# Declarative Process Mining in Healthcare

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**Abstract**

Clinical guidelines aim at improving the quality of care processes through evidence-based insights. However, there may be good reasons to deviate from such guidelines or the guidelines may provide insufficient support as they are not tailored towards a particular setting (e.g., hospital policy or patient group characteristics). Therefore, we report a case study that shows how process mining techniques can be used to mediate between event data reflecting the clinical reality and clinical guidelines describing best-practices in medicine. Declarative models are used as they allow for more flexibility and are more suitable for describing healthcare processes that are highly unpredictable and unstable. Concretely, initial (hand made) models based on clinical guidelines are improved based on actual process executions (if these executions are proven to be correct). Process mining techniques can be also used to check conformance, analyze deviations, and enrich models with conformance-related diagnostics. The techniques have been applied in the urology department of the Isala hospital in the Netherlands. The results demonstrate that the techniques are feasible and that our toolset based on ProM and Declare is indeed able to provide valuable insights related to process conformance.

*Keywords:*
Healthcare Processes, Process Mining, Declarative Modeling Languages

## 1. Introduction

Healthcare processes can be classified either as *medical treatment processes* – concerning diagnostic and therapeutic activities performed to treat a patient – or as *generic organizational processes* – more related to administrative aspects (Lenz and Reichert, 2007a). The latter are generally handled according to well-established procedures; conversely, medical treatment processes must be flexible enough to be adapted to the variability of the healthcare environment and to the doctors' freedom in their execution. Medical treatment processes are universally performed according to clinical guidelines, thus translating the evidence-based insights into actions that have proven to be effective (Eddy, 2005).

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Guidelines are expected to be followed as they formalize the best practices. Nonetheless, it has been observed that a 'gap' exists between these recommendations and the actual clinical practice (Hay et al., 2008; Cochrane et al., 2007; Lew and DeMaria, 2013). Standard operating procedures may be missing in the guidelines, whereas some guidelines may describe an idealistic scenario that should not be enforced for all cases. The confrontation between actual clinical processes (as recorded in event logs) and the recommendations given in guidelines is a crucial challenge for the healthcare management sector (Milchak et al., 2004; Hetlevik et al., 1997). This is the realm of *process mining* (van der Aalst, 2011), which emerged a little over a decade ago. Process mining aims at extracting process knowledge from event logs. These logs may originate from different types of systems such as generic enterprise information systems as well as from Hospital Information Systems (HIS). Typically, event logs contain information about the start/-completion of process tasks together with related context data (e.g., actors and resources) and timestamps. In a relatively short timespan, process mining has proven to be capable of providing deep insights into process-related problems that contemporary institutions face, including hospitals. Through the application of process mining, institutions can discover the processes as they are conducted in reality, check whether certain practices and regulations were really followed and gain insights into bottlenecks, resource utilization, and other performance-related aspects of processes.

This paper proposes a methodology to check the compliance of the clinical guidelines (the de jure model) against the actual clinical practice, recorded as an event log. The confrontation between the de jure model and the clinical practice is later used to semi-automatically create a de facto model obtained by adjusting the de jure model to take into consideration the actual clinical practice. Another important aspect of the methodology is related to the modeling language employed. In the field of business process management and mining, the lion's share of attention has been focusing on techniques based on procedural models. Using procedural modeling languages, such as BPMN or UML activity diagrams, models explicitly describe the allowed sequences of activities. However, as illustrated, e.g., in Rebuge et al. (Rebuge and Ferreira, 2012), medical treatment processes are, in fact, *highly dynamic, highly complex, increasingly multidisciplinary and often ad hoc*. Moreover, due to the complexity of the environment in which they are executed, they usually involve several variables that can be handled differently depending on the specific patient being treated (Anyanwu et al., 2003). Therefore, these process models need to provide more freedom and should not restrict users in taking appropriate actions. As suggested by Mulyar et al. (Mulyar et al., 2008), declarative process modeling languages provide more flexibility with respect to procedural languages when describing process behavior. In particular, procedural languages can lead to unreadable and complex models in unpredictable and variable environments. Conversely, declarative languages offer more possibilities for executions since, in a declarative model, the process is represented as a set of constraints and can be executed in all possible ways as long as these constraints are respected (Maggi et al., 2011).

In addition to reporting on the methodology, this paper shows how this methodology has been operationalized in *ProM*[1]. To assess its validity, we conducted an evaluation using a case study pertaining to a process handled in the urology department of the Isala hospital. The hospital is one of the top-clinical hospitals in the Netherlands treating more than half a million patients per year distributed over five locations in and around Zwolle.

The paper is structured as follows. Section 2 motivates the work. The methodology followed in the case study is described in Section 3. Section 4 shows how recently developed plug-ins of the process mining tool ProM support the methodology. Section 5 illustrates the experimental results. Section 6 concludes the paper.

## 2. Motivation and Problem Definition

In several application domains, when a business process is executed, there are discrepancies between the expected behavior and the actual behavior. For example, in medical treatment processes, process executions can diverge from clinical guidelines for several reasons. The contribution of this paper is to show, through a case study pertaining to a medical treatment process, how process mining techniques can be used to analyze the discrepancies between the expected and the actual behavior of a business process and to understand their root cause. We show that the analysis of the discrepancies is useful to improve future process executions if they derive from mistakes the clinical practice. In addition, this analysis may also support the update of the clinical guidelines based on the daily practice if the discrepancies are due to uncompleted and/or outdated descriptions of the expected behavior.

### *2.1. The Problem*

The differences between clinical guidelines and the actual process executions is one of the key concerns of healthcare management (Bansal et al., 2012; Hay et al., 2008; Dresselhaus et al., 2000; Cahill and Heyland, 2010). This gap has been highlighted for fields such as dermatology (Hajjaj et al., 2010), psychology (Newnham and Page, 2010), urology (Cornu et al., 2010), etc. In (Freeman and Sweeney, 2001), the authors investigate the reasons why clinicians do not always follow in detail the instructions provided by the clinical guidelines when caring for (or treating) patients. Through structured interviews, they found that personal experiences, backgrounds, relations with individual patients, logistic and practical aspects usually influence clinical decisions: as a consequence, the actual practice deviates from the prescriptions.

Sometimes, clinical decisions can also be influenced by the cost of a treatment and by the patients' socioeconomic status (Bernheim et al., 2008). Furthermore, as reported in (Grol, 2010), clinical guidelines may not adequately address issues relevant to everyday's patient care. For example, patients can exhibit allergies that do not allow for some way of treating the pathology from which they are affected. Surgery, even

[1] `http://www.processmining.org`

if prescribed by the clinical guidelines, can be sometimes critical for patients having coagulation defects, diabetes, or heart problems. The coexistence of many pathologies can require further examinations or treatments not listed by the guidelines. Hence, the expected treatment can be delayed or even avoided in some cases. Therefore, in many circumstances this gap is patient-related, since the doctors have to deal with the particular patient conditions which may require specific and exceptional treatments.

In addition, there are some deviations that can be attributed to the difficulties of translating research findings into practice. As reported in (Graham et al., 2006), sometimes patients cannot benefit of treatments of proven validity because of the time needed to incorporate research results into practice.

Generally speaking, if some deviations can positively affect the patient process care, others represent errors that can compromise the patient recovery. Therefore, it is crucial to detect these deviations and to investigate the corresponding reasons in order to assess which of them can be classified as positive - and therefore can be taken into account to update the clinical guidelines statements - and which ones should be avoided and corrected in the clinical practice. As reported in (Mahajan, 2010), safety can be improved by learning from incidents and near misses. The need of monitoring the patient safety is becoming even more widespread in the healthcare sector, both in order to protect patients from adverse events (Berenholtz and Pronovost, 2007) and to avoid the related costs in terms of money (Bolsin et al., 2005). Moreover, one would like to learn from "positive deviants". As shown in this paper, process mining techniques can be used to address all these issues.

### *2.2. What are the Disadvantages of the Existing Solutions?*

According to (Newnham and Page, 2010), our goal should be to address the gap between daily practice and clinical guidelines with more (objective) data rather then only with debates or subjective arguments. Chart abstractions, observational studies, chart audits, results of clinical trials, structured interviews have proven to be useful instruments to investigate this gap in various clinical fields (Hajjaj et al., 2010; Dresselhaus et al., 2000; Petzold et al., 2010; Newnham and Page, 2010; Lew and DeMaria, 2013). However, most of these techniques are manual and, therefore, error-prone and time consuming.

In (Bates et al., 2001), the authors highlight how the frequency and consequences of errors in medical care can be reduced by monitoring the activities through Hospital Information Systems. In general, as summarized by Lenz et al. (Lenz and Reichert, 2007b), various studies have reported positive effects when using process-oriented IT systems in healthcare to support and monitor the processes execution (Fichman et al., 2011). The use of process-oriented IT systems in healthcare also results in a growth of the data stored and/or exchanged electronically. Analyzing this data manually is unfeasible. Automatic business intelligence tools can be used in this context. However, they aim at improving operational performance, e.g., reducing flow time and defects, whereas medical treatment processes put more emphasis on risk management and compliance checking.

Process mining techniques offer a means to more rigorously check compliance and ascertain the validity and reliability of information about processes. In addition, several case studies have proven the usefulness of process mining in healthcare (Rebuge and Ferreira, 2012; Mans et al., 2009, 2008). De Weerdt et al. (Weerdt et al., 2013) stressed the importance of process mining to acquire knowledge about past clinical experiences in order to avoid medical errors in the future. However, these studies are based on standard process mining techniques. These techniques mainly use procedural process models like BPMN, UML activity diagrams, Petri nets and EPCs in which all that is not explicitly specified is forbidden. The explicit representation of all the possible paths in highly dynamic environments characterized by high complexity and variability make process models quickly unreadable.

### *2.3. How can the Proposed Approach Help Solving the Problem?*

The analysis methodology presented in this paper is based on process mining techniques. In particular, we suppose that the expected behavior of a business process is represented through a process model. In addition, we assume that process executions are supported by information systems that record data about each execution in event logs. We show how a combination of process mining techniques can be used to:

- identify discrepancies between process models and logs;
- derive useful diagnostics about the discrepancies;
- if there are mistakes in the actual behavior of the process, suggest actions to be undertaken to avoid the same mistakes in future process executions;
- if the deviances in the process executions are justified by an inaccurate description of the expected behavior, adapt the process models to fit the actual behavior automatically (through model repair).

