Expectations from a Process Mining Dashboard in Operating Rooms with Analytic Hierarchy Process

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Abstract. The wide-spread adoption of real-time location system is boosting the development of software applications to track persons and assets on real-time and perform analytics. Among the vast amount of data analysis techniques, process mining allows to conform work-flows with heterogeneous multivariate data, enhancing the model understandability and usefulness in clinical environments. However, such applications still find entrance barriers in the clinical context. In this paper we have identified the preferred features of a process mining based dashboard deployed in the operating rooms of a hospital equipped with a real-time location system. Work-flows are inferred and enhanced using process discovery on location data of patients undergoing an intervention, drawing nodes (states in the process) and transitions across the entire process. Analytic Hierarchy Process has been applied to quantify the prioritization of the features contained in the process mining dashboard (filtering data, enhancement, node selection, statistics, etc..), distinguishing on the priorities that each of the different roles in the operating room service assigned to each feature. The staff in the operating rooms (N=10) was classified into three groups: Technical, Clinical and Managerial staff according to their responsibilities. Results show different weights for the features in the process mining dashboard for each group, suggesting that a flexible process mining dashboard is needed to boost its potential in the management of clinical interventions in operating rooms.

1 Introduction

Operating Rooms (ORs) is an essential and central element in modern hospitals [1]. Cost estimations of ORs are around 16% and 20% of total hospital budget, due to the amount of human resources mobilized, use of high technology,

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the heterogeneity of roles involved the importance it plays in the image of the institution [2,3]. Efficiency in the management and interventions in ORs aims to reduce the non-occupation time of the surgical blocks and the way to organize the different types of interventions to optimize medical teams (surgeons and nurses). To achieve a good efficiency rates in OR it is crucial to have a protocol and a high skilled staff to take over daily-basis decision making for scheduled and unscheduled interventions [3].

Recent reviews conclude that managerial surgeons make decisions to increase the clinical work per time-unit in individual ORs and that command displays may be an effective way to gain efficiency [4]. This behavior is well-known as reactive scheduling, which involves schedule definition and posterior assessment [5]. The schedule definition entails to foresee starting, duration and ending times for the regular operations sequences (preparation, anesthesia induction, intervention, wake-up and turnover) in terms of time and resources. The posterior assessment monitors the schedule execution and adapts the planned scheduled to deal with unexpected events [6]. Reactive scheduling process occurs when unexpected events or disruptions occur along the process [7]. Nevertheless, the main disadvantage in the ORs planning and management is that processes are often recorded manually by nurses. This issue has been already identified as a bottleneck in the performance assessment of ORs [8]. Moreover, manual notes can also lead to bias: unnecessary delays, under-use of the operation rooms, unnecessary transfers, etc. In addition it could cause an increase in the probability of the adverse effects in the surgical process which, according to [9] stand for the 40% of all the adverse effects in hospitals.

Information and Communications Technology (ICT) can provide tools and systems to support both programming and assessment of operations. To perform this tracking process a pragmatic task *Gonzalez et altres* proposed a semi-automatic information collector [10]. Nowadays, some hospitals are equipping them with Real-Time Location System (RTLS) to manage the location of patients and assets that could help to optimize the management of ORs by applying process mining (PM) techniques.

An example of the use of the extracted data from the RTL Systems to manage the patient locations is introduced by *Fernandez-Llatas et altres* [11], in which PM is applied to perform an analysis of operation sequences and locations in the ORs showing the most common paths and insights of the entire process in ORs based on RTLS data. In this study, researchers developed a front-end application to analyze ORs process providing a complete suite of tools to discover, compare and enhance surgical processes.

Technologies should be presented in a meaningful way to the ORs staff to ensure a successful deployment. The application of computer decision systems in an interactive way will not only increase their effectiveness and efficacy [12], but also involve the staff of ORs in the process of knowledge extraction, avoiding frustrations using technology for managing complex processes [13].

Process mining has multiple unknowns when landing to real applications when the intended user is the clinical staff. In this paper we report a study based on the Analytic Hierarchy Process (AHP) to identify which are the preferred features of a web-based process mining dashboard. This front-end has been presented in [11]. To distinguish the preferences of each role, we have grouped the users in three groups: manager, hospital staff and technical staff of the ORs. We have obtained feature prioritization of 10 subjects including the three roles. The AHP is particularly effective for quantifying experts' opinions that are based on personal experience and knowledge to design a consistent framework for the application of process mining in ORs.

2 Related Work

Real-Time Location Systems (RTLS) monitor with the position of a moving element with a given sampling frequency. In a hospital, moving elements are equipped with an active or passive element (tag) which identifies it when is nearby a beacon. In our study patients are the moving elements who bear a wristband with the tag before entering the operating room service.

Lean principles present a condensed primer of RTLS in health care environment [14]. Throughput is a key performance indicator for a patient pathway across a facility, which linked to RTLS could provide valuable information such as waiting times and resources utilization [15].

RTLS systems in 23 hospitals in the US have been analyzed from a qualitative perspective in [16]. In this work, researchers observed the systems in use and conducted 80 semi-structured interviews with hospital personnel and vendors. Authors find asset tracking as the best feature and identify several obstacles related to the technical set-up and organizational context.

Specifically, the operating room service (Fig. 1) consist of several spaces, each of them equipped with a beacon to identify a patient whenever he/she goes to that specific area.

The application of process mining techniques in combination with RTLS systems provided an easy to use and unobtrusive way to achieve a view of the deployed process. In this paper we analyze the web-based dashboard to perform process mining discovery and enhancement analytics presented by Fernandez-Llatas et altres [11] (Fig. 2).

Analyzing RTLS data from a discovery perspective and enhancing these work flows with information related to the average time and overload it is possible to create pre-programmed contingency plans for the management and allocation of resources of the operating rooms. But, why this promising applications are still not widely used in the clinical context? Instead of using a semistructured interview we have used the Analytic Hierarchy Process [17] to quantify the features of a dashboard for discovering and enhancing processes based on RTLS data in a ORs service.

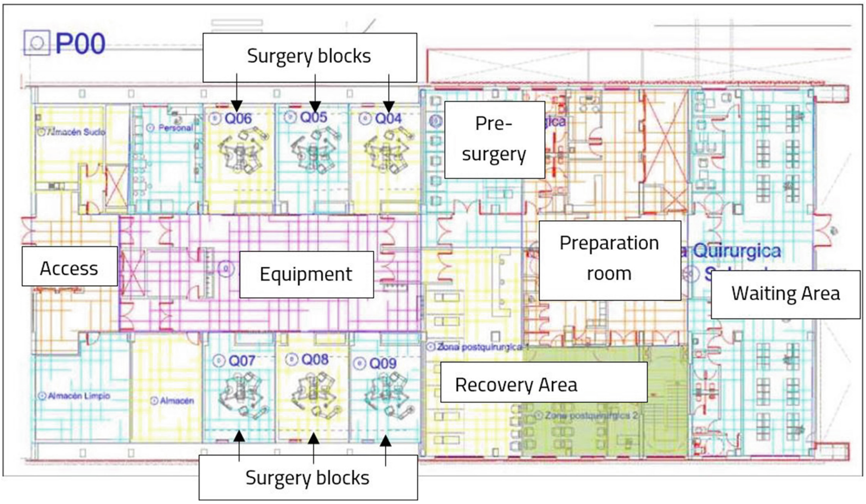

Fig. 1. Composition of the operating room service

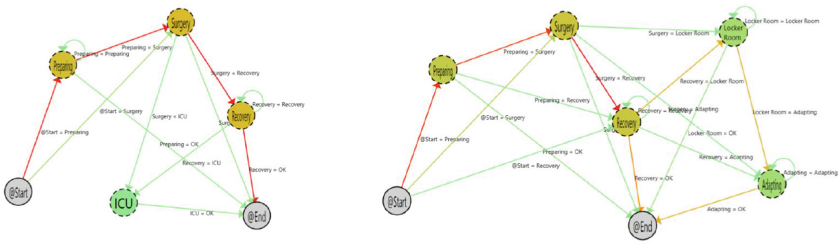

Fig. 2. Example of the inferred and enhanced work flows of patients across the operating room service [11].

3 Materials and Method

3.1 Analyzing ORs Processes with PALIA

PALIA consists on a web-based dashboard which allows to perform process mining analysis on a given dataset. The software (Fig. 3) is composed of three major areas: Filters, for the selection of the data; Mining, for the configuration of the visualization of work flows and Information, to show the information about the operation tool and the selected tracks. These three major areas are divided into five functional areas:

1. **Filters (1–2)**, for the selection of the input data in each analysis. There are several types of filters depending of the type of data and the required information: dates, times, durations, type of intervention, etc. This component shows the percentages of the samples meeting the filtering characteristics, so the user can have an idea on the extension of the selected subgroup of data.

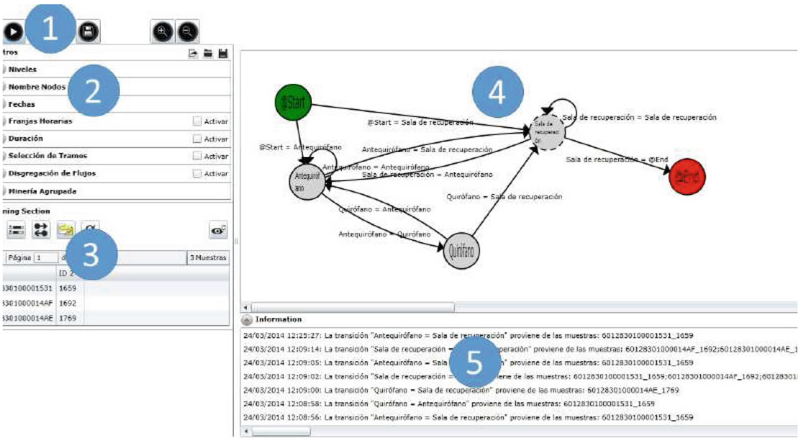

Fig. 3. Areas of the analyzed PM Tool

2. **Miner (3–4)**, for the configuration of the work flow visualization. Graphical representations of the inferred processes are depicted in the central part of the web-tool(4) by means of ORs states (nodes) and transitions (arrows). The visualization component allows adding meta-information to the work flow, for instance, rendering heats maps to discover frequencies or occupation in the ORs. There is also a list with all the samples selected with the filters (1–2)
3. **Information (5)**, which shows details about how the process mining algorithm was applied and also features of the selected samples: Information on the number of merged branches, a log on how the process mining algorithm analyzed the events and infers work-flows, errors on data selection and statistics on the transitions and states in the work-flow.

PALIA works in the following way: First a Comma-separated Value file containing the RTLS data is loaded using a default file dialog window. Then, the user is able to filter the data and apply a discovery topological algorithm. The inferred work-flow appears in the screen with nodes and arrows, which represent the track followed by the patients across the surgical process (Preparation - Surgery - Recovery - Intensive Care Unit - Locker room - Adaptation).

3.2 Analytic Hierarchy Process to Determine Priorities

AHP is a methodology for decision-making which aims at solving complex problems. It allows quantifying opinions and transforming them into a coherent decision model. The process is derived from a pairwise comparison using a numerical scale. AHP has found its widest applications in multi-factors decision-making, planning, and resource allocation and in conflict resolution [18]. The AHP is a method which incorporates benefits and risks, explicitly by combining the importance of differences in probabilities of outcomes related to alternatives and the weighting of the importance of those outcomes [19]. Instead other method for feature selection as the Conjoint Analysis [20], AHP has a special concern on the consistency of choices, their measurement and dependencies between the groups of elements [21]. Some key and basic steps of AHP were introduced by *Pecchia et altres* [17]:

– Define the problem.
– Broaden the objectives of the problem or consider all actors, objectives, and its outcome.
– Identify the criteria that influence the behavior.
– Structure the problem in a hierarchy of different levels constituting goal, criteria, sub-criteria and alternatives.

Our aim was to develop a hierarchy of elements grouped into categories to describe the functionalities of the PM tool used to manage ORs processes. These categories were ranked using questionnaires to extract the relative importance of each need per category (local weights, LW), the relative importance of each category (category weights, CW), and the importance of each need compared to all the others (Global weights, GW) [22].

3.3 Applying AHP to PALIA

The AHP was applied to this study, mainly because of its inherent capability of handling qualitative and quantitative criteria used in reclamation method selection problems. Six factors for applying AHP [18] were considered and fulfilled in this study. The hospital was motivated to adopt PALIA to support ORs processes management and was committed to implement the decision and involved staff from the ORs department. Stakeholders were active participants in the entire decision process from development to implementation. In order to identify the elements and the categories of the hierarchy we have used the different functionalities of PALIA. The hierarchy is composed of four levels which have a 1:n relationship with on the three functional areas described in Subsect. 3.1. The first hierarchy level is generic and only describes the functional area (Filters, Miner and Log). The second hierarchy level describes the main features of the functional area (for Filters it contains Dates, Times, Duration, Type of Intervention, Type of OR, etc...). The third hierarchy level contains details of the main features within the functional area (in Filters, for the Type of Intervention it contains details of the medical service, the type of program, the surgical process, the surgeon in chief, etc..). The fourth and final hierarchy level contains low granularity details. For creating the hierarchy tree and collecting the answers we have used the application web BPMSG AHP Online System (https://bpmsg.com/academic/ahp.php). In this study we focus on two hierarchy priority Levels:

1. **Hierarchy Level 1**, Functional Area: Filter, Miner and Information
2. **Hierarchy Level 2**, Features of the functional level:
   – **Filter:** Dates, Time, Duration, Level, Node Name, Features, Stretch, Disgregation, Statistics

- **Miner:** Frequency, Occupation, Transitions, List of samples
- **Information:** Sample cleaning, Wrong Selection, Evolution of process, Error messages and extra information.

3.4 Participants

Table 1 shows the profiles of the involved participants and their specific role into the ORs service. Only one of the initial 11 participants (complete ORs Staff) was unable to fill the AHP questionnaire successfully and was discarded for the analysis. Responders, who signed the informed consent of this study, were employers of the *Hospital General de Valencia*, one of the four hospitals of reference at the city covering a population of 350,000 inhabitants. It has 27 operating rooms and in the 2014 it registered 26,497 surgeries [23]. We organized a meeting in the Hospital General with all the participants which lasted 2 h. The session consisted of an introduction to the dashboard (Fig. 3) and a walk through with real data to showcase examples.

Table 1. Profiles of the participants in the AHP study

Variable	Type	Distribution
Role	Manager	20%
	Hospital staff	60%
	Technical	20%
Age		46.2 ± 10.3
Gender	Male	40%
	Female	60%
Years of expertise		21.2 ± 10.7
Computer literacy	Low	0%
	Medium	70%
	High	30%

4 Results

A total of 10 questionnaires were collected after the session held in the University General Hospital of Valencia with professionals working in the ORs service. For the analysis of the responses, participants were grouped into three categories depending of their roles within the ORs service.

The AHP questionnaire allows to assign priorities for each of the features contained in the defined hierarchy levels, each of which correspond to a particular functional area of the PALIA web-tool.

The overall analysis of priorities shows a 57% level of consensus (relative homogeneity $\beta = 77\%$), in which the Miner component achieves the higher priority rates for the features of Visualization (heat maps) and views selection (maximum occupation and current occupation). Collecting the relative priorities within each of the three main categories, we could extract the importance that each group of users assign to each of the PALIA functional areas.

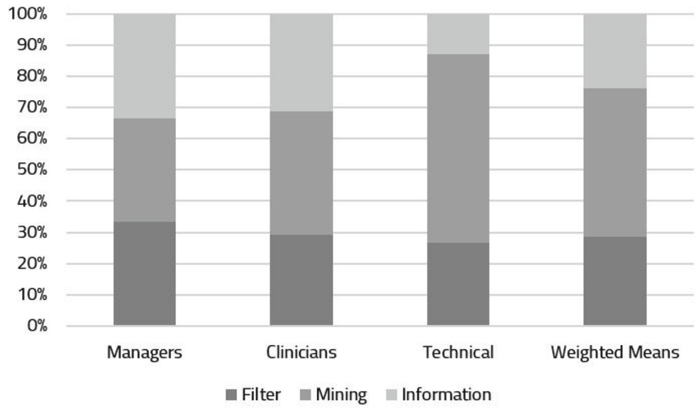

Fig. 4. Assigned priorities for the functional areas

Figure 4 depicts the relative weights (%) assigned to each of the modules. Manager and Clinical user groups show a similar consensus on the prioritization of functional areas, whereas the group composed by the Technical staff provides more priority to the Mining component. The stack in the right part of Fig. 4 is a weighted mean of the relative priority assigned by participants, in which we can see that the Mining component is still the most important, and the two other components (Filters and Information) share a lower similar importance.

Figures 5–7 shows the spider-web diagram containing the assigned priorities within the Hierarchy Level 2 for each of the features, splitting responses by user groups.

Regarding the Filters (Fig. 5) we can see a similar consensus between the Managers and the Clinicians, whereas the Technical staff is weighting two features which were not that relevant for the former groups: Date and Level selection. The answers for the Filter component achieved a 65.7% group consensus.

Regarding the Miner (Fig. 6), which was the most weighted component overall, we can see that Clinicians are more interested on knowing the Occupation of the rooms flow, but with respect to the Frequency, there are similar priorities with the Manager's choice. This figure shows also that only the Technical staff is interested on having the list of samples which composed the work-flow. The answers for the Miner component achieved a 78.5% group consensus.

