Conformance Checking for Care Pathway Compliance Assessment

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Abstract

With the growing adoption of care pathways worldwide, the urge to deliver high-quality healthcare services and treatment excellence is constantly increasing. However, a gap has been observed where clinical practice often deviates from the clinical best-practices model, which can lead to lower levels of quality care and patient outcomes. It is essential for healthcare improvement to monitor and fully understand how reality conforms to the care pathway. Built on process mining techniques, supported by a set of metrics computed on non-compliant scenarios considering skipped and inserted activities, this study devises a model to assess the compliance between the clinical practice and the specifications in a care pathway. The proposed model addressed 345 clinical cases from Hospital da Luz Lisboa with Colorectal Cancer, divided into colon and rectum cancer patients cases, and reviews the conformance level for each group, providing diagnostic compliance analysis on the medical behaviours. Results on the real-world dataset allowed to conclude that no patient case had data evidencing full compliance with the pathway. On average, only about half of the pathway was completed, proving that there is room for improvement. Concerning clinical outcomes, results showed that the number of post-operative days until discharge was lower for patient cases with higher compliance levels (CI=95%). Therefore, this work provides a robust model for monitoring clinical practice as an attempt to increase the quality of healthcare.

Key words: Care Pathway, Compliance Analysis, Process Mining in Healthcare, Conformance Checking, Fitness, Colorectal Cancer

1 Introduction

Due to the rapid development of hospital information systems, Electronic Health Records (EHR) are becoming more complex and complete, to cope with the large series of patient data being captured. The collected data contains details on the patients’ progression, along or around the expected course expressed in the care pathways (CP). This provides the opportunity for studying medical cases, clinical evidences and to extract relevant knowledge about the medical treatment processes (Yan et al., 2017). However, a gap between the clinical recommendations and the clinical practice has been observed, which can lead to lower compliance levels. In fact, the reality often deviates from the clinical practice guidelines (Rovani et al., 2015). Therefore, the urge to monitor the activities performed by healthcare professionals (HCP) and identify where the care given has deviated from the care expected is a matter of utmost importance.

Compliance management is a crucial step to be considered when an organization intends to accomplish a higher degree of process maturity (Weidlich et al., 2011), specially concerning healthcare organizations, due to the complexity of medical treatment processes. In this context, the need for compliance checking is becoming increasingly relevant to leverage a cost-efficiency in the quality of the care provided, to reduce unnecessary variations through standardization of treatment behaviours and to improve/redesign CPs. Once non-compliance cases are detected, the healthcare organizations can update their CPs or adopt new techniques to enforce the best practice executions (Weidlich et al., 2011).

Based on the premise that CPs are used to increase the quality of healthcare, this study presents a model to assess the compliance between the clinical practice and the expected course of care described in the pathway, enabling the process improvement, the detection of predominant deviations and to understand how well adjusted to the reality the clinical recommendations in a CP are. This work offers the strategy to effectively examine the performance of HCPs according to a pathway, so that healthcare organizations can properly monitor how HCPs are operating, and audit for deviation. For this purpose, the proposed model measures to what extent the clinical executions conform with the CP through a fitness metric computed with the algorithm proposed by Adriansyah et al. (2011). The model provides computed clinical domain-specific metrics that allow to collect insights on the compliance of individual activities, the order and pathway constraints, for the inspection of the underlying non-compliant events.

The second main contribution of this study is the compliance analysis of a real-world dataset of colorectal cancer (CRC) patients, provided by Hospital da Luz Lisboa. It allowed to report the reality of medical diagnostic and treatment interventions for this disease, giving an overview of the non-compliant events observed, and to validate the proposed model. Also, to establish an asso-
ciation between the compliance levels achieved and the impact in the patients’ health.

Colorectal cancer is the most common malignancy of the gastrointestinal tract (Kumar et al., 2015). According to the American Cancer Society\(^1\), more than fifty thousand patients die of this disease each year in the United States, which makes CRC the third most deadly cancer in the United States. The incidence of CRC is slightly higher in men than in women and it is more frequent in age group of 60-70 years old, with less than 20% of the cases occurring before 50 years old. It is prevalent in the United States, Canada, Australia, New Zealand, Denmark, Swedish amongst other developed countries.

2 Concepts and Related Work

In clinical practice, the patients careflows are usually subjected to recommended and standardized treatment interventions. A care pathway, also known as a clinical pathway, care maps or critical pathway, is the term assigned to the evidence-based medical treatment processes of operational nature that HCPs should act in accordance with. They anchored in international approved clinical recommendations, named clinical practice guidelines.

According to Every et al. (2000), a CP corresponds to a set of integrated management plans to reach the patients’ health goals, which provide the course, sequence, and timing of actions. CPs are viewed as algorithms, detailing structured processes for the appropriate healthcare for a specific and concrete clinical setting and individual circumstances, designed by each organization (Basse et al., 2000).

CPs are widely adopted by healthcare providers to deliver high-quality standardized care services, in order to reduce unnecessary clinical practice variations, and to enhance the efficiency of the medical treatment processes. Implementing care pathways translates evidence-based medicine into clinical practice and identifies which bad behaviours and malpractices must be removed, leading to better patient outcomes (Quaglini et al., 2018).

Due to the gap observed and the growing adoption of care pathways worldwide, clinical pathway compliance checking is of utmost importance in the healthcare environment. Care pathway compliance analysis is the process of (1) discovering knowledge about how clinical activities impact on the patients careflow and whether they act in accordance with a CP and (2) using the discovered knowledge for: CP redesign and iteration of internal medical processes; CP optimization; clinical decision support; medical deviation detection; and business management (Huang et al., 2012).

2.1 Process Mining in Healthcare

Process mining, a method for business process management (BPM) and analysis, is gaining increasing attention in healthcare (Mans et al., 2013). Process mining aims at extracting knowledge and non-trivial useful information from the process executions, to discover, monitor and improve processes (Mans et al., 2013). It provides a comprehensive sets of tools to return fact-based insights and, thus, to support process improvement.

There are three main current types of process mining: discovery, conformance and extension (Rojas et al., 2016).

1. Discovery is related to inferring process models that are able to reproduce the observed behaviour. The outputed model can be represented with Business Process Management Notation (BPMN) or another notations (e.g. Petri Net).

2. Conformance checking allows to compare an a priori model with the observed behaviour, to analyze if the reality conforms with the process model.

3. Extension/Enhancement corresponds to the projection of the information extracted form the observed behaviour onto the model, where the goal is to enrich the model with the data in the event log.

Despite the difficulties due to the richer diversity and complexity of medical behaviours over other business processes (Huang et al., 2013), discovering process models and analyzing their performance provides relevant opportunities for extracting knowledge out of the abundant information recorded in an hospital’s EHR. Process mining ensures that not only the healthcare processes are well-understood, but also allows to achieve a high level of process efficiency. With the usage of process mining techniques, healthcare organizations can discover the processes as they are executed in reality, check whether certain practices were really followed and gain insights into resource utilization and performance-related aspects. Thus, process mining’s wide applicability in healthcare can help to construct or redesign the processes, to analyze and improve the performance and collaboration between physicians, to identify which activities are bottlenecks and to add alternative or supplementary data to the activities of the process (Rojas et al., 2016).

The ProM framework is an open-source that has become the standard tool for process mining studies and the most frequently used tool for the application of process mining techniques in healthcare (Rojas et al., 2016).

2.2 Compliance to a Care Pathway

Rich literature describing how to measure compliance and to discriminate compliant from non-compliant events has been reported. For this purpose, given the process model and the event log (standard format containing all the activities a patient was subjected to) with all process ex-

\(^1\)https://www.cancer.org/
executions, the objective is to output a set of compliance metrics to measure the observed deviations.

van de Klundert et al. (2010) developed a method to define and measure deviations and adherence, which provides insights on the pros and cons of CPs. The model proposed to evaluate that adherence to the pathway using costs for the deviations measured on a numerical scale, based on the input of clinical experts. Two combined algorithms to measure the adherence are described and the model outputs an adherence value for each case.

Weidlich et al. (2011) presented a set of compliance metrics for the cases of a process, not specifically in field of health. The method can be applied to any process model and event log. They present an algorithm based on the behavioural profiles of a process and a case, in which each pair of activities is in, at least, one of the following relations: strict order relation (one activity that occurs after the other, not necessarily adjacent), exclusive activities (activities that cannot occur in a same sequence of activities), interleaving relation (one activity that can occur before or after the other) or causal relation (the occurrence of one activity enforces the occurrence of another one).

Rovani et al. (2015) proposed a methodology to check the conformance of the clinical guidelines against the real clinical practice in the event log. Through a set of process mining techniques supported by different ProM plug-ins, they identify the main discrepancies and provide an analysis on such deviations in the process executions, suggesting actions to be undertaken to adapt and improve the CP.

Adriansyah et al. (2011) present an algorithm for conformance checking given a process modelled and the corresponding event log. The algorithm, based on the A* algorithm (Dechter and Pearl, 1985), details a cost-based replay technique that measures deviations with a fitness metric, allowing to account for the severity of specific activities. In contrast to other classical fitness techniques, as the similar algorithm proposed by Rozinat and van der Aalst (2008), the method developed by Adriansyah et al. (2011) does not penalize the conformance for existence of either skipped or inserted activities and allows to consider the severity of the activities. The algorithm is available from the ProM framework.

3 Care Pathway Compliance Assessment

Given the modelled CP, the event log and the severity costs set for each activity of the pathway, the proposed model outputs the conformity value for each patient case in association with metrics computed on the compliance of individual activities, the order and pathway constraints, for the inspection of the underlying non-compliant events (that supports the CP compliance analysis) – Figure 1. The model encompasses the following processes:

- Definition of the event log and CP required as input, as well as the formalization of the concepts and non-compliance criteria;
- Conformance measurement of individual clinical cases to pathway, using process mining techniques;
- Definition of a set of metrics for the diagnostic compliance analysis based on the possible non-compliant criteria identified.

3.1 Architecture of the Model Based on Non-compliance Criteria

In order to apply the data of medical behaviours on the patients careflow stored in the information systems of an healthcare organization to process mining tools, the first stage involves the generation of the event log table. The event log is the standard structure used to represent the sequence of HCPs’ interventions for single patient cases. The event log that serves as input for the proposed model must contain three different attributes: the clinical case identifier, the activity that occurred and the timestamp in which the activity was performed. Each entry corresponds to a specific activity of a case and the event log must be ordered by the timestamp. However, additional attributes can be considