# CONTINUOUS CLINICAL PATHWAYS EVALUATION BY USING AUTOMATIC LEARNING ALGORITHMS

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Abstract: The standardization of care processes in medicine, like Clinical pathways, is becoming more and more a common practice in health care organizations. Nevertheless, their design is not an easy task. Some approaches in the literature are based on using Workflow technology for defining Clinical Pathways. These approaches allow the creation of unambiguous, complete and automatically executable protocols. In addition to this, the use of Process Mining technology can help the design using information from real executions of Clinical Pathways cases. Nevertheless, to ensure a correct continuous evaluation and improvement of care processes, the creation of a tool that allows to know the current status of the Clinical Pathway execution it's mandatory. In this paper, we present a tool able to compare the designed Clinical Pathways with the real implantation cases in order to detect their differences. This allows Clinical Pathways designers to improve the care protocols making them more adequate to real cases.

## 1 INTRODUCTION

Nowadays, current trends on process management are focused in the standardization of processes in order to evaluate and improve the strategy to achieve better quality and efficiency in most common actions. In Health environments, the care processes standardization is becoming more and more present. The use of standardized protocols, for normalizing the care process, like Clinical Pathways (Audimoolan et al., 2005) is more and more adopted by health professionals in order to improve the quality of care of patients.

The use of Clinical Pathways for Health Care standardization is a difficult task. Clinical Pathways are usually multidisciplinary complex documents that coordinate the actions of patients, doctors and the rest of involved care process stakeholders. In order to create efficient care protocols it's necessary to avoid ambiguity, describe completely the whole problem and facilitate the use of ICT (Information and Communication Technologies) to make the system usable.

The use of Workflow Technology (WfMC, 1999) can help doctors to design formal, non ambiguous and automatically executable care protocols to describe complete Clinical Pathways. In addition, the Process Mining technology can be used to automatically infer workflows to facilitate the design of the processes in a formal way (Fernández-Llatas et al., 2010).

Nevertheless, the control of the implantation of Clinical Pathways requires a high level view that supports the detection of inefficient processes and bottlenecks. This paper presents a tool created to facilitate this management and to evaluate the fitness of executing Clinical pathways by automatically comparing the real execution care protocols cases with the designed Clinical Pathway. This tool uses Pattern Recognition techniques to detect and quantify exceptions occurred in real cases. These exceptions are divergences from the 'expected' path that was designed and the real performance that can be later analyzed by the healthcare organizations and corrected if needed and possible.

The paper is structured in the following way. Firstly the solution to Clinical Pathway design using Workflow languages in described. The following section explains how process Mining techniques can be used to help the design of Workflow based Clinical Pathways. Following this, a tool for the continuous evaluation of ongoing Clinical Pathways is presented. The last part summarized the conclusions of this work.


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## 2 CLINICAL PATHWAYS AS HEALTH CARE STANDARDIZATION MODELS

Since the appearance of the Evidence Based Medicine(EBM) paradigm (Elstein, 2004) that was born in the early 90's, the works focused on applying the scientific method to medical research are each year growing significantly. The idea of standardizing health care processes is more and more adopted to improve daily actions of nurses, doctors and the rest of stakeholders. In some of the most commons medical knowledge public repositories, like COCHRANE (The Cochrane Collaboration, 2010) or PubMed (PubMed Library, 2010), it's possible to find detailed care protocols to address the management of almost any disease. These standardized health care protocols, also known as Clinical Pathways (Audimoolan et al., 2005), deeply describe all the steps that patients, doctors, nurses and the rest of the stakeholders must follow to perform the care process efficiently and efficaciously.

These protocols are usually described in natural language. This is due to the high expressivity needed by Health professionals to describe care protocols. The situations that a Clinical Pathway can express are very complex. However, this use of natural language supposes a big problem when moving to Clinical Pathways interpretation. Natural language models have clear ambiguity problems. Different health professionals can understand the same phrase in totally different way. This situation can lead to an erroneous interpretation of a Clinical Pathway that might affect the patient's quality of care. In addition to this, defining Clinical Pathways using natural language does not allow to ensure that the process is completely defined. In that case, it's possible that the process has undefined states that must be lucubrated by health professionals.

