form that SANE used. Since then, SaneMob has registered medical procedures for over 14 thousand patients.

Mobility was a key aspect during SaneMob development since most interviews and procedures done by the team happened in several different hospitals throughout the city. Mobile systems should always consider moments when the user does not have access to an online connection [Satyanarayanan, 2001]. Thus, SaneMob can be used offline through a local database. Once the system becomes online again, it synchronizes the data with the central server.

SaneMob records a significant amount of data from procedures but lacks in turning that data into information for use in future procedures. We have reviewed related work on alert systems for AIMSs (section 5) and, based on this literature review, we have concluded that the current AIMs also lack strategies for automated data use to assist anesthesiologists. More specifically, none explores previous medical data to send alerts during surgical procedures. So, the objective of our work was the development of SaneWatch, an anesthesia alert system based on medical history of patients. In this sense, we saw the opportunity to use the patient’s history to manage a dynamic profile [Wagner et al., 2014] that can be used to display alerts. The profile information can contain relevant patient data, such as allergies and previous complications in the operating room. This type of information can minimize human error and improve the efficiency of anesthesia procedures.

SaneWatch continuously processes the patient’s historical data to generate a dynamic profile. In addition, the system uses the profile to send alerts during an anesthesia procedure. SaneWatch is based on our previous research in trails management [Silva et al., 2010; Rigo et al., 2015; Oliveira et al., 2013; Oliveira et al., 2015], profiles management [Wagner et al., 2014] and ubiquitous care [Vianna and Barbosa, 2014]. The system follows the principles established by Wagner et al. [2014], but focuses the profile management on AIMSs and alert systems.

The remainder of this article is organized as follows. First, the background concepts are introduced in section 2. Section 3 describes the SaneWatch system. Section 4 approaches evaluation aspects, describing experiments and results. Section 5 discusses related works focusing on contribution of the proposed system. Finally, section 6 presents the concluding remarks and directions of future works.

2 Theoretical Foundation: Trails, Profiles, and AIMSs

Studies show that not only the current contexts of users are important to provide adaptive services, but also their contexts histories [Wagner et al., 2014; Hong et al., 2009], which can also be called Trails [Silva et al., 2010; Driver and Clarke, 2008]. Although the concept of trails is typically connected to the location of a user, the term can have a broader definition, encompassing past activities, used applications or accessed content [Silva et al., 2010].

SaneWatch uses trails formed by procedures that patients had with the SANE team and were recorded in the SaneMob system. All procedures are placed in a chronologically structured database, which allows the historical analysis of the patient or anesthesiologist.

Complementarily, profiles contain the most important facts about users [Wagner et al., 2014] from the system point of view, such as interests, preferences, goals, among others. The profiles and how they are obtained vary depending on the application [Schiaffino and Amandi, 2009]. SaneWatch manages anesthesia profiles and gets relevant facts by analyzing patients' trails as detailed in Section 3.

Anesthesiologists have the task of keeping a patient physiologically stable while a surgeon performs a surgical procedure. Sometimes, the anesthesiologist can be overloaded, increasing the likelihood of errors in the data registration or in the task itself. For example, the anesthesiologist may forget to register an already administered antibiotic [Nair et al., 2013].

Until the development of the electronic anesthesia record, all information was placed and kept in a paper form that has changed very little since its development in 1890. Since then, information was added to the form and new technologies have enabled the use of electronic forms. However, the model has been kept as a longitudinal table with the measurements made by the anesthesiologist during the procedure.

Some of the problems with the paper record are the possibility of data loss or difficulty reading and especially the difficulty sustaining attention on the patient while entering data in the form [Kadry et al., 2012]. The first AIMSs emerged in the 70s when an anesthesiology department implemented a system for the manual electronic record of anesthetics data and its visualization through charts [Daub et al., 1975].

The data collection by the anesthesiologists starts in an interview done prior to the procedure. This interview considers the condition of patients, evaluating whether they are fit for the procedure. The detection of pre-existing medical conditions and their severity is relevant for risks reduction during the procedure.

Although the importance of this preoperative visit is recognized worldwide, there is no specific set of questions to be asked. Generally, the anesthesiology team determines the data to be collected and treats them as a pattern [Ausset et al., 2002]. Some of the information normally collected are medical history, physical conditions obtained through an examination, laboratory exams, medications taken by the patient, perioperative risk assessment (ASA), cardiac risk assessment and pulmonary risk assessment [Zambouri, 2007].

Preoperative data collection tools are as important as those used during the procedure. However, accessing a system to peruse pages and pages of medical records from previous procedures can be exhausting work [Kadry et al., 2012].

3 The SaneWatch System

This section describes the proposed system. Section 3.1 discusses the AIMS in which the SaneWatch was integrated. The remainder of this section approaches the architecture of SaneWatch, focusing primarily on its profile management.

3.1 SaneMob System

SaneMob was based on the recording process used by the SANE team. Among the main requirements that guided the development, some that stood out were the mobility support, the maximum sharing of data between the doctors and legal aspects such as the requirement of hospitals to have a paper record. In this sense, SaneMob was organized in two parts: (1) a central server accessed by a Website and a Web service; (2) an Android application for mobile devices. Figure 1 shows the SaneMob architecture and its integration with SaneWatch.

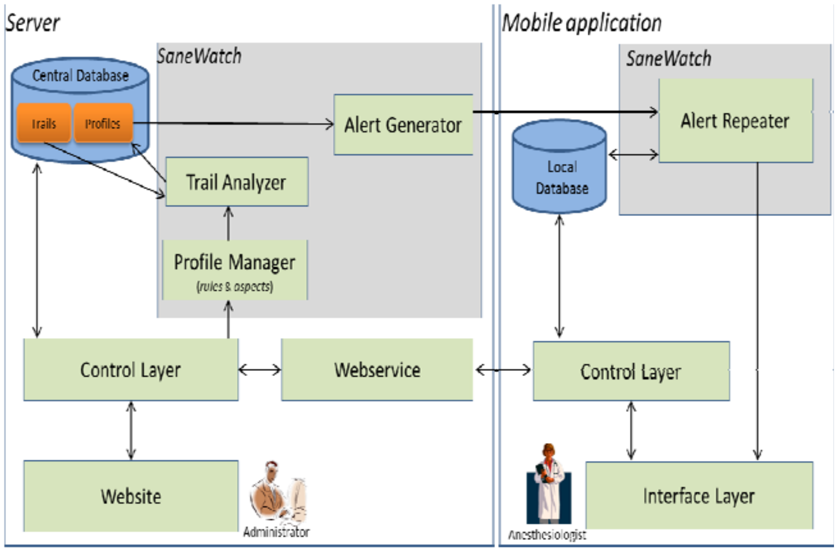


Figure 1: SaneWatch architecture integrated to SaneMob

The server has a Central Database that stores all the data needed for filling out the anesthesia forms, such as cities, occupations, diseases, exams and drugs. The Webservice allows communication with the mobile devices running an Android application (detailed in Section 4.3). The Website allows the inclusion and changing of patient data and the visualization of procedures records.

The Control Layer is divided into two parts to support the synchronization between data in the mobile database (Local database) and the server database (Central database). On the mobile device, this component always searches the Webservice when it is connected and sends any information that was included in the offline mode. On the server, this component is accessed whenever some action is performed through the Website or Web service.

The offline mode can generate inconsistency if different clients update data in the Local databases and, after some time, they synchronize with the Central database. SaneMob deals with this data conflict through a simplified strategy based on consistency of versions. If the version of data that the user is attempting to update on the central server is the same version that is being used on the local device, the user will be allowed to update. On the other hand, if the version on the server is more recent, it means that another user made changes to the database. In this case, the user is directed to contact the user who made the changes to complement the data. This simplified strategy is feasible because simultaneous access to the central database is rare and the SaneMob team is small and collaborative. However, this strategy would not be feasible for a larger system. A more adequate strategy would be to automatically merge the version on the server with the version being updated. We intend to include this approach in future versions of SaneWatch.

The mobile application allows the inclusion of personal information of patients, but its main use is to introduce the data obtained in the preoperative interview and the monitoring data of anesthetic procedures. The Interface Layer supports this interaction with users. Section 4.3 shows screenshots and describes functionalities of the mobile application prototype.

The preoperative form contains information on the medical history of patients, such as the daily use of drugs, allergies and risk assessments by the anesthesiologist based on this information. SaneMob considers that connectivity to the central server can be intermittent since the wireless Internet connections in hospitals may be limited, and therefore data entry during procedures may be lost. Considering that, the mobile application has the Local Database and synchronizes information with the central server whenever possible. This synchronization maintains consistency between local and central databases. However, updating profiles and generation of alerts are performed on the server. Thus, intermittent communication can be a problem on certain critical occasions, such as surgical procedures. In such situations, a trusted connection must be guaranteed to allow real-time input of information and receipt of alerts.

3.2 SaneWatch System

SaneWatch extends SaneMob system including components in the server and the mobile application, as can be seen in Figure 1. SaneWatch analyzes the trails of anesthesia data in the Central Database and generates the patients' profiles. The profile generation follows inference rules, and each user has a dynamic profile [Wagner et al., 2014] stored in the Central Database.

The Profile Manager contains rules and services to manage the profiles. The Trail Analyzer applies the rules on trails to generate the profiles. These components were included in the server. The Alert Generator monitors the profiles to emit alerts. In the mobile application, the Alert Repeater accesses the interface to show the emitted alerts. Next subsections detail the SaneWatch architecture.

3.3 Patient Profile

The medical history of a patient contains most of the information used by the anesthesiologist for decision-making during an anesthesia procedure [Zambouri, 2007]. In previous versions of SaneMob and in all related works described in Section 5, the doctors are restricted to use information gathered from the interview and on their own effort to study the patient anesthesia records.

The Patient Profile of SaneWatch covers this gap, enabling AIMSs to consider all patient records in an automatic manner (trail [Silva et al., 2010; Driver and Clarke, 2008]). In addition, information is shared and used in any anesthesia procedure regardless of who is the anesthesiologist.