Regarding the Information (Fig. 7), we can see that the priorities assigned by the Clinicians are the same for each feature, which could indicate a strong

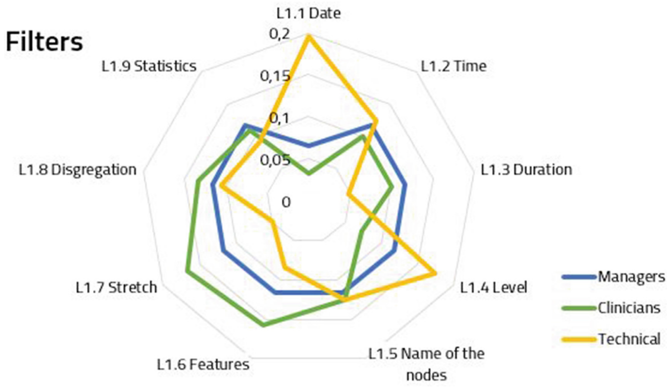

Fig. 5. Priorities for filter functional module features

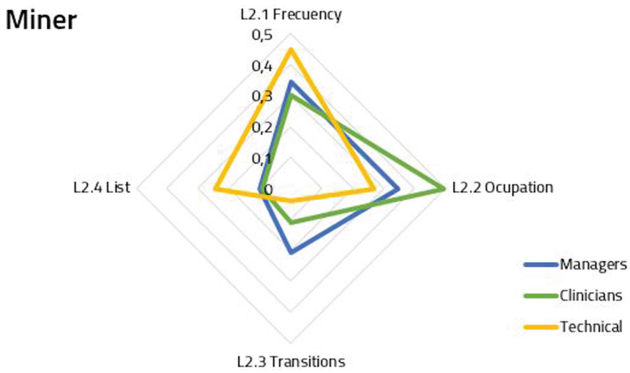

Fig. 6. Priorities for miner functional module features

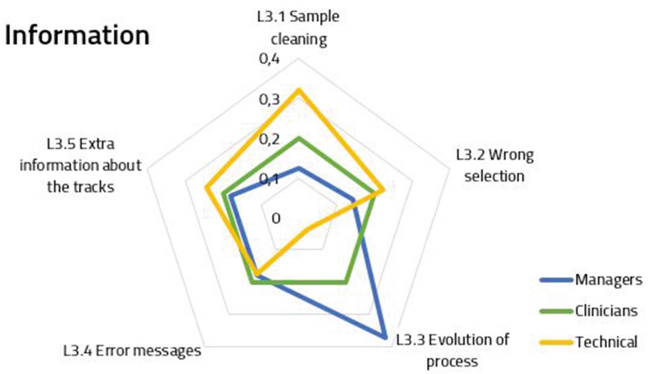

Fig. 7. Priorities for information functional module features

consensus or that the features are not relevant to this group. For the other two groups there are two different features which received a significant different prioritization. Managers are more likely to have information about how the process evolved during time, and Technical Staff is more prone to have information about the sample cleaning (which moreover has a similar weight to other related features such as the wrong selection of samples and extra information). The answers for the Information component achieved a 80.8% group consensus.

5 Conclusions

AHP questionnaires allowed us to extract valuable and quantifiable information about the use of a dashboard for the exploitation of Process Mining on Real-Time Location System samples in the Operating Rooms of a Hospital. The sample size of the questionnaire could be considered small (n=10) to provide significant findings. Nevertheless, this population contains all professional staff working in the operating room services and our results should be considered as a starting point to perform large scale evaluations.

The assessment of PALIA features allow to enhance the communication with the clinical environment to create a powerful and usable tool for the application of process discovery on RTLS data. The distinction between the different groups according to their roles allowed us to analyze how assign priorities to each of the stages of the application of process discovery.

The group of Clinicians shows always a high variability, which can be explained because has less management tasks and their opinions vary more depending of the specific work they do. Another relevant finding is how the group of Managers give a high priority to the feature of comparing the process evolution during time. Technical staff assigns prioritization to the management of timestamps (Date Filters and Occupation Frequency) and information of the data cleaning process.

Moreover, knowing the priorities each role assigned to the dashboard features we are capable of improving the application to provide end-users with specific tools to perform the type of analytics they can benefit the most on daily basis. New features (not assessed with AHP questionnaire) should be also assessed in a semi-structured discussion with experts to evaluate the possibility of creating a specific application to perform specific tasks (data filtering, process discovery, process enhancement, etc...).

Future work will focus on using the dashboard to perform advanced tasks, for instance how errors and high noise problems (e.g. patient safety and medication issues) can be resolved using process mining as one possible application in an operating room environment.

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