A key-characteristic of the process mining techniques used in this paper is that they are based on declarative process models. Instead of explicitly specifying all possible sequences of activities in a process, declarative models implicitly specify the allowed behavior using constraints that must be followed during execution. In comparison to procedural approaches, which produce closed models, declarative languages are open. In this way, declarative models enjoy flexibility and still remain compact.

### *2.4. Who will Benefit from the Proposed Approach?*

The proposed analysis methodology can be used by business process analysts from different fields and can be used for process improvement. Being based on declarative process models, the methodology can be used to analyze business processes working in unstable and unpredictable environments (like medical treatment processes). While procedural models are more suitable to support business processes working in stable environments, in which participants have to follow predefined procedures (they suggest step by step what to do next), declarative models provide process participants with a (preferably small) set of constraints to be followed during the process execution. In this way, process participants have the flexibility to follow any path that does not violate these constraints. The proposed methodology is, therefore, a powerful instrument for process analysts who need to analyze business processes working in unpredictable environments and characterized by several exceptions and several execution paths.

## 3. Methodology

The methodology that we propose is based on the fact that often the medical guidelines are idealized processes, which need to be specialized for the hospital in question. Therefore, we propose a methodology to automatically (i) Check the conformance of the de jure model, which encodes the medical guidelines, against the actual process executions, which are recorded in logging data; (ii) "Repair" the de jure model to be in line with the actual executions, thus obtaining a de facto model. For repairing the Declare model, we employ a methodology based on cross validation. The idea is that the event log is split in two fragments of (roughly) the same size. The splitting is done completely randomly. The first fragment, the so-called training log, is used to repair the process model; the second fragment, the so-called test log, is used to validate the process model by checking the conformance of the repaired model against it. If the conformance level is satisfactory, the repair model is retained and considered as a de facto model. Otherwise, the splitting is repeated again, so like the repairing and the conformance checking, till the conformance level is satisfactory. As for the application of data-mining techniques, the use of cross validation guarantees that the repair model is more accurate. The proposed methodology is outlined in Figure 1 and described below in detail. The methodology is supported by different ProM plug-ins as described in Section 4.

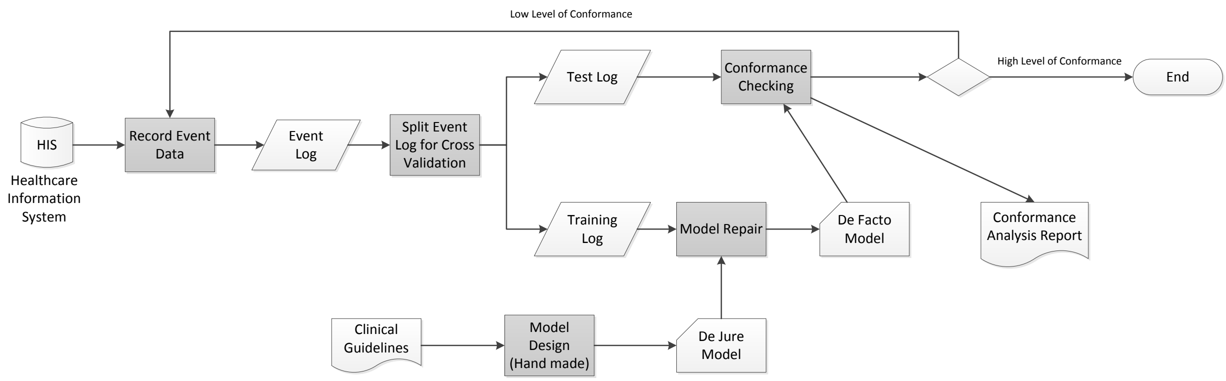


Figure 1: Methodology for the analysis of medical treatment processes.

### 3.1. Model Design Based on Clinical Guidelines

In the *model design* phase, a process model is created. The aim of this phase is to obtain a standard representation of a medical treatment process as described by the corresponding clinical guidelines. Since this representation is based on theoretical statements established by the scientific literature, we will refer to it as a *de jure* model. In recent years, many different approaches aiming at representing clinical guidelines through formal models have been proposed, e.g., in the context of simulations for medical decision-support systems (Mulyar et al., 2008; Grando et al., 2009; Seyfang et al., 2007). One of the crucial points of these representations concerns how to deal with the variability characterizing healthcare processes: as reported in (Mulyar et al., 2008) and motivated in Section 1, we use a declarative process modeling language to represent healthcare processes based on guidelines statements.

As shown in Figure 1, the actual behavior of a medical treatment process can be analyzed using the information recorded by process oriented IT Systems recently introduced in the healthcare sector (Lenz and Reichert, 2007a). These systems typically log the activities performed during the process execution in an *event log*. An event log contains information about activities and cases (process instances); it can also contain time information (timestamps) and indications about the actors involved in a specific case. Process mining techniques (van der Aalst, 2011) use event logs to investigate the actual behavior of a process. Model repair, conformance checking, performance analysis and (unsupervised) process discovery, all belong to this family of techniques.

### 3.2. Model Repair and Cross Validation

Medical treatment processes have some basic characteristics (as stated in the clinical guidelines) but also some characteristics that can differently be interpreted and handled according to the background and the experience of the end-users as discussed in Section 2. The *model repair* phase aims at revising some aspects of the de jure model based on information derived from the actual execution of the process as recorded in the logs. Of course, these modifications must be justified from a medical point of view and still be consistent with the intent of the guideline. The model derived from the repair procedure, called *de facto* model, represents how the process should be executed in the clinical practice, according to both the guideline and everyday reality.

Our methodology for model repairing is based on cross validation. As shown in Figure 1, the event data is split into a training set for repairing the model and a test set for validating the result. The splitting is performed randomly such that 50% of the event data is used for repairing and 50% for validating. This way, the repaired model is confronted with process executions that have not been used to repair the model. If the conformance result is not satisfactory, the entire procedure is repeated by splitting again the event log. Figure 1 shows that there is a possible feedback loop to further refine or revise the model. Once the de facto model has been created, conformance checking techniques (van der Aalst, 2011) are applied to measure the adherence of future executions of the process with respect to this model.

## 4. Operationalization

This section describes the tools that have been used to perform each phase of the methodology proposed in Section 3. A combination of *Declare*[2] and *ProM*[3] is used. *Declare* is used for manipulation and enactment of declarative process models. *ProM* is a "pluggable" open-source framework for process mining. *ProM* can be used to discover declarative process models from event logs, repair models and check their conformance (Maggi, 2013).

### *4.1. Model Design*

To perform the model design, we use Declare. Declare is an LTL-based declarative language (van der Aalst et al., 2009; Pesic and van der Aalst, 2006) supported by a toolset that includes a designer, a workflow engine, a worklist handler, and various analysis tools (Westergaard and Maggi, 2011). The designer can be used to support this study, since it allows us to obtain a formal representation of clinical processes by designing the activities and the constraints characterizing the process behavior.
Declare is based on an extensible set of templates, i.e., abstract entities defining parameterized classes of constraints specified through *Linear Temporal Logic* (LTL) with semantics based on finite traces[4] and each one equipped with its own graphical representation. Templates can be classified according to four groups: *existence*, *relation*, *negative relation* and *choice*. *Existence* templates involve only one activity and define the allowed cardinality or position of an activity in a case. *Relation/negative relation* templates define a dependency/negative dependency between two activities. *Choice* templates define alternative relations between activities. Constraints are concrete instantiations of templates and inherit the graphical representation and LTL semantics from the corresponding templates (van der Aalst et al., 2009). A Declare model is a set of constraints that should hold in conjunction during the process execution.

Figure 2 shows an example of a Declare model. The model describes a process for gastric cancer surgical treatments. The first hospital admission requires the registration of the patient's data when he/she is admitted to the hospital. This activity precedes all diagnostic/therapeutic treatments. The preoperative screening , is performed before any surgical treatment in order to assess whether the patient's conditions are good enough for the surgery to be performed and to estimate potential risks. As far as the surgical technique is concerned, the gastric resection for malignant diseases can be performed by using either a laparoscopic

[2] `http://www.win.tue.nl/declare/`
[3] `http://www.promtools.org`
[4] For compactness, we simply write LTL to refer to LTL on finite traces.

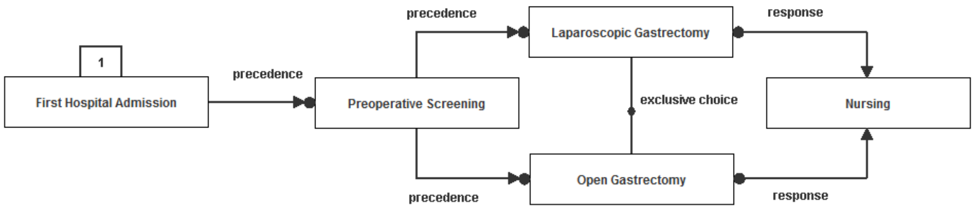


Figure 2: An example of a Declare model modeling the surgical treatment of gastric cancer.

surgery or a traditional open approach (Qiu et al., 2013). Furthermore, in both cases a nursing period is needed to monitor the patient after the operation.

The Declare model for this process involves five activities: *First Hospital Admission*, *Preoperative Screening*, *Open Gastrectomy*, *Laparoscopic Gastrectomy* and *Nursing*, and seven constraints: three derived from the *precedence* template, one from the *exactly1* template, one from the *exclusive choice* template and two from the *response* template.

A *precedence* constraint between two activities A and B indicates that B can only be executed after that A has been executed at least once. In the model shown in Figure 2, a precedence constraint is used to indicate that activity Preoperative Screening can be executed only after that First Hospital Admission has occurred before. Also, precedence constraints are used to specify that the surgical treatment, either performed by using the open or the laparoscopic technique, can occur only if the Preoperative Screening has been performed before.

An *exactly1* constraint applied to an activity A indicates that A occurs exactly once. In the model shown in Figure 2, an exactly1 constraint specifies that First Hospital Admission occurs exactly once in a case. This is the only admission where the personal details of the patient are specified. Later on, other hospital admissions can be performed but differently from the First Hospital Admission the personal details of the patient can be (in case) modified but are already available in the HIS.

An *exclusive choice* constraint between two activities A and B indicates that one of them must be executed, but not both. In the model shown in Figure 2, an exclusive choice constraint indicates that the surgical intervention can be executed either by using the Laparoscopic Gastrectomy or the Open Gastrectomy; these techniques cannot be both applied to the same patient (unless emergent conditions require the conversion from the laparoscopic to the open approach (Qiu et al., 2013)).

A *response* constraint between two activities A and B states that B has to be executed at least once after that A has been executed. In the model shown in Figure 2, response constraints are used to indicate that both activities Laparoscopic Gastrectomy and Open Gastrectomy must be followed by a Nursing period.

Referring to the example above, Table 1 shows the semantics for each constraint involved in the model. Each constraint is defined in terms of an LTL formula (here, First Hospital Admission is indicated as FHA,

Table 1: Semantics of the Declare constraints from Figure 2 and their "activating" activities ($\Box$ means "always", $\Diamond$ means "eventually", $\bigcirc$ means "next", $X \sqcup Y$ means "$X$ should hold until $Y$" (strong until).

| **Constraint** | **LTL semantics** | **Activation** |
|---|---|---|
| $response(LG, N)$ | $\Box(LG \Rightarrow \Diamond N)$ | $LG$ |
| $response(OG, N)$ | $\Box(OG \Rightarrow \Diamond N)$ | $OG$ |
| $precedence(FHA, PS)$ | $(\neg PS \sqcup FHA) \vee \Box(\neg PS)$ | $PS$ |
| $precedence(PS, LG)$ | $(\neg LG \sqcup PS) \vee \Box(\neg LG)$ | $LG$ |
| $precedence(PS, OG)$ | $(\neg OG \sqcup PS) \vee \Box(\neg OG)$ | $OG$ |
| $exactly1(FHA)$ | $\Diamond FHA \wedge \neg(\Diamond(FHA \wedge \bigcirc(\Diamond FHA)))$ | $FHA$ |
| $exclusivechoice(LG, OG)$ | $(\Diamond LG \vee \Diamond OG) \wedge \neg(\Diamond LG \wedge \Diamond OG)$ | $LG$, $OG$ |

Preoperative Screening as PS, Laparoscopic Gastrectomy as LG, Open Gastrectomy as OG, Nursing as N). For example, $\Box(LG \Rightarrow \Diamond N)$ is the LTL constraint stating that every occurrence of $LG$ should eventually be followed by $N$. $(\neg PS \sqcup FHA) \vee \Box(\neg PS)$ models that $PS$ should be preceded by $FHA$.

Table 1 also shows the activities activating a constraint. An *activation* of a constraint in a case is an event whose occurrence imposes, because of that constraint, some obligations on other events in the same case. For example, if we consider the model shown in Figure 2, the occurrence of activity Laparoscopic Gastrectomy is an activation for the response between Laparoscopic Gastrectomy and Nursing, because the execution of Laparoscopic Gastrectomy forces Nursing to be also executed eventually. An activation of a constraint can be a fulfillment or a violation for that constraint. For example, the execution of Laparoscopic Gastrectomy is a fulfillment for the response between Laparoscopic Gastrectomy and Nursing if Laparoscopic Gastrectomy is followed by Nursing. The execution of Laparoscopic Gastrectomy is a violation for the response between Laparoscopic Gastrectomy and Nursing if Laparoscopic Gastrectomy is not followed by Nursing.

Note that, for example, a response constraint between two activities $A$ and $B$ is satisfied in a trivial way in a case if $A$ never occurs. In this case, we say that the constraint is *vacuously satisfied* (Kupferman and Vardi, 2003). In (Burattin et al., 2012), the authors introduce the notion of *behavioral vacuity detection* according to which a constraint is non-vacuously satisfied in a case when it is activated in that case. The example presented in Figure 2 shows that, using Declare, it is possible to design formal models that are easily understandable due to its simple graphical representation. Moreover, since Declare models are based on formal LTL semantics, they are verifiable and executable (van der Aalst et al., 2009).

If events referring to activity executions are stored in an event log, it is possible to apply process mining techniques (van der Aalst, 2011) for further analysis on the process. Table 2 shows an example of an event log related to the surgical treatment of gastric cancer. Each line refers to the occurrence of an event with a unique id, a corresponding activity, a resource, a cost, and a timestamp. Events are grouped per case, where each instance represents an individual patient. An event log can be used to apply process mining techniques for process analysis.

Table 2: Fragment of event log including for each case: case ID, event ID, timestamp, activity, resource, cost.

| Case ID | Event ID | Timestamp | Activity | Resource | Cost |
|---|---|---|---|---|---|
| 1 | 7785621 | 30-11-2011:08.27 | First Hospital Admission | Carol | 90 |
| 1 | 7785624 | 2-12-2011:13.24 | Preoperative Screening | Susanne | 350 |
| 1 | 7785625 | 4-12-2011:8.30 | Laparoscopic Gastrectomy | Andrew | 500 |
| 1 | 7785631 | 4-12-2011:13.30 | Nursing | Paul | 250 |
| 2 | 7785631 | 1-12-2011:11.00 | Preoperative Screening | Giuseppe | 350 |
| 2 | 7785634 | 2-12-2011:15.28 | Laparoscopic Gastrectomy | Simon | 500 |
| 2 | 7785638 | 2-12-2011:16.35 | Nursing | Clare | 250 |
| 2 | 7785640 | 3-12-2011:13.00 | Laparoscopic Gastrectomy | Paul | 500 |
| 2 | 7785641 | 3-12-2011:15.00 | Nursing | Andrew | 250 |
| 2 | 7785661 | 4-12-2011:9.00 | First Hospital Admission | Victor | 90 |
| 3 | 7785654 | 7-12-2011:10.00 | First Hospital Admission | Jane | 90 |
| 3 | 7785624 | 8-12-2011:13.24 | Laparoscopic Gastrectomy | Giulia | 500 |
| 3 | 7785625 | 9-12-2011:16.35 | Nursing | Paul | 250 |
| 4 | 7785640 | 6-12-2011:14.00 | First Hospital Admission | Gianluca | 90 |
| 4 | 7785667 | 8-12-2011:13.24 | Preoperative Screening | Robert | 350 |
| 4 | 7785671 | 10-12-2011:16.35 | Preoperative Screening | Giuseppe | 350 |
| 4 | 7785685 | 13-12-2011:11.00 | Laparoscopic Gastrectomy | Simon | 500 |
| 4 | 7785698 | 13-12-2011:16.00 | First Hospital Admission | Jane | 90 |
| 5 | 7785701 | 7-12-2011:15.00 | First Hospital Admission | Carol | 90 |
| 5 | 7785711 | 9-12-2011:7.30 | Preoperative Screening | Susanne | 350 |
| 5 | 7785723 | 13-12-2011:11.00 | Laparoscopic Gastrectomy | Simon | 500 |
| 5 | 7785728 | 13-12-2011:13.50 | Nursing | Clare | 250 |
| 5 | 7785732 | 13-12-2011:19.50 | Nursing | Vivianne | 250 |
| 6 | 7785701 | 7-12-2011:15.00 | First Hospital Admission | Gianluca | 90 |
| 6 | 7785711 | 9-12-2011:7.30 | Preoperative Screening | Susanne | 350 |
| 6 | 7785723 | 13-12-2011:11.00 | Laparoscopic Gastrectomy | Andrew | 500 |
| 7 | 7785744 | 11-12-2011:7.00 | First Hospital Admission | Jane | 90 |
| 7 | 7785754 | 12-12-2011:9.30 | Preoperative Screening | Susanne | 350 |
| 7 | 7785757 | 13-12-2011:16.00 | Laparoscopic Gastrectomy | Andrew | 500 |
| 7 | 7785761 | 13-12-2011:18.50 | Nursing | Vivianne | 250 |
| 7 | 7785763 | 14-12-2011:8.30 | Laparoscopic Gastrectomy | Gabriel | 500 |
| 8 | 7785765 | 11-12-2011:7.00 | Preoperative Screening | Gianluca | 350 |
| 8 | 7785766 | 12-12-2011:9.00 | Preoperative Screening | Susanne | 350 |
| 8 | 7785768 | 13-12-2011:7.40 | Preoperative Screening | Gianluca | 350 |
| 8 | 7785771 | 14-12-2011:9.30 | Laparoscopic Gastrectomy | Giulia | 500 |
| 8 | 7785777 | 14-12-2011:16.00 | Nursing | Vivianne | 250 |
| 9 | 7785785 | 16-12-2011:12.00 | Preoperative Screening | Robert | 350 |
| 9 | 7785795 | 17-12-2011:9.00 | Preoperative Screening | Susanne | 350 |
| 9 | 7785797 | 19-12-2011:9.30 | Laparoscopic Gastrectomy | Andrew | 500 |
| 9 | 7785891 | 19-12-2011:18.50 | First Hospital Admission | Carol | 90 |
| 9 | 7785893 | 20-12-2011:18.00 | Nursing | Paul | 250 |
| 10 | 7786185 | 19-12-2011:13.00 | First Hospital Admission | Jane | 90 |
| 10 | 7786189 | 20-12-2011:9.30 | Preoperative Screening | Robert | 350 |
| 10 | 7786193 | 22-12-2011:8.50 | Laparoscopic Gastrectomy | Andrew | 500 |
| 10 | 7786198 | 22-12-2011:10.30 | Nursing | Clare | 250 |
| 10 | 7786223 | 23-12-2011:14.30 | Nursing | Vivianne | 250 |

### *4.2. Model Repair*

In the model repair phase, the de jure model is adjusted and repaired based on the information extracted from an event log. The result is a de facto model. To repair the model, the *Declare Miner* plug-in in ProM can be used (Maggi et al., 2013a). It takes as inputs a Declare model and an event log and produces a new Declare model that better reflects how the process is executed in the reality (van der Aalst, 2011). Model repair can be performed through the Declare Miner. Three possible modalities can be used to repair the model using event data:

1. The first modality generates a Declare model that includes constraints defined starting from only those templates that have been used in the input Declare model but over all the activities contained in the event log.
2. The second modality generates a Declare model that includes constraints defined starting from only those templates and activities that have been used in the input Declare model.
3. The third modality replaces a constraint in the input Declare model with a stronger constraint if this constraint holds in the event log (for example, a response constraint between A and B could be replaced by a chain response constraint indicating that B must immediately follow A).

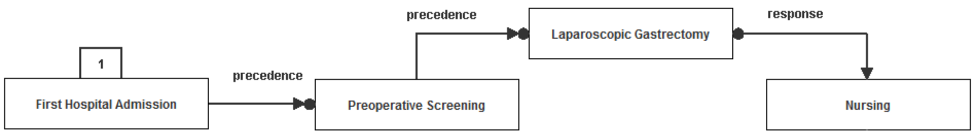


Figure 3: Surgical treatment of gastric cancer: repaired model.

A minimum support can be specified as an input of the repair algorithm (Maggi et al., 2012). Through this parameter, it is possible to leave out those constraints that are rarely activated in the log (i.e., constraints with a low support). Using different combinations of configuration options, the de jure model can be modified by removing or changing existing constraints or adding new constraints.

Consider the Declare model shown in Figure 2 and the event log in Table 2. The Declare model shows that, according to the clinical guidelines, one of activities Laparoscopic Gastrectomy and Open Gastrectomy has to be applied for each patient. However, in the event log in Table 2, we can observe that Open Gastrectomy is never executed. Therefore, the model repair algorithm would generate a new Declare model in which activity Open Gastrectomy and all the constraints connected to it are removed, as shown in Figure 3. Indeed, these constraints are trivially satisfied, i.e., they are never really activated being the frequency of open gastrectomy equal to zero. This result could be justified with the fact that, due to the specific clinical environment (e.g., doctors' expertise, type of patients treated, medical instruments available), the doctors prefer to apply the laparoscopic approach. Note that, if in a different department the open technique is preferred, the same Declare model would be repaired by removing activity Laparoscopic Gastrectomy. These differences are related to particular aspects of the real clinical environment and can be included in the de facto models, since they do not violate the clinical guidelines.

*4.3. Conformance Checking*

Conformance checking techniques (van der Aalst, 2011) can be applied to investigate the deviations between a process model and process executions (de Leoni et al., 2012, 2015). Two ProM plug-ins, the Declare Analyzer and the Declare Checker, provide concrete tool support for conformance checking.

The Declare Analyzer takes a Declare model and an event log as inputs and pinpoints the deviations between the actual behavior as recorded in the event log, and the admissible one as described in the Declare model. In particular, it shows activations, fulfillments and violations of each constraint involved in the model. Note that when a case is compliant with respect to a constraint, every activation of that constraint leads to a fulfillment. Consider the model shown in Figure 2 and the event log in Table 2. In case 2 of the event log, the response constraint between Laparoscopic Gastrectomy and Nursing is activated and fulfilled twice (see Figure 4), whereas, in case 1, the same constraint is activated and fulfilled only once (see Figure 5). When a case is non-compliant with respect to a constraint, an activation of a constraint can lead to a fulfillment but also to a violation (and at least one activation leads to a violation). See, for example, the response constraint between Laparoscopic Gastrectomy and Nursing in the model in Figure 2 and case 7

| | | |
|---|---|---|
| 7785631 | 1-12-2011: 11.00 | Preoperative Screening |
| 7785634 | 2-12-2011: 13.24 | Laparoscopic Gastrectomy |
| 7785638 | 2-12-2011: 16.35 | Nursing |
| 7785640 | 3-12-2011: 13.00 | Laparoscopic Gastrectomy |
| 7785641 | 3-12-2011: 15.00 | Nursing |
| 7785661 | 4-12-2011: 8.30 | First Hospital Admission |

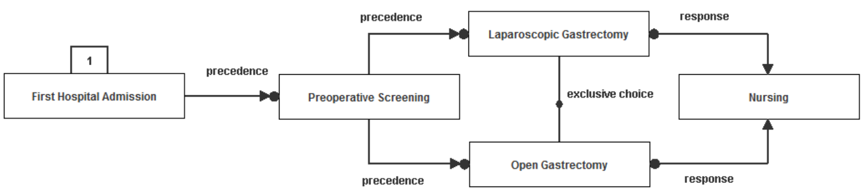


Figure 4: Surgical treatment of gastric cancer: the response constraint between *Laparoscopic Gastrectomy* and *Nursing* is fulfilled twice for case 2.

| | | |
|---|---|---|
| 7785621 | 30-11-2011: 8.27 | First Hospital Admission |
| 7785624 | 2-12-2011: 13.24 | Preoperative Screening |
| 7785625 | 2-12-2011: 8.30 | Laparoscopic Gastrectomy |
| 7785631 | 3-12-2011: 13.00 | Nursing |

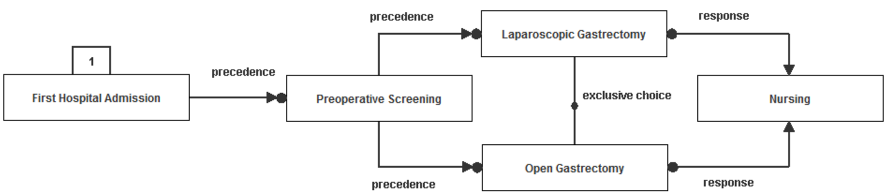


Figure 5: Surgical treatment of gastric cancer: the response constraint between *Laparoscopic Gastrectomy* and *Nursing* is fulfilled once for case 1.

| | | |
|---|---|---|
| 7785744 | 11-12-2011: 7.00 | First Hospital Admission |
| 7785754 | 12-12-2011: 9.30 | Preoperative Screening |
| 7785757 | 13-12-2011: 16.00 | Laparoscopic Gastrectomy |
| 7785761 | 13-12-2011: 18.50 | Nursing |
| 7785763 | 14-12-2011: 8.30 | Laparoscopic Gastrectomy |

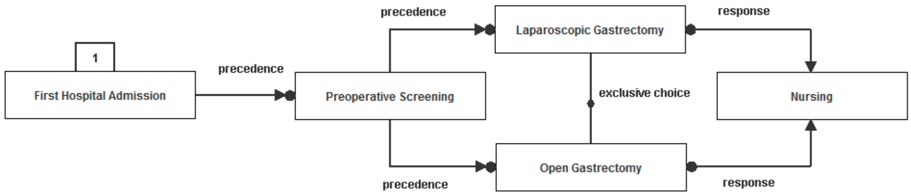


Figure 6: Surgical treatment of gastric cancer: the response constraint between *Laparoscopic Gastrectomy* and *Nursing* is violated for case 7.

in the event log in Table 2 (Figure 6). In this case, the constraint is activated twice, but the first activation leads to a fulfillment (eventually Nursing occurs) and the second activation leads to a violation (Nursing does not occur eventually). Another example of a violation can be found in the event log if we consider the precedence constraint between First Hospital Admission and Preoperative Screening. Indeed, for cases 2, 8, and 9 we can find respectively one, three and two violations of this precedence constraint.

Since each case is referred to an individual patient treatment process, using the information provided by the Declare Analyzer at the case level, it is possible to investigate the deviations based on the characteristic of the specific patient. For example, when First Hospital Admission is missing in a case, it is possible that the patient has already been registered in a different department of the same hospital for a different pathology. For each constraint in the input Declare model, the Declare Analyzer also provides the total number of fulfillments and violations on the entire log. In the considered event log, for example, for the response constraint between Laparoscopic Gastrectomy and Nursing, there are 9 fulfillments and 3 violations.

As already mentioned, the conformance of the event log with respect to a Declare model can also be checked using the Declare Checker. In particular, the Declare Checker estimates the fitness (van der Aalst, 2011) between the model and the log, and, also, shows how non-compliant cases should be modified to be aligned with the desired behavior, leading to the identification of reparative actions.

The Declare Checker is composed of two different plug-ins: the *Declare Replayer* and the *Declare Diagnoser*. The Declare Replayer takes as inputs a Declare model and an event log and measures for each case in the log the fitness of the case with respect to the model in a range from 0 (worst fitness) to 1 (best fitness) (van der Aalst et al., 2012; de Leoni et al., 2012, 2015). If, for some case, the corresponding fitness value is less than 1, an *alignment* between the case and the model is created to show how the case should be modified to perfectly fit the model. To establish an alignment between a process model and an event log we need to relate "moves" in the log to "moves" in the model. In case of deviations, there are moves in the log that cannot be mimicked by the model or vice versa. We explicitly denote a "no move" by $\gg$. Consider, for example, case 9 of the event log in Table 2 and the model in Figure 2. To align this case with the model, activity First Hospital Admission should be moved to the first position. Table 3 shows the alignment. The first line denotes a move on model only (see $\gg$) due to the missing First Hospital Admission event before Preoperative Screening. The fifth line denotes a move on log only: the $\gg$ symbol in the last column shows that First Hospital Admission cannot follow Preoperative Screening.

Starting from the results derived from the Declare Replayer, the Declare Diagnoser generates a map to give a helicopter view of the discrepancies between the log and the model. In particular, constraints and activities in the reference Declare model are annotated with numbers (ranging from 0 to 1) representing their degree of conformance (de Leoni et al., 2012, 2015). The degree of conformance of an activity in the model is an indication of the number of times the activity has been removed or added to compute the alignments between all the cases in the log and the reference model (van der Aalst et al., 2012). The degree of conformance of a constraint in the model is an indication of the number of times the constraint has been violated in the event log. In the map, activities and constrains of the reference model are colored with colors ranging from red to green to indicate a degree of conformance varying from 0 (red) to 1 (green).

## 5. Case Study

In this section, we illustrate a case study in order to demonstrate the applicability of the described methodology in practice. In particular, we apply our methodology for a process handled in the urology department of the Isala hospital in Zwolle to deal with patients affected by cryptorchidism. The Isala hospital consists of multiple clinics and is the largest non-university hospital in the Netherlands. Isala aims at providing efficient and safe care to their patients. Therefore, they are looking for innovative ways to analyze and improve their care processes. Within Isala, the urology department is involved with diagnosing and treating patients suffering from illnesses on the male and female urinary tract, and on the male reproductive system.

The logging data about the actual process executions have been extracted from the database underlying the information system used by urology department of the Isala hospital. The extraction of the events from the database has been done to guarantee the right level of granularity from a business perspective. Each

Table 3: Example of a trace alignment: There is one move in model and one move in log due to the wrong position of the First Hospital Admission event in case 9.

| Case ID | Event ID | Timestamp | Activity in Log | Activity in Model |
|---|---|---|---|---|
| 9 | - | - | $\gg$ | First Hospital Admission |
| 9 | 7785785 | 16-12-2011:12.00 | Preoperative Screening | Preoperative Screening |
| 9 | 7785795 | 17-12-2011:9.00 | Preoperative Screening | Preoperative Screening |
| 9 | 7785797 | 19-12-2011:9.30 | Laparoscopic Gastrectomy | Laparoscopic Gastrectomy |
| 9 | 7785891 | 19-12-2011:18.50 | First Hospital Admission | $\gg$ |
| 9 | 7785893 | 20-12-2011:18.00 | Nursing | Nursing |

event corresponds to the execution of an activity by a doctor or a nurse. Examples of activities are the doctor's visits to patients, blood tests and surgeries. In the log there are 10, 793 events referring to 160 different activities. Events are grouped in cases by patients. The event log is composed by 289 cases, where each case is associated with a different patient and comprises all events referring to that patient.

Section 5.1 discusses the process of patients' treatment with cryptorchidism. Section 5.2 discusses the guidelines of the treatment of this disease and how they have been elaborated to construct the de jure model. As already mentioned, the methodology to repair the de jure model to comply with the actual executions is based on the idea of cross validation. Randomly, the event log has been split in two parts: 50% for training and 50% for test. The training and test part of the log has been used to respectively repair the de jure model and validate the repaired model. Section 5.3 reports on the checking of the conformance of the training log with respect to the de jure model. Section 5.4 illustrates how the model has been repaired, whereas Section 5.5 reports on the validation. The de facto model validation, i.e., the conformance checking of the repaired model and the test event log, may return unsatisfactory results. According to the methodology, this would require to repeat the random splitting of the event log in test and training, the model repairing and the cross validation. Here, we limit ourselves to one iteration.

### *5.1. Context*

Cryptorchidism is the absence of one or both testis in the scrotum caused by a deficient or irregular testicular descent; it is one of the most common disorders of childhood, affecting 0.8 − 1.8 percent of infants at 1 year of age, 3 percent of full-term newborns, and 21 percent of premature babies (Smolko et al., 1983). It has been assessed that it can also lead to an increasing risk of infertility and cancer (Ferro et al., 1996). Thus, early diagnosis and treatment of undescended testis are needed to preserve fertility and to prevent testicular malignancy. According to the European guidelines, although 15 − 20 of retained testes descend during hormonal treatment, the intake of such substances may be harmful to future spermatogenesis by increasing the apoptosis of germ cells; it was also assessed that the descended testes, when pharmacologically treated, often reascend later. Thus, the hormonal treatment is no longer recommended.

On the other hand, the success rate of surgical treatment for undescended testes, named 'Orchidopexy' is 70 − 90 percent (Jones, 1995). Gapanya et Al. (Gapanya et al., 2008) state that the surgery is the cornerstone of treatment. To surgically treat the cryptorchidism, either the open or the laparoscopic approach can be applied, even if it is still open for debate which one of them should be preferred (Guo et al., 2011). The laparoscopic approach is more used because, according to Gapanya et al. (Gapanya et al., 2008), to date, no imaging technique for non-palpable testes has proven to be superior to laparoscopy, which allows both the diagnosis and the surgical treatment if there is a pathology affecting testes. Whenever the operation cannot be completed through the laparoscopic approach, a switch to the open technique can be applied. This decision can be made by surgeons either before or during the actual operation, in those cases in which it remains opportune for patients safety (Dominguez, 2001; Mathers et al., 2009). Generally, as reported in the guidelines, a staged orchidopexy (Fowler-Stephenson) procedure can be performed, using the open surgery, or mini-invasive approaches like laparoscopy or microsurgery. A biopsy at the time of orchidopexy can be performed to reveal intratubular germ cell neoplasia of unclassified type, which can be removed thereby preventing development of a malignant tumor. [5]

An association between cryptorchidism and testis cancer has been known for more than a century (Wood and Elder, 2009). As reported by (Rogers et al., 1998a) and (Rogers et al., 1998b), when unilateral cryptorchidism with postpubertal male is identified through diagnostic procedures, the orchiectomy – a surgical procedure to remove a testicle and the full spermatic cord through an incision in the lower lateral abdomen – should be performed instead of the orchidopexy.

### *5.2. Design of the De Jure Declare Model*

The model of the process has been designed through the Declare Designer, mentioned in Section 4. Information derived from the European guidelines and from some scientific articles found in PubMed (Smolko et al., 1983; Ferro et al., 1996; Jones, 1995; Guo et al., 2011; Denes et al., 2008; Gapanya et al., 2008; Rogers et al., 1998b,a) has been used to define activities and constraints characterizing the process. Attention has been paid to considering only the activities, among those characterizing the process, that appeared at least once in the event log extracted from the information system of the urology department of the Isala hospital. The model is shown in Figure 7.

The model is composed of 10 activities and 13 constraints using 4 different templates. The LTL semantics of some Declare templates have been provided in Section 4. Hereby, the particular meaning of each constraint in the context of the process of interest will be illustrated.

- Precedence between Radiological Examination and First Hospital Admission and between Lab Tests and First Hospital Admission: the hospital admission should be preceded by the examinations required to assess the presence of the pathology. Among these, radiological examination and lab tests are the most common ones needed for cryptorchidism.

- Precedence between First Hospital Admission and Preoperative Screening: to undergo the preoperative screening, the patient must be first admitted to the hospital.

- Precedence between Preoperative Screening and Open Surgery, Preoperative Screening and Orchidopexy, Preoperative Screening and Inguinal Hernia Treatment: according to the World Health Organization clinical guidelines for surgery, every surgical treatment cannot be executed without preliminary examinations required in order to prevent risks for patients. It is important to outline that, according

[5] http://www.uroweb.org/fileadmin/guidelines/EAU_GO_Manual_November_28th_2012.pdf

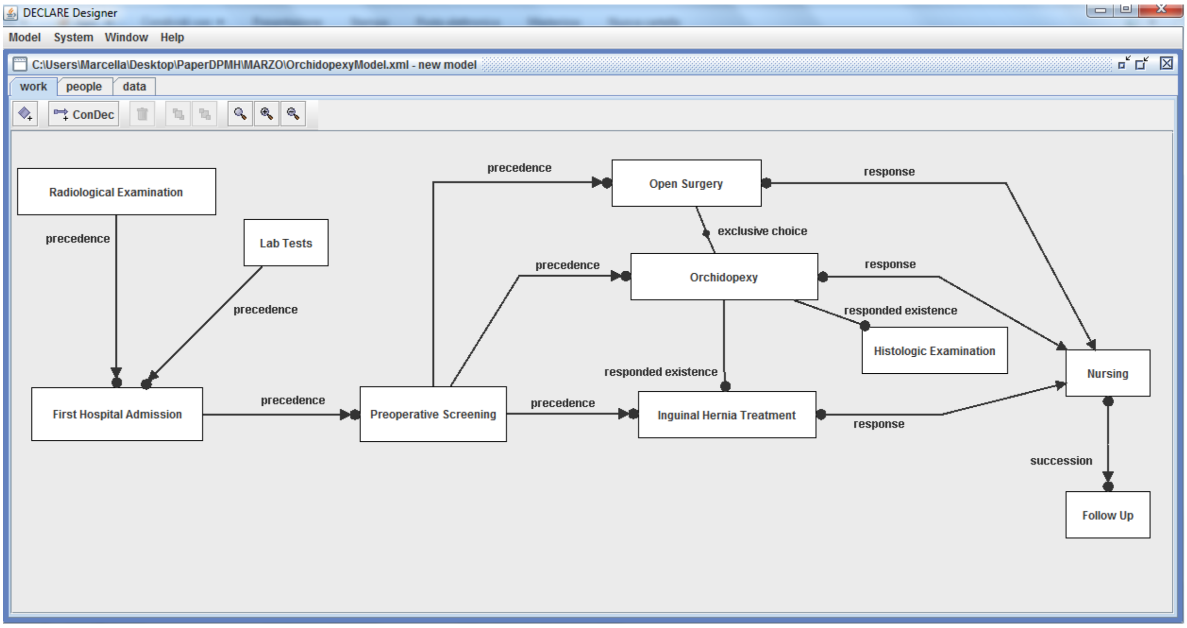


Figure 7: The cryptorchidism treatment according to scientific literature: representation through a Declare model.

to the Isala Hospital denomination of the activities, the word orchidopexy indicates the testes treatment carried out through the laparoscopic approach, while the open surgery indicates those treatments performed through the open approach.

- Response between Orchidopexy and Nursing, Inguinal Hernia Treatment and Nursing and between Open Surgery and Nursing: according to the World Health Organization Guidelines mentioned above, a nursing period must follow every surgical treatment, in order to monitor the patient conditions after the operation.

- Responded Existence between Histologic Examination and Orchidopexy: according to the European Guidelines of Urology, [6] the biopsy with the histologic examination can be performed when the orchidopexy is performed whenever it is retained recommendable to analyze the nature of the tissue. Therefore, if the histologic examination occurs, the orchidopexy should occur as well in the process execution.

- Succession between Nursing and Follow Up: after the nursing period, patients must undergo the follow up check in order to define whether the treatment has been effective and the patient can be discharged, or further examinations and interventions are required. Also, the follow up is usually preceded by a nursing period.

[6] http://www.uroweb.org/fileadmin/guidelines/EAU_GO_Manual_November_28th_2012.pdf

- Responded Existence between Inguinal Hernia Treatment and Orchidopexy: according to the European Guidelines of Urology, the inguinal hernia treatment can be performed at the time of the orchidopexy; therefore, if the inguinal hernia treatment is performed, the orchidopexy is also performed.

- Exclusive Choice between Orchidopexy and Open Surgery: as explained above, to surgically treat the cryptorchidism, it is possible to choose either the open or the laparoscopic approach, but not both (Guo et al., 2011).

This model is the result of some iterations with the doctors to ensure that the model is a valid representation of the official guidelines. After the last iteration, doctors confirmed its accuracy and correctness. The continuous interaction with doctors to discuss models and analysis results represents a fundamental requirement for the application of the proposed methodology.