Figure 2 illustrates the process of profiles composition. A profile consists of aspects of a patient, which are updated through inference rules that analyze the trail. The profile is stored in the central database, and created or updated automatically at a certain time (for example, prior to a surgical procedure). As shown in Figure 2, a specific rule can be used to infer in different trails and update the aspect in different profiles.

We have shown in previous studies [Rigo et al., 2015; Wagner et al., 2014] that this strategy is suitable for generating profiles through inferences on trails, because trails are usually very dynamic, and inference rules propagate this dynamism to profiles. Dynamic profiles [Wagner et al., 2014] are constantly updated, thus allowing automatic adaptation of profiles to the medical history of patients.

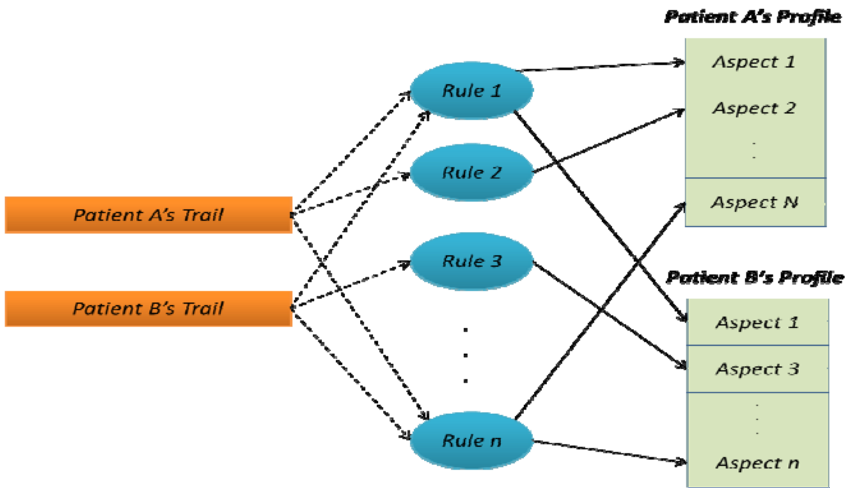


Figure 2: Composition of a profile

The most relevant aspects to be considered in anesthesia procedures were organized into three categories with the help of SANE team:

1. *Chronical Diseases:* Diseases of slow progress, long duration and non-communicable, such as obesity, heart diseases, diabetes, cancer and the use of alcohol or tobacco [NCD, 2016];

2. *Previous Complications:* Any report of an unforeseen consequence in a previous procedure, such as an allergic reaction to a drug or an unexpected

difficulty with the patient's airways is valuable information when preparing a new procedure;

3. *Drug Use:* The anesthesiologist needs to be aware of any drug the patient takes or has taken regularly [Zambouri, 2007], as well as any allergies that arose in previous procedures.

3.4 Profile Manager

The Profile Manager maintains information for guiding the Trail Analyzer during updating of profiles, organizing rules and their composition to form aspects, as shown in Figure 2.

The rules create dynamic relationships between aspects and data recorded by anesthesiologists about the medical history of patients (trails). These data can be, for example, a disease, a drug or a type of complication, as indicated in the previous section.

An alert level is also assigned to each aspect (low, medium or high). This level determines how the Alert Generator will differentiate the priority aspects. An aspect may be more significant than others due to a greater impact on anesthesiologist's risk assessment.

Figure 3 shows an example representing a specific moment of composition of three profiles through four rules. The rules are simple sentences that are used to infer the trails to identify if the patient has a specific aspect to be included in the profile. When an aspect is identified on a trail through a rule, it is included in the profile. In the example, the patient 2 has three aspects, namely, one previews complication and two allergies. The aspect is composed by three fields: (1) its kind; (2) a specification related to the kind of aspect; (3) the alert level. The profile is a list of aspects that is created by the rules.

The Profile Manager stores a collection of rules and their related aspects. The example in the figure 3 contains the four rules used in the SaneWatch's evaluation described in section 4, but any kind of rule can be included to monitor other aspects. For example, a rule can be used to monitor if the patient was indicated with obesity or depression in a moment of his treatment.

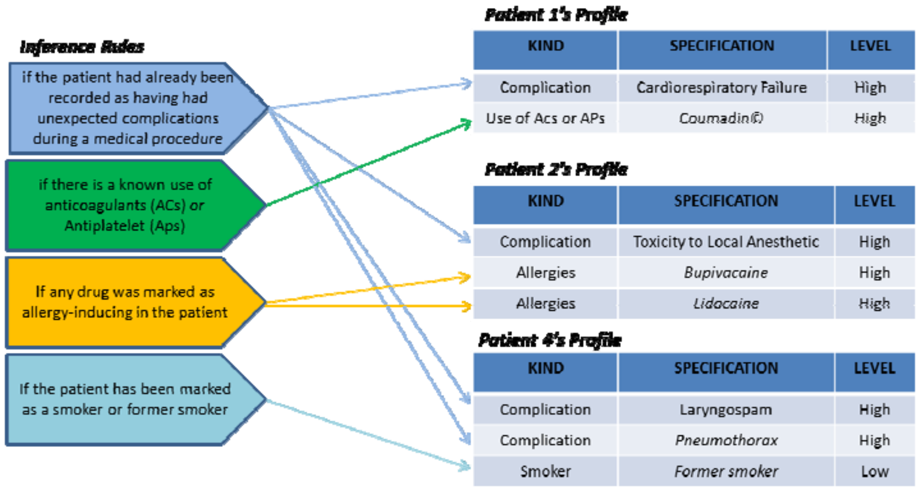


Figure 3: Example of rules and profiles

3.5 Trail Analyzer

The Trail Analyzer is the engine that analyzes patients' trails to update the profiles. Updates are managed through the rules and aspects, which are available in the Profile Manager. Every time a rule associated with an aspect is satisfied, the aspect is added to the patient's profile.

Whenever the patient's trail is changed, such as when a new medical procedure is added, the Trail Analyzer is enabled to update the profile of this particular patient. In addition, once a rule or aspect is added or updated, the Trail Analyzer is activated to examine all trails, making sure that the new or modified rule or aspect was taken into account for all profiles.

Figure 4 shows an example of Trail Analyzer operation. At the top, the figure contains two trails with information from medical histories of patients 2 and 5. Information related to previous anesthesia procedures is considered strategic. This information is used by Trail Analyzer to generate the profiles. As indicated in Section 3.4, the Profile Manager has the rules and aspects used by Trail Analyzer. On the right are the two profiles generated in the example.

The Trail Analyzer performs its function in three steps as shown in the figure: (1) the rules and their respective aspects are read to guide the analysis of trails; (2) the trails are searched for relevant aspects to be considered in anesthesia procedures; (3) whenever a rule is satisfied on a trail, the respective aspect is included in the patient´s profile. In the example, two profiles were created. The Patient 2's profile contains three aspects, one previous complication and two allergies. The Patient 5's profile has two aspects, one indicating prior use of anticoagulants or antiplatelet drug and other related to an allergy. As shown in Figure 1, trails and profiles are stored in the Central Database. In addition, updating profiles does not change the content of the trails, which remain in the database.

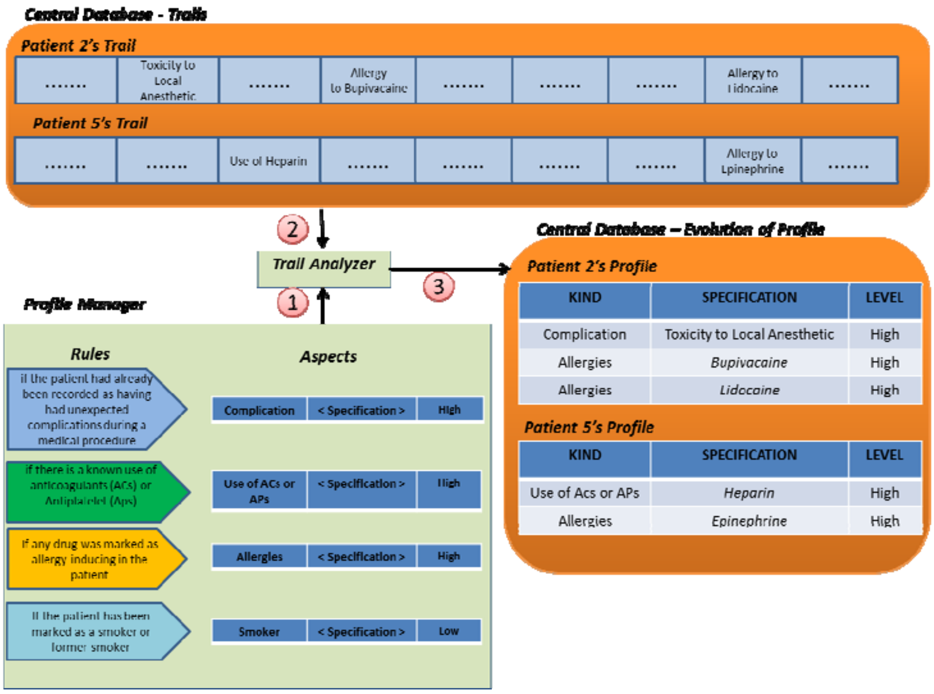


Figure 4: Example of Trail Analyzer's steps

3.6 Alert Generator and Alert Repeater

The Alert Generator manages the delivery of information to the anesthesiologist. This component monitors the profiles and generates alerts at strategic moments during the form filling process. For example, an alert about the patient allergies can be generated whenever a doctor is about to register the use of a drug in the procedure.

Alerts are related aspects and if a patient has a specific aspect in the profile and this aspect is relevant at a time, an alert is issued. In addition, every aspect has an alert level (low, medium or high) that regulates the priority of emissions.

The Alert Repeater acts as an interface manager, showing alerts via messages in the interface layer where the user visualizes a form used in the procedure.

4 Prototype and Evaluation

This section describes the implementation and evaluation of SaneWatch. The first subsection defined a set of aspects and rules to generate profiles. The second describes the implementation of server components that allowed the application of these rules in the database currently in use by SANE team in order to get the system use metrics. The development of an Android prototype application for the Alert Repeater is presented in the third subsection. The prototypes of the server and client were completely integrated with SaneMob. The fourth and final subsection contains a

Technology Acceptance Evaluation [Marangunić and Granić, 2015] involving the current users of the system.

4.1 Testing Aspects and Rules

The SANE team considered four aspects as strategic to be initially incorporated into SaneWatch. Each aspect is based on a set of rules that allows the Trail Analyzer to correlate the aspect to a patient's profile (see Figure 2). The selected aspects are as follows:

1. Previous occurrence of complications: This aspect indicates "if the patient had already been recorded as having had unexpected complications during a medical procedure" (inference rule), such as cardiorespiratory failure;

2. Use of anticoagulants and/or antiplatelet drugs: Several restrictions are applied to patients before a medical procedure "if there is a known use of these drugs" (inference rule);

3. Allergy to Drugs: "If any drug was marked as allergy-inducing in a patient" (inference rule), this information must be part of the profile, helping to prevent allergies in a future procedure;

4. Smoking history: "If the patient has been marked as a smoker or former smoker" (inference rule), this aspect must be linked to the profile.

4.2 SaneWatch Server Prototype

SaneWatch development used the same tools applied in the implementation of SaneMob system. The profiles were included in the already-existing Microsoft SQL Server database (see Central Database, Figure 1). Patient trails were already in the database but without a pre-established format or order.

Therefore, an inference engine (Trail Manager) to read the trails was implemented, allowing the use of rules to compose profiles. The prototypes of Trail Analyzer, Profile Manager, and Alert Generator were implemented using C# language, Microsoft .NET framework and Microsoft's EntityFramework.

On the first run, SaneWatch analyzed the complete trails of all patients enrolled in the database. The four aspects indicated as strategic by the SANE team (Section 4.1) were used to create the profiles. Table 1 shows the number of occurrences of each aspect.

4.3 SaneWatch Android Prototype

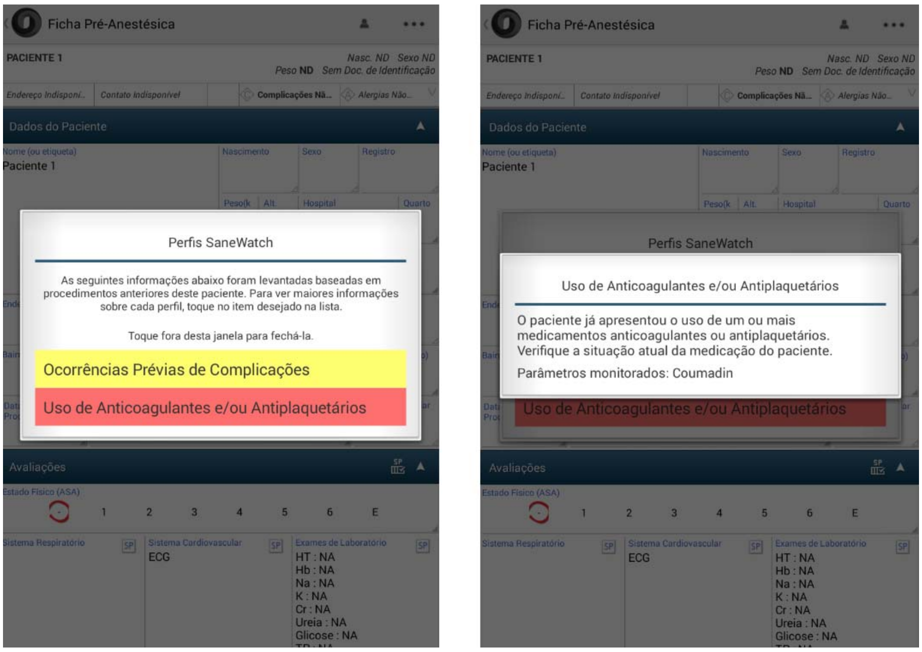
The SaneMob mobile client was implemented using Android technology, and SaneWatch was integrated into SaneMob client using the same technology.

The Alert Repeater on the mobile device receives an alert from the Alert Generator in the server, whenever an action in the anesthetic procedure involves an aspect highlighted in the profile.

The Alert Repeater opens a window that contains the name of the aspect and a background color based on the alert level configured for the aspect (Figure. 5a). If anesthesiologists need more information about the aspect, they can follow the link to the aspect, and a new window opens with additional information (Figure 5b). To dismiss these alerts, the user simply has to touch outside of the window boundaries.