Other reason to avoid natural language in Clinical Pathways design it's the impossibility that this bring to the automatic execution of guidelines. Currently, the healthcare organizations are more and more computerized and the data is each time more available in digital way. The use of dynamic systems that allow the computerized guidance of the health professional in the care process following the Clinical Pathways description will suppose a crucial help to the deployment of those protocols. This is important because, in some cases like multidisciplinary protocols, the high bureaucratic load and the required coordination of specific teams demands the use of computer systems in order to allow the standardization of protocols. Natural language is not understood by computers. For that reason, in order to create systems enabling the guidance of health professionals with automatic guidelines it's necessary to translate the process definition to a formal language that could be executed automatically.

There are some efforts in literature focused in addressing this problem. Some high level languages have been defined to formally describe Clinical Pathways: GLIF language (Peleg et al., 2001) was defined to describe and evaluate health care protocols; In Carepaths project (Naranjo et al., 2006) an ontology for describing and automatically executing Heart Failure Clinical Pathways was developed. Other works are purely based on Workflow technology to describe general purpose and high expressivity languages for Clinical Pathways definition (Dominguez et al., 2008).

Workflow Technology is a research field focused on the creation of process specification languages and its dynamic execution. A Workflow is defined as *the automation of a business process, in whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules* (WfMC, 1999). A Workflow is a formal description of a process designed to be automated. A Workflow language is a formalism that allows the definition of Workflows. A formal Workflow can be automatically executed in a computerized system by using a Workflow Engine. This will allow the automatic execution of standardized protocols and the guidance of processes in computerized environments.

The advantages of the use of Workflow technology over other techniques in Clinical Pathways definition are several. In the literature, we can find available some Workflow engines for automatic execution of processes like jBPM from jBoss or Workflow Foundation from Microsoft. Workflow languages have a great understandability. The majority of Workflow Languages have a graphical view and it's possible to design the execution of processes. A graphical definition of a Workflow can be seen on Figure 2. In addition, there is the possibility to measure the expressivity of a Workflow language according to the Workflow Patterns (van der Aalst et al., 2003a) to decide the most adequate language to be used in the formal description. Workflow Patterns are flow structures that describe the state change rules in a process. Examples of Workflow Patterns are sequences, choices, parallel actions... etc. The more Workflow Patterns a language is able to define, the better expressivity it has.

```
07/05/2010 10:22:59 => i:1 BeginAction: Admission
07/05/2010 10:34:01 => i:1 EndAction: Admission Res: OK
07/05/2010 10:35:03 => i:1 BeginAction: Triage
07/05/2010 10:46:06 => i:1 EndAction: Triage Res: InHospital
07/05/2010 10:56:07 => i:1 BeginAction: TNS
07/05/2010 10:56:08 => i:1 BeginAction: TMP
07/05/2010 11:23:10 => i:1 EndAction: TNS Res: OK
07/05/2010 11:33:12 => i:1 EndAction: TMP Res: Fever
07/05/2010 11:43:19 => i:1 BeginAction: TMP
07/05/2010 11:50:19 => i:1 EndAction: TMP Res: OK
07/05/2010 11:51:24 => i:1 BeginAction: QualityTest
07/05/2010 12:00:28 => i:1 EndAction: QualityTest Res: OK
07/05/2010 12:15:29 => i:1 BeginAction: Discharge
07/05/2010 12:20:30 => i:1 EndAction: Discharge Res: OK
```

Figure 1: Example of Clinical Pathway case log.

## 3 PATTERN RECOGNITION TECHNIQUES FOR CLINICAL PATHWAYS AUTOMATIC LEARNING

The use of Clinical Pathways does not ensure that the processes was always executed in the same way. In this line, it's very common that the care process of a patient is changed during execution. This change can be motivated by the daily problems in the care process (like administrative errors, malfunctioning or unavailability of devices to perform medical tests described on the care protocol, etc) and the variability of the patient illnesses. For example, a pluripathologic patient can suffer changes in his treatment protocol due to an allergy or due to contraindications of the protocol with the recommendations for other illness not documented on that Clinical Pathway.

These exceptions to the care protocol can be very useful to detect design problems in the Clinical Pathway or underperformance of the care processes. Knowing that information would enable the correction and fine-tuning of the Clinical Pathways in an iterative process. The correction could be done in the design or in the real execution problem, depending on the cause for the divergences but the important touch-point would be to know when, how and under which conditions those divergences happen. Using this model on each iteration the errors detected will be used to correct the Clinical Pathway that will be changed for the next iteration. This problem can be approached in an automatic way using Process Mining Technology. The Process Mining idea (also known as Workflow Mining) (van der Aalst et al., 2003b) is the automatic learning of Workflows for business process inference. Process Mining algorithms use the execution samples to infer the Workflow that describe the real process. Using this technique the logs of care protocols actions applied to each patient can be used to learn Workflows that formally represent those Clinical Pathways. This helps Clinical Pathways designers to modify previous iteration processes according to the real deployment incorporating the new exceptions and correcting design errors.

In (Fernández-Llatas et al., 2010) a Process Mining algorithm (called PALIA) has been proposed to discover the execution model of the Clinical Pathway from the data gathered about the actions executed of the patient past cases. This algorithm takes as entry data information about the activities performed by Clinical Pathways stakeholders in a case assigned to a patient.

Figure 1 shows an example of the logs of activities in a case. This log is composed by a set of events that represents begin action and end action events. The begin action event has the identification of the case, the name of the action and the time when the action was started. The end action event has the identification of the case, the name of the action, the time when the action was finished and the result of this activity.

Analyzing a set of samples like the shown in Figure 1, using Pattern recognition techniques, PALIA algorithm is able to infer automatically a Workflow like the shown in Figure 2. This Workflow represents a model that resumes graphically all the possible flows that the log samples can follow. This formally defined Workflow can be used by Clinical Pathway designers as the basis for the description of a formally defined care protocols that explains all the situations that can occur in reality in a concrete scenario.

Nevertheless, these techniques can be used not only for helping design of Clinical Pathways but also to support the continuous evaluation of them. This allows comparing formal protocols to detect differences between the designed and the executed one and facilitate the detection of problems in individual or

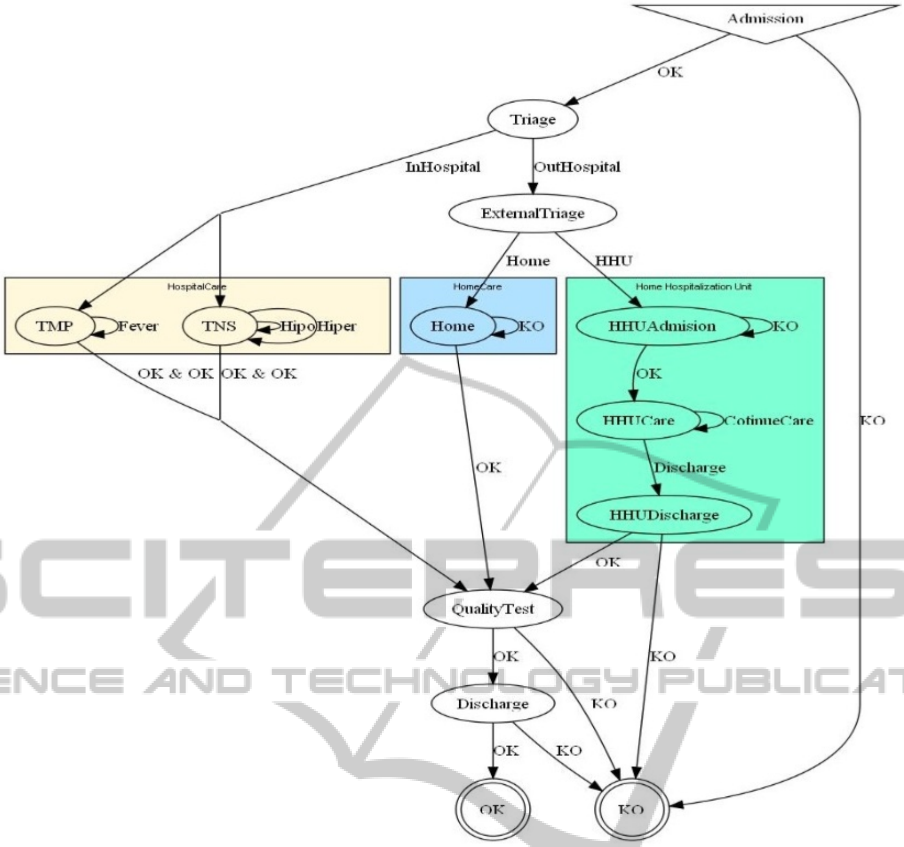


Figure 2: Original Clinical Pathway deployed.