### *5.3. Conformance Checking of De Jure Model*

Once the de jure model has been designed, conformance checking has been applied in order to measure the adherence of this model with the training log. For conformance checking, we used the Declare Checker and the Declare Analyzer plug-ins of ProM (see Section 4). The results obtained with the Declare Replayer and the Declare Diagnoser are shown in Figures 8 and 9.

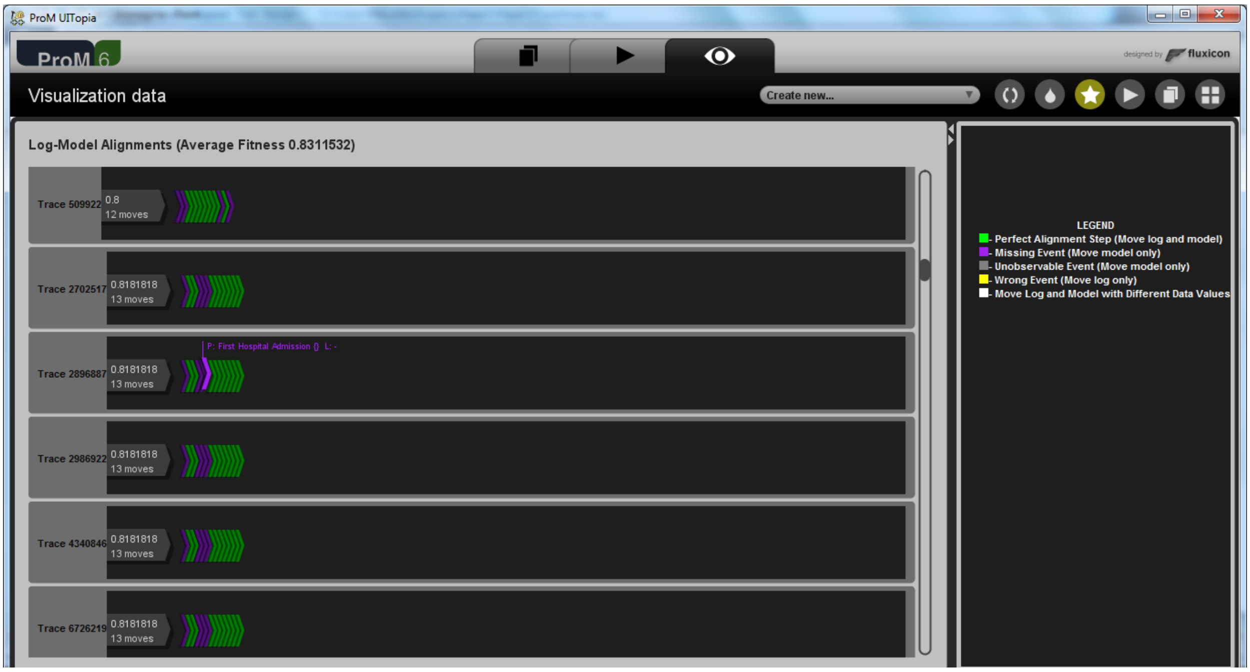


Figure 8: Conformance checking between the de jure model and the training log: the Declare Replayer.

As shown in Figure 8, the average fitness between the de jure model and the training log is approx. 0.831. This fitness value is not very high and shows that the medical protocol is not followed in a number of cases.

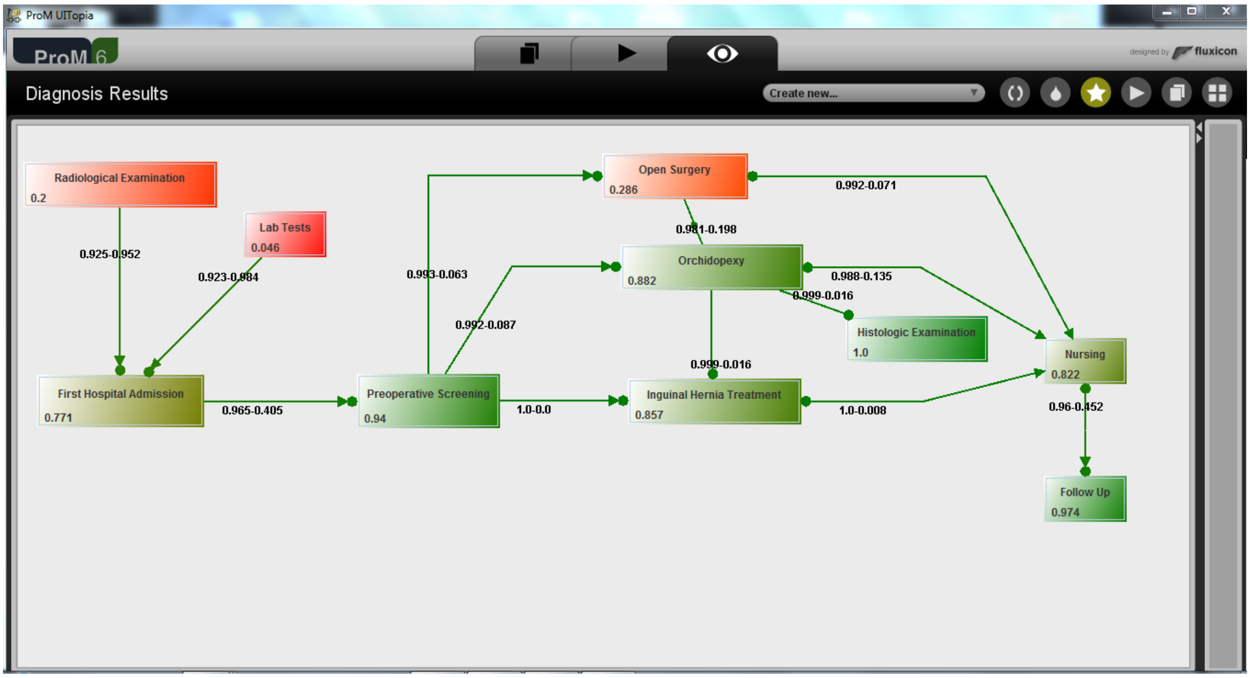


Figure 9: Conformance checking between the de jure model and the training log: the Declare Diagnoser.

The doctors acknowledged that the de jure model encodes the protocols defined in the medical literature. Nonetheless, there are many valid reasons why the protocol has not always been followed. Figure 9 shows that the most severe conformance problems between the theoretical model and actual practice are related to the diagnostic activities preceding the first hospital admission. This can be explained, by considering that patients can undergo diagnostic examinations outside the hospital and then they can be admitted to the hospital if these examinations highlight pathologies like cryptorchidism that may require surgical treatments.

Through the Declare Analyzer plug-in it has been possible to gather a global overview about fulfillments and violations for each constraint in the model. The results are outlined in Table 4 (here, First Hospital Admission is indicated as FHA, Preoperative Screening as PS, Laparoscopic Gastrectomy as LG, Open Gastrectomy as OG, Nursing as N, Orchidopexy as OR, Inguinal Hernia Treatment as IHT, Radiological Examination as RE, Lab Tests as LB, Follow Up as FU).

The Declare Analyzer confirmed that, in most of cases, the First Hospital Admission is not preceded by Lab Tests and Radiological Examinations (a screenshot of the Declare Analyzer showing this violation in one of the cases in the log is shown in Figure 8. Indeed, when patients have already undergone the exams required for the diagnosis - and the surgical treatment has been recommended by the doctors - the repetition of the diagnostic examination is not required at the time of the admission to the Hospital. Therefore, in these cases, the process starts with the First Hospital Admission, and the Lab Tests and Radiological Examination are not present. It is also interesting to observe that there are some cases in which the precedence between

Table 4: The cryptorchidism treatment: conformance checking between the de jure model and the training log through the Declare Analyzer.

| **Constraint** | **Activations** | **Violations** | **Fulfillments** |
|---|---|---|---|
| Precedence [PS - OR] | 197 | 7 | 190 |
| Precedence [PS - OS] | 4 | 0 | 4 |
| Precedence [PS - IHT] | 7 | 0 | 7 |
| Precedence [RE - FHA] | 172 | 162 | 10 |
| Precedence [FHA - PS] | 264 | 86 | 178 |
| Precedence [LT - FHA] | 172 | 168 | 4 |
| Responded Existence [HE, OR] | 3 | 2 | 1 |
| Responded Existence [IHT, OR] | 7 | 6 | 1 |
| Exclusive Choice [OR-OS] | 201 | 0 | 201 |
| Succession [N-FU] | 667 | 150 | 517 |
| Response [OS-N] | 4 | 0 | 4 |
| Response [OR-N] | 197 | 9 | 188 |
| Response [IHT-N] | 7 | 1 | 6 |

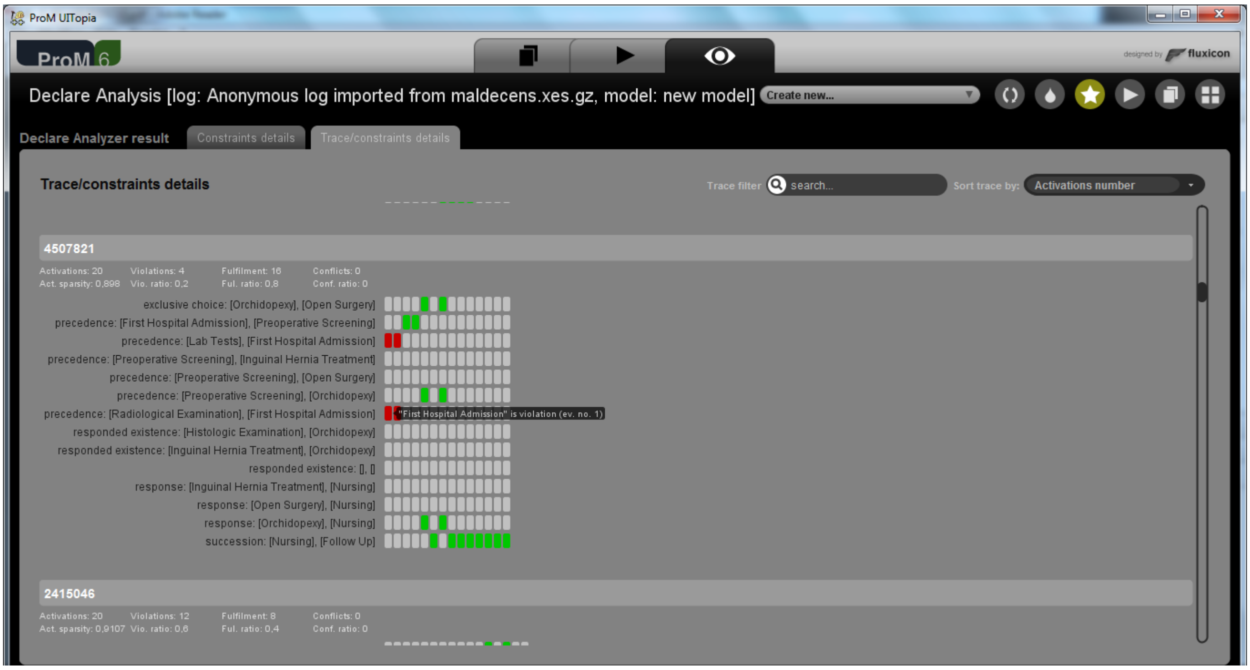


Figure 10: Conformance checking between the de jure model and the training log: the Declare Analyzer.