Aspects	**Occurrences**	**%**
Previous occurrence of complications	529	3,57
Use of anticoagulants and/or antiplatelet drugs	1241	8,37
Allergy to drugs	1581	10,66
Smoking history	4384	29,57

Table 1: Occurrences of aspects



(a) (b)

Figure 5: SaneWatch execution (screens in Portuguese). (a) Two alerts to aspects detected - yellow (medium level) to "Previous occurrence of complications" and red (high level) to "Use of anticoagulants and/or antiplatelet drugs". (b) The anesthesiologist asked more information about the second alert

4.4 Technology Acceptance Evaluation

A technology acceptance test was conducted to evaluate the user acceptance of the system [Marangunić and Granić, 2015]. In total, 47 doctors were invited to try out the prototype. Of these, 20 participated in the survey. All anesthesiologists were users of SaneMob, so they were able to give qualified opinions specifically about SaneWatch and its new features.

Five patients were simulated with medical conditions specifically chosen to better configure the evaluation. Two doctors from the SANE team participated with suggestions to make the clinical situations of patients as real as possible. Based on real profiles, an amount of complications, drugs, allergies and medical assessments were chosen for each patient (see Table 2).

Name	Complications	Use of ACs or Aps	Allergies	Smoker
Patient 1	Cardiorespiratory Failure	Coumadin©		
Patient 2	Toxicity to Local Anesthetic		Bupivacaine, Lidocaine	
Patient 3		Marevan©		Smoker
Patient 4	Laryngospasm, Pneumothorax			Former Smoker
Patient 5		Heparin©	Epinephrine	

Table 2: Patients of the Technology Acceptance Evaluation

The prototype was made available to the anesthesiologists, and they were asked to perform for each one of the five patients the same procedure as they are accustomed when filling the anesthetic procedure forms on SaneMob. The methodology adopted in the experiment involved three steps which are described in the following paragraphs.

The **first step** comprised the creation of the five patient profiles indicated in Table 2 and recording them in the mobile device to be used by the evaluator. In the **second step**, the doctors accessed the SaneMob and received instructions to carry out the test considering the five previously recorded profiles. Because they knew the system and the simulated profiles, they were able to test real situations that occur in their professional lives. Users were advised to freely test the entire system according to their interests. Because the alert generator was added to the existing system, it did not limit any pre-existing functionality. Alerts were issued automatically when the doctors generated specific situations created by them in procedures involving the five profiles. They received alerts regarding the aspects indicated in the Table 2, requesting additional information according to their interest. Possible interaction problems with the mobile devices were minimized, because doctors used the prototype in their own tablets and smartphones.

In the **third step**, after trying the system the subjects were asked to answer an assessment questionnaire. The questionnaire was created following the Technology Acceptance Model (TAM) proposed by Davis [Davis, 1989] and applied and expanded by Yoon and Kim [Yoon and Kim, 2007] in their study on the acceptance of wireless networks.

Category	Statement
Perceived Usefulness	1. Patient identification via profile is useful for the analysis of the patient.
	2. The profile helps in understanding a particular patient´s condition.
	3. The reason for having an aspect linked to a patient is clear and understandable.
	4. The alerts are generated at the appropriate moments according to the current context.
	5. The alerts help in the decision-making process.
	6. The colors system helps in the perception of the severity of each alert.
Perceived Ease of Use	7. The names and descriptions of the aspects allow understanding them.
	8. The alert window is easily understandable.
	9. Even with several aspects displayed on the same alert window, it stays coherent and easily understandable.
	10. The button in the top menu to open the aspects window is easily found and accessed.
	11. The alert window is easily closed.

Table 3: Questionnaire Statements

Currently, TAM is considered a standard to evaluate the technologies acceptance [Marangunić and Granić, 2015]. In the TAM model, user satisfaction is measured through perceived usefulness and perceived ease of use. The first perception determines whether the proposed technology can help the user to do a better work, while the second evaluates if the technology can be used with minimum effort.

The questionnaire (Table 3) was composed of eleven statements that were organized in the two categories proposed by TAM. For each statement, the anesthesiologist could answer with "Completely Agree", "Partially Agree", "Indifferent", "Partially Disagree" and "Completely Disagree". These options were proposed according to the Likert scale [Likert, 1932]. Also, there was an open field where the evaluator was free to add remarks about SaneWatch use.

Figure 6 organizes the answers of the 20 doctors according to TAM. On the perceived usefulness, 96% of participants agreed with the system utility and 4% said they were indifferent. A user commented that "The names and alert levels of the aspects can be changed to better reflect their importance". While this need can be seen as a flaw by the evaluator, it shows the importance of flexibility supported by SaneWatch, because both attributes can be modified individually for each aspect.

On the perceived ease of use, 64% of users said to agree with the statements completely, 22% partially agreed, 2% said they were indifferent and 12% disagreed. User comments indicated that the disagreements were related to the alert interface in the Android prototype.

Many participants had trouble closing the alert windows by touching outside the borders, sometimes rendering all the application useless, since the alert could not be closed. The evaluators used their own equipment in the test and most of the anesthesiologists of SANE use the same model of the equipment where the prototype was tested initially (Samsung Tab 2). However, some doctors used other models; it is likely that the problem occurred due to the difference in their interfaces with relation to the development model. Two evaluators who did not report this problem indicated that SaneWatch was "a great alerting system" and that "it was wonderful to handle the system".