population cases to improve the efficiency. Furthermore, it provides a guideline for managers to understand the reasons for incompliance to protocols and evaluate if the compliance support strategies put in place are followed. This is also an important achievement as compliance of health professionals to care processes whenever is possible is highly desirable. Consequently, to allow the use of the described techniques in Clinical Pathways Evaluation, it's necessary to create a software tool that incorporate those techniques to allow the inference and evaluation of ongoing Clinical Pathways.

## 4 USING PROCESS MINING TECHNIQUES IN CLINICAL PATHWAYS EVALUATION

In this paper, a tool for Process Mining use in Clinical pathways Evaluation is presented. This prototype was developed in the framework of the Heart Cycle European project (Heart Cycle Consortium, 2008).

This tool has some mining algorithms to allow Clinical Pathway designers to detect errors on execution time and helps the refinement and redesign of the process in order to improve the efficiency and efficacy of the systems.

Basically, the tool has two kinds of algorithms implemented.

- An Activity-Based Process Mining algorithm was implemented to discover the whole process that is occurring in its real execution. The algorithm implemented is based on Parallel Activity-based Log Inference Algorithm(PALIA) definition (Fernández and Benedí, 2008).
- Two algorithms able to compare the original protocols with the inferred one were implemented. The first algorithm is able to compare two workflows to detect differences between them. This algorithm is based in classical Error Correcting techniques (Rulot and Vidal, 1987) based on grammar inference theory. The Second algorithm is able to compare a workflow with a individual case. This algorithm will allow the systems to show the path followed by the case in the Clinical Pathway flow.

To allow the interaction of the tool with other Workflow management systems the tool admits dif-

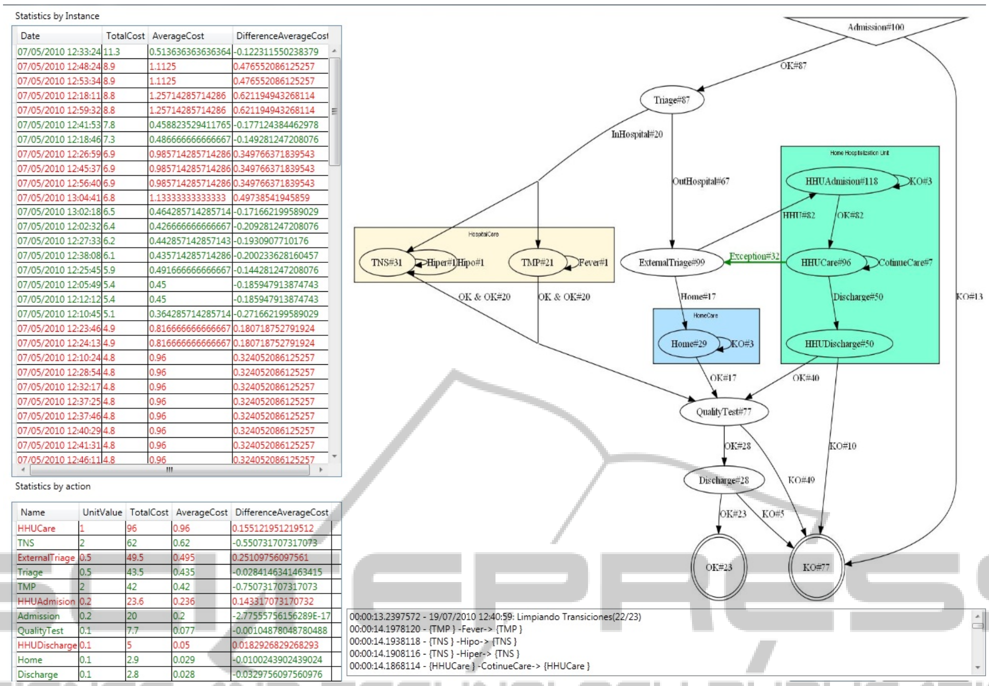


Figure 3: Clinical Pathway Inferred compared with the Designed one.