First Hospital Admission and Preoperative Screening is violated. According to the doctors, the observed violations correspond to patients admitted to different departments of the hospital and then transferred to the urology department because urinary pathologies such as cryptorchidism were suspected. The same considerations hold for the cases in which the precedence between Preoperative Screening and Orchidopexy was violated. It is indeed possible that patients have already undergone different surgical treatments in other departments of the hospital and the data of the preoperative examinations were transferred to the urology department. In these cases, the orchidopexy was directly performed, without repeating the exams. Patients can move from one department to another of the hospital. This also explains the violations of the succession constraint between nursing and follow up and between orchidopexy and nursing, since, after the treatment within the urology department, patients can be moved to other departments if other pathologies arise, and monitored there. The obtained results also show that the responded existence between Orchidopexy and Inguinal Hernia Treatment is violated in some cases. This can be explained by considering that, based to the clinical guidelines, the inguinal hernia treatment can be performed at the time of the orchidopexy. [7] According to the doctors there are cases in which inguinal hernia treatment is performed either in association with other treatments or alone, without performing an orchidopexy.

*5.4. Repairing of the De Jure Model: The De Facto Model*

The doctors recognized the validity of the de jure model and justified the discrepancies between the de jure model and the log based on specific contingencies characterizing the process that generated the log used for this case study. This triggered the need of repairing the de jure model to obtain a de facto model, which takes into account the actual process executions. This has been achieved by using the function *Repair a Declare Model* of the Declare Miner plug-in in ProM, described in Section 4. We assume that all the discrepancies identified in the conformance checking phase should be considered as well justified and taken into consideration to repair the de jure model. Different combinations of configuration options have been set to generate different models. All these models have been shown to the doctors in order to choose the one that better reflects the cryptorchidism treatment process in the Isala Hospital. Figure 11 shows a comparison between the repaired Declare model chosen by the doctors and the model in Figure 7, which conversely implements the procedure according to the scientific literature. The gray constraints are those present in the original model but not present in the repaired model; the black ones are those introduced by the repair task; the precedence constraint between Preoperative Screening and Orchidopexy is the only one retained from the original model. By comparing this model with the original one, important insights can be derived. First, the repaired model does not show constraints related to activities performed before the First Hospital Admission, i.e., Lab Tests and Radiological Examination. As already mentioned before, there are several cases in which patients undergo diagnostic examinations outside the hospital: therefore, if the diagnosis is established, it is not mandatory to repeat the examinations when patients are admitted to the hospital, and they are directly prepared for surgical treatments.

[7] `http://www.uroweb.org/fileadmin/guidelines/EAU_GO_Manual_November_28th_2012.pdf`

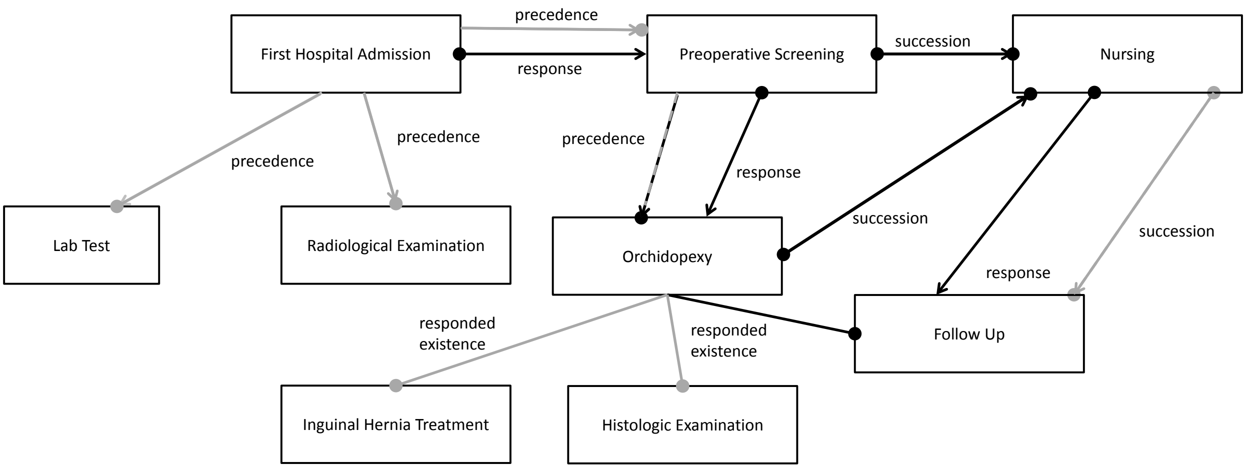


Figure 11: The cryptorchidism treatment: comparison between the repaired model and the original model based on the scientific literature. The gray constraints are those present in the original model but absent in the repaired model; the black are those introduced by repairing; the precedence constraint between Preoperative Screening and Orchidopexy is the only one retained from the original model.

Moreover, the precedence constraint indicating that Preoperative Screening must be preceded by First Hospital Admission is removed. This is due to the fact that, when patients are admitted to different departments of the hospital and then moved to the urology department for the testis treatment, they directly undergo the screening for the surgical treatment, without a new registration. However, the precedence is replaced by a response. This indicates that in the actual process, if the First Hospital Admission occurs, the preoperative screening must happen afterwards.

For what concerns the surgical activities, the responded existence between Inguinal Hernia Treatment and Orchidopexy is removed. This is justified by considering that hernia treatment can either be performed in the actual practice or not according to the specificity of the cases treated. Such a situation represents a typical example of those aspects of the clinical guidelines that are strongly dependent on the specific cases to be treated. In the considered event log, indeed, it is possible that most of the patients were not affected from inguinal hernia, so that the treatment was not performed. The same considerations hold for activity Histologic Examination, which is not constrained anymore.

Since the Open Surgery is performed only in three cases in the event log, the model repairing technique does not find sufficient support to retain any of the constraints associated with that activity. Therefore, all constraints are removed from the model. This is in accordance to (Gapanya et al., 2008), in which it is stated that the laparoscopic approach represents the best method to treat cryptorchidism, since, with this approach, the zone to be treated becomes more visible; in addition, nowadays, the mini-invasive approaches are likely to replace the traditional open surgery in several medical sectors.

In the repaired model it is also shown that the precedence relation between Preoperative Screening and Orchidopexy is respected, in line with the clinical guidelines statements. There is also a response that has been added between them, indicating that usually, if preoperative screening is carried out, the orchidopexy occurs afterwards. Furthermore, the response relation between Orchidopexy and Nursing appears to be reinforced in the actual practice: in the repaired model, indeed, it is replaced by a succession constraint, which indicates that not only after the surgery the nursing must be provided, as stated by the clinical guidelines, but also that in the actual process Nursing is always preceded by Orchidopexy. Finally, a response constraint between Nursing and Follow Up is shown instead of succession: it indicates that after the nursing period, the follow up is needed for patients, but it is not mandatory that the nursing occurs before the follow up. A responded existence links Follow Up to Orchidopexy, meaning that, in the actual process, if Follow Up occurs, Orchidopexy occurs as well.

### *5.5. Cross Validation: Conformance Checking of the De Facto Model against the Test Log*

In this step of the study, the repaired model has been matched with the actual process by applying conformance checking between this (de facto) model and the test log. As shown in Figure 12, the Declare Replayer indicates a fitness value between the repaired and the actual model of 0.884. The results returned

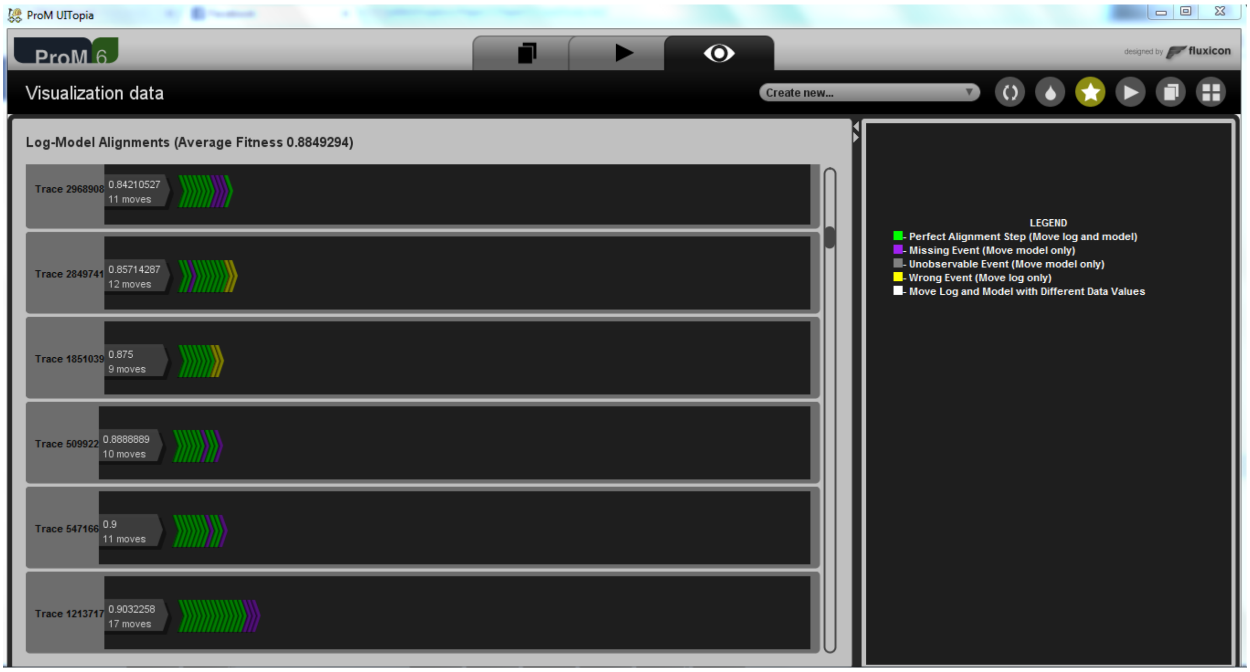


Figure 12: The cryptorchidism treatment: conformance checking between the repaired model and the test log (Declare Replayer).

by the Declare Diagnoser are shown in Figure 13. It is possible to notice that all the activities are represented in green, indicating a good degree of conformance.