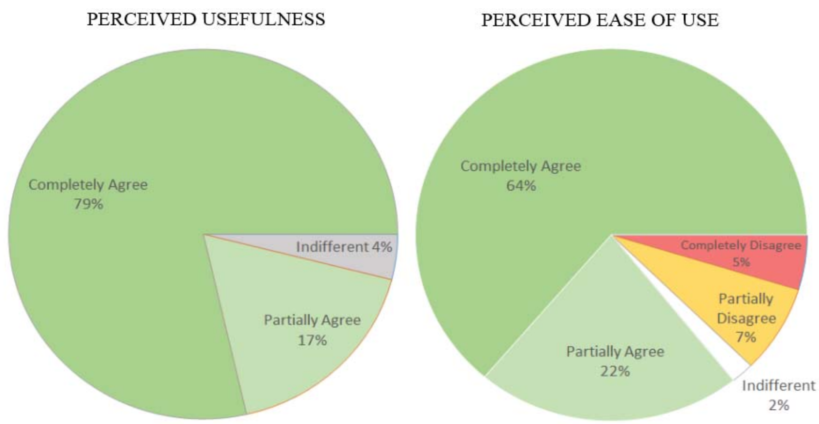


Figure 6: Results of the technology acceptance survey

5 Related Works

The study of related works has focused on four alert systems for AIMSs [Nair et al., 2013; Kheterpal et al., 2007; Wax et al., 2007; Jacques et al., 2005], seeking to discuss the contribution of SaneWatch. The comparison criteria were selected according to the topics considered as strategic for the research, mainly the use of medical history of patients.

Smart Anesthesia Manager (SAM) [Nair et al., 2013] was developed by Washington University Medical Center, applying conditional logic in an existing AIMS. SAM increases awareness of anesthesiologists on multiple data sources during a procedure. A notification system uses rules defined in the Rules Composer module to send alerts according to the relative importance of pending notifications. Research has shown improvements in carrying out tasks that are usually forgotten by anesthesiologists, as well as a drop in the consumption of anesthetics.

Michigan University Anesthesiology Department developed a system to improve the billing of an anesthesia procedure [Kheterpal et al., 2007]. When anesthesiologists forget to report that arterial catheters were used, the billing does not occur at the end of the procedure. Based on vital signs, the system alerts when a catheter may have been used and not registered. The system increased by 15% the correct billing of catheters.

According to the Center for Disease Control (CDC) of the United States, antibiotics should be administered 60 minutes before beginning a medical procedure [Wax et al., 2007]. Mount Sinai Medical School has developed an alert system that reminds the anesthesiologists on this initial administration [Wax et al., 2007]. The system increased by 7% the correct previous administration of antibiotics.

Vanderbilt University Medical center also sought to improve the correct prophylaxis with antibiotic through a system that warns users when a redose is due [Jacques et al., 2005]. Users receive a message and can choose to ignore it or be reminded again in a short period. The correct time of redose increased from 20% to 58%.

We compare the related works in the way they provide support for flexibility in the configuration of the alert system; necessity of external hardware in order to function; and if the system uses the medical history of patients. Table 4 summarizes the results of this comparison.

The flexibility in the configuration of the alert system is determined by support for configuring alerts according to different data and contexts. While the systems proposed by Vanderbilt [Jacques et al., 2005], Mount Sinai [Wax et al., 2007] and Michigan [Kheterpal et al., 2007] show no flexibility, SAM [Nair et al., 2013] uses the Rules Composer to set alerts for any data obtained by AIMS.

The necessity of external hardware is a hindrance for anesthesiologists, because it implies other equipment that demands their attention. SAM [Nair et al., 2013] allows flexibility, but it is the only system that requires the use of additional equipment (pager) to alert the user. All other systems show the alerts directly on AIMS interface.

The use of the medical history of patients explores previous medical data to send alerts in the current procedure. None of the related works explores this opportunity.

SaneWatch uses configurable rules to enable flexibility in the alerts. In addition, the system continuously reviews the medical history of patients and automatically generates their anesthesia profiles. These dynamic profiles are used to show alerts directly on SaneMob interface during surgical procedures. Therefore, SaneWatch contributes through the use of the medical history of patients considering previous procedures and preoperative interviews.

Comparison Criteria	**SAM [Nair et al., 2013]**	**Michigan [Kheterpal et al., 2007]**	**Mount Sinai [Wax et al., 2007]**	**Vanderbilt [Jacques et al., 2005]**	**SaneWatch**
Flexibility in the configuration of the alert system	Rules Composer	No	No	No	Configurable Rules and Dynamic Profiles
Necessity of external hardware	Pager	No Alerts on AIMS interface	No Alerts on AIMS interface	No Alerts on AIMS interface	No Alerts on AIMS interface
Use of the medical history of patients	No	No	No	No	Yes

Table 4: Related works comparison

6 Conclusions and Future Studies

SaneWatch is an anesthesia alert system guided by the medical history of patients (trails). The system generates dynamic profiles of patients through inference rules that continuously monitor relevant aspects of anesthesia procedures.