ferent input and output formats. The tool implemented accepts log process samples codified in plain Activity-based Log Format (Fernández and Benedí, 2008) or in extended MXML format (van Dongen et al., 2005) for Activity-Based Logs. The graphical flows inferred can be exported to dot format (Ellson et al., 2004), TPA format (Fernández and Benedí, 2008) and, as a Petri Net, to PNML format (Billington et al., 2003).

To explain the functionality of the tool, a Clinical Pathway and some evaluation samples will be used. This example will be widely explained to show how the application uses Process Mining techniques to evaluate the execution of Clinical Pathways.

For this experiment a simplification of a general triage process in a Hospital was used. The formal care protocol used in the experiment is shown in Figure 2. This protocol was specifically selected because resumes the most complex Workflow Patterns that are used in Workflow Patterns according the experience acquired in Heart Cycle Project (Heart Cycle Consortium, 2008). This Protocol combines the use of action sequences, parallel activities and joins as well as complex multichoice Workflow Patterns (van der Aalst et al., 2003a).

The Clinical Pathway of the Figure 2 shows a triage process in a hospital A modification of that protocol has been used to simulate 100 samples using a Workflow simulation engine (Fernández et al., 2008). Each one of these samples represent a real execution of the designed protocol. In order to be more realistic in the simulation, the Clinical Pathway simulated is not exactly equal to base. This allows to represent how the system detects cases in which the patient does not follow exactly the same path in the Clinical Pathway. In this way, in our experiment, on one hand the protocol will represent the Clinical Pathway designed to be evaluated, and in the other hand the 100 cases will represent 100 patients assigned to the protocol.

The first step to follow for Evaluating a Clinical Pathway using the Heart Cycle Pathway Evaluation tool is to discover the Clinical Pathway that represents the real protocol described by the 100 patients assigned to the protocol. In order to do that, the 100 samples are used to infer the real Workflow to be compared with the designed one. The Workflow algorithm implemented in the tool allows do that.

Figure 3 shows the results offered by the tool. At the right of the screen it's possible to see the comparison between the original workflow and the inferred one. In that image, the transitions and states are labelled with numbers. This represents how many times this state or transition has been accessed. This allows Clinical Pathways designers to discover bottle necks and unused actions to make more efficient and simplify the Clinical Pathway's Design. In this case, it's easily detected that only the 23% of samples complete the care protocol until the end. Other important data that can be deduced of this example is that the majority of patients are derived to HHU (63 of 87).