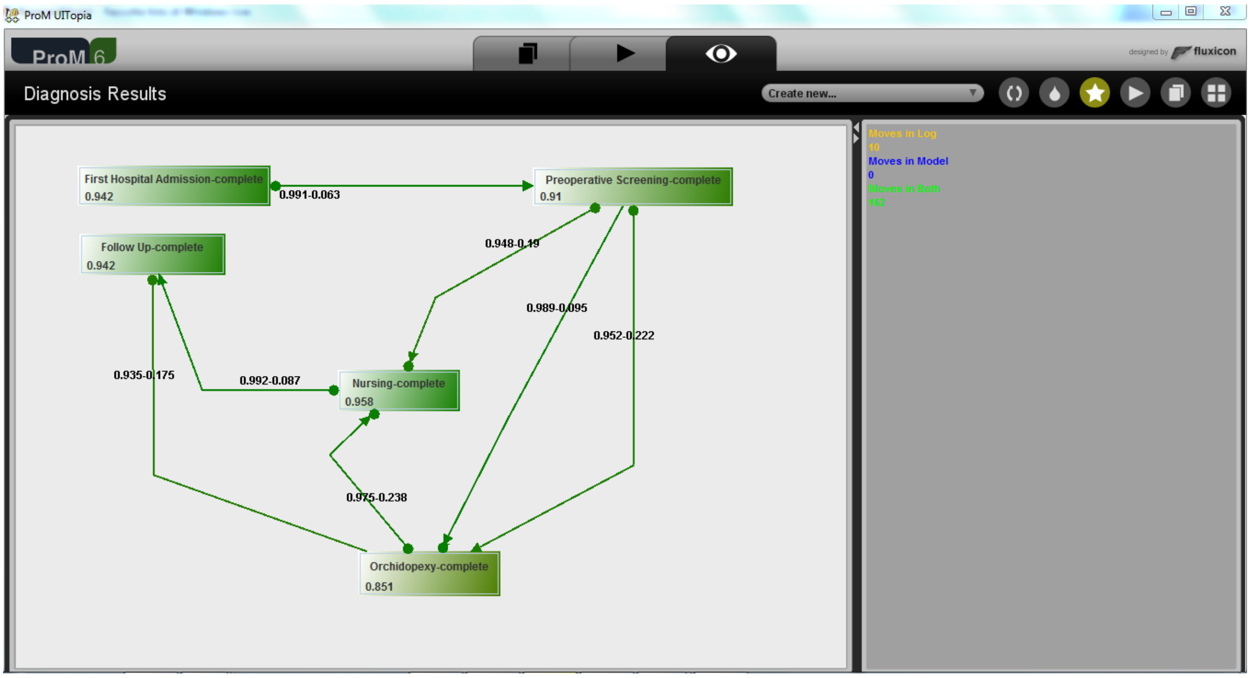


Figure 13: The cryptorchidism treatment: conformance checking between the repaired model and the test log (Declare Diagnoser).

The results obtained with the Declare Analyzer are represented in Table 5 (here, First Hospital Admission is indicated as FHA, Preoperative Screening as PS, Laparoscopic Gastrectomy as LG, Open Gastrectomy as OG, Nursing as N, Orchidopexy as OR, Follow Up as FU). It is interesting to notice that there are 14 cases in which Nursing is not followed by Follow Up and 43 cases in which the succession between Orchidopexy and Nursing is violated. According to the doctors' opinion, these violations are due to the fact that there are cases in which, after the testis treatment, patients are moved to different departments. The same consideration holds for the precedence between Preoperative Screening and Orchidopexy, which was violated in 7 cases. There are also cases in which the responded existence between Follow Up and Orchidopexy is not respected, indicating that Follow up is performed whereas Orchidopexy is not. Examples of violations detected from the Declare Analyzer are shown in Figure 14.

## 6. Conclusion

In this paper, we presented the application of a methodology showing how to use process mining techniques based on declarative models to analyze medical treatment processes. The applied methodology aims at (i) discovering and pinpointing the deviations between the *de jure model*, i.e., the model that complies with existing medical protocols, and the actual behavior as observed in the event log extracted from the HIS, and (ii) creating a *de facto model*, i.e., the model that represent the right compromise between the de

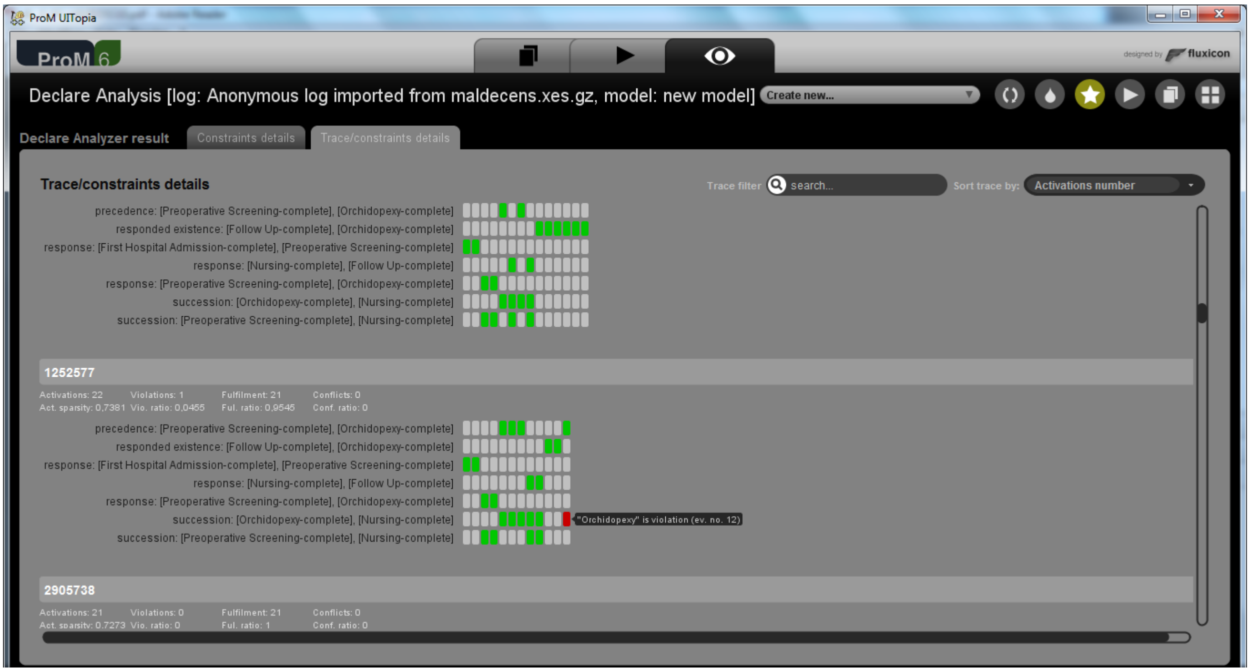


Figure 14: Conformance checking between the repaired model and the test log: the Declare Analyzer.

Table 5: The cryptorchidism treatment: conformance checking between the repaired and the test log through the Declare Analyzer.

| **Constraint** | **Activations** | **Violations** | **Fulfillments** | **Conflicts** |
|---|---|---|---|---|
| Succession [OR-N] | 446 | 43 | 403 | 0 |
| Precedence [PS - N] | 513 | 48 | 465 | 0 |
| Responded Existence [FU - OR] | 418 | 80 | 338 | 0 |
| Response [PS - OR] | 264 | 58 | 206 | 0 |
| Response [FHA - PS] | 172 | 16 | 156 | 0 |
| Precedence [PS - OR] | 197 | 7 | 190 | 0 |
| Response [N - FU] | 249 | 14 | 235 | 0 |

jure model and what is practically observed.

The methodology has been applied to a real healthcare case study in the Isala hospital. Doctors, nurses and process analysts are familiar with procedural modeling languages, even though these models tend to be large and barely readable. In the case study, we had to make the stakeholders acquainted with Declare. Although Declare has a simple graphical notation and succinct semantics, quite some time is required to fully grasp the notation. Therefore, it is good to investigate how to improve the understandability of the notation. However, in spite of this, the results of the case study have shown to be quite insightful, thus being helpful for the process analysts to improve how patients are treated.

The main limitation of the presented methodology is that it relies on the availability of event logs that record the executions of cases. Information systems in a hospital are typically poorly integrated: many systems coexist within the same hospital, thus returning different event logs that cannot be easily merged and that often contain inconsistencies. Even in the current case study a preprocessing phase was needed to extract useful data from the information systems of the Isala Hospital.

As future work, we aim at (i) experimenting techniques that take into consideration also the data and the time perspectives available in event logs (not only control flow), like the ones presented in (Bose et al., 2013; Maggi and Westergaard, 2014; Montali et al., 2013a; Westergaard and Maggi, 2012; Maggi, 2014; Montali et al., 2013b; De Masellis et al., 2014; Montali et al., 2013a; Maggi et al., 2013b; Burattin et al., 2015; Borrego and Barba, 2014), (ii) identifying possible solutions to compare two models or two logs for analysis (not only a model and a log), (iii) developing a general framework supporting process analysts to extract event logs from healthcare information systems, (iv) applying the proposed methodology in different scenarios to evaluate it in a systematic way.


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