The profile summarizes strategic information about patients, helping anesthesiologists to prevent medical errors. None of alert systems studied [Nair et al., 2013; Kheterpal et al., 2007; Wax et al., 2007; Jacques et al., 2005] took into account previous medical procedures of patients. In this sense, SaneWatch contributes by including trails management [Silva et al., 2010; Rigo et al., 2015; Oliveira et al., 2013; Oliveira et al., 2015] and dynamic profiles management [Wagner et al., 2014] in AIMSs.

SaneWatch was implemented and fully integrated into the SaneMob system, an AIMS used in the last four years by over 40 anesthesiologists to perform procedures in over 14 thousand patients. Approximately half of these doctors participated in the technology acceptance evaluation.

The first test applied the prototype in SaneMob database to create profiles based on aspects indicated as strategic by the SANE team. The data generated showed that 10% of patients had at least one aspect associated with their profiles.

After that, 20 doctors tried the system and filled out a questionnaire based on TAM [Ehrenfeld and Rehman, 2011; Davis, 1989; Yoon and Kim, 2007]. This second test confirmed that SaneWatch provides useful and relevant information to users, according to the perceived usefulness rate of 96% (completely or partially agreed).

Moreover, 86% of users perceived (completely or partially agreed) that SaneWatch is easy to use. However, 12% of them disagreed (completely or partially) with the ease of use. Comments presented in the open question showed that the system needs improvement in user interface.

The exploration of the possibilities introduced with SaneWatch depends on the administrator's ability to create and maintain aspects that are relevant to the anesthesiology team. The importance of making the aspects and their rules flexible was shown in the comments on the need to change some of the profiles settings. SaneWatch is directly linked to the AIMS, ensuring that all changes made to aspects reach the users as soon as possible.

SaneWatch is an initial proposal, as is its prototype and the integration with SaneMob. According to the results obtained and limitations identified during the development of the work, some proposals to continue the development and expansion of the system can be presented. First, users pointed interface restrictions, as discussed in Section 4. These limitations should be addressed and a more complete evaluation of user interaction with the system should be performed.

Currently, alerts are generated only during a surgical procedure and viewed only in SaneMob interface. Alerts can be sent in different ways (such as email or Twitter) and at different times, for example, when the doctor inserts the data from the interview made prior to the procedure, anticipating a possible critical situation.

This flexibility would allow SaneWatch worked to improve the anesthetic process from an administrative point of view. For example, if a patient had a condition requiring a special kind of equipment or an expert, an automatic e-mail could be sent at the time that a new procedure is initiated for this patient.

Although the real SaneMob database with over 14 thousand patients' trails has been used to generate profiles, SaneWatch acceptance was evaluated through simulation of surgical procedures. An ideal evaluation would involve real procedures of an anesthesiology team for an extended period of time. This test would provide more accurate results and would take into account situations not covered in the simulation.

In this sense, the SANE team and the authors intend to carry out an alpha test. SaneWatch will be available to SANE's anesthesiologists to be applied in their daily procedures. The use will be accompanied by a significant period to measure the effectiveness and to improve the technology acceptance evaluation.

SaneWatch was modeled and implemented specifically for SaneMob AIMS. We did not consider any health information standard, and so SaneWatch cannot be used in other AIMSs. Future studies will be conducted to use standards to improve the generality and portability of our proposal. For example, the use of the Arden Syntax standard can be considered in SaneWatch for clinical decision support [Samwald et al., 2012].

The current prototype was developed to support a first evaluation of the system. We have developed the client for Android because of our extensive experience with this technology. In addition, the SaneMob mobile client was implemented using Android technology and SaneWatch was integrated into SaneMob. Finally, we knew that a large part of the potential users (SANE team) had equipment with Android. On the other hand, we believe that the development of versions for other platforms, especially IOS, will expand the possible number of users. Soon, we intend to implement a version for IOS platform.

We have conducted initial performance tests on SaneWatch, mainly related to the time needed to analyse trails to create profiles. The results were not considered conclusive enough to be included in this article. We intend to carry out as future work an analysis to evaluate the impact of performance in the feasibility of the proposal. In this sense, a specific future work will study how to improve the current strategy for updating the profiles. Currently, all profiles are updated using all trails whenever needed. An alternative to be studied is an incremental strategy to update in the profiles only those aspects affected by the changed rules.

Finally, as demonstrated in recent research works [Rigo et al., 2015; Oliveira et al., 2013; Oliveira et al., 2015; Wagner et al., 2014], inferences on trails allow to develop intelligent strategies for different applications such as logistics management [Oliveira et al., 2013; Oliveira et al., 2015] and learning systems [Rigo et al., 2015]. We intend to use these strategies to introduce intelligent alerts in SaneWatch.

These alerts would allow, for example, the similarity analysis of trails to infer anesthesia risk patterns or the use of trails collected in the ubiquitous care systems [Vianna and Barbosa, 2014] to infer strategic information, improving automatically the anesthesia profiles.

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