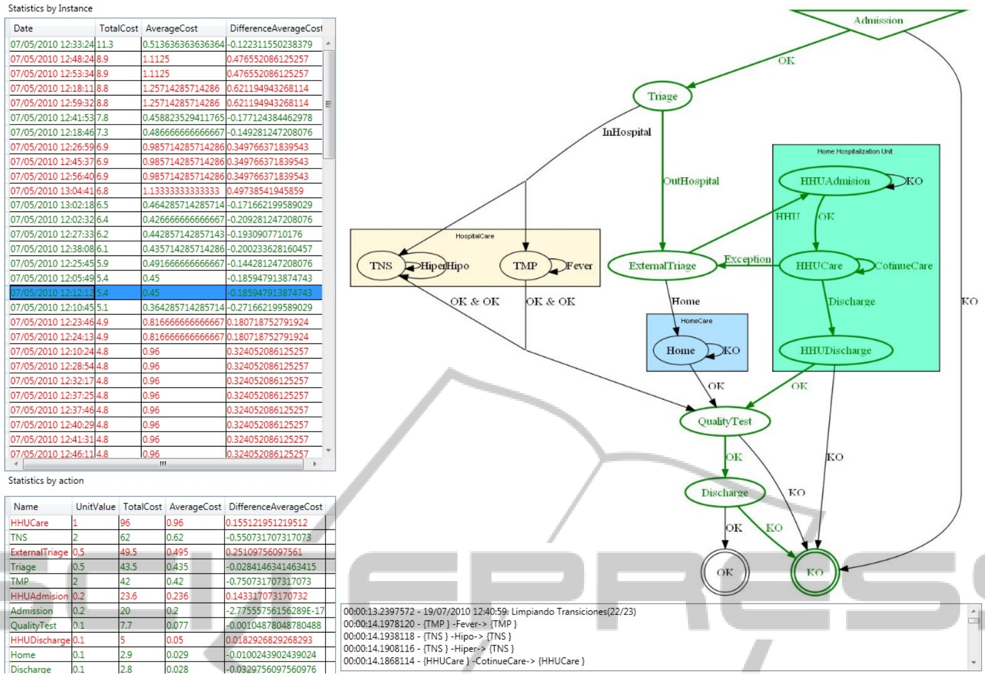


Figure 4: Clinical Pathway Instance path view.



In this example, it is shown how Clinical Pathways exceptions affect the Protocol execution. In the example, 32 executions of the 82 cases that are assigned for *HHU Care* are returned to *External Triage*. This step, not covered by the original Workflow, is shown in the example as a green arrow. With this information, the Clinical Pathways designer can deduce that there is an error on *External Triage* or *HHU Admission* process that makes inefficient the HHU Unit producing an high percentage of exceptions in the *HHU Care* process. Then will be the role of the manager of the process to find the best solution for this divergence, but the proposed tools has highlighted where it happens and can reproduce and analyze the conditions in which it happened: typology of patients, time or date frames, specific teams or professionals, etc.

In the left part of the screen some statistical information can offer more data about the efficiency level of the Clinical Pathway execution. The upper part shows information about the 100 execution cases. Each one of the actions of the Clinical Pathway has assigned a relative cost. Using that information the system can calculate the total cost of each case and shown they ordered. In addition, the average of cost by action made in a case is also show. This allow to detect the kind actions that has a bigger relative percentage cost. To make easier the detection of groups of deficitary cases, the application shows in red the cases that has an average cost below the mean, and marks in green those that has an average cost over the mean.

The lower part shows statistical information about the actions executed in all the cases. In that case, it is shown the relative cost of an action executed in all the cases, and the average cost by case. In the same way, the application shows in red the actions that has an average cost below the mean, and marks in green those that has an average cost over the mean. This information allows detecting which actions are more used and its usual cost in their global execution.

In order to facilitate the detection of inefficient cases, the application allows to Clinical Pathways designers the single view of a patient case. In this case, selecting a case from the left instances list with the mouse, the correspondent flow is shown on the right

Figure 4 shows an example of how a Clinical Pathway execution is displayed in the application. The Workflow shows in green the states and arrows that are followed by the selected case. This allows health professionals to detect punctual errors in individual cases and how those errors affect patients. In this example, the case does not follow exactly the Clinical Pathway originally designed and provokes an exception in *HHU care* process returning to *External triage* process and, after that, returning other time to *HHU Admission* process. In the example, a simulated administrative error provokes the exception that throws out the patient from HHU that finally was detected and corrected by *External Triage* process. In that case, the health professionals can revise the *HHU Care* process rejection protocol to detect possible errors.

## 5 CONCLUSIONS

In this paper, a tool for the continuous evaluation of Clinical Pathway deployment is presented. This tool is able to compare real execution cases with the theoretical designed Clinical Pathways. This allow to easily discover the differences between the care protocols predefined and how they are actually applied. This allows Health professionals detect inefficient processes, exceptions, inconsistencies and bottlenecks in the designed Clinical Pathways or to identify possible problems in the organization that prevent the efficient work of the care teams. In addition to this, the application offers the possibility to associate cost measurements to the actions and have a view of the process relative costs in order to quantify the inefficiency of the system.

The tool has been tested in laboratory conditions using a simulated Clinical Pathway and a set of cases to achieve a first evaluation of the system capabilities.

This tool is currently in evaluation and it is planned to be validated in real systems in Hearth Cycle (Heart Cycle Consortium, 2008) European project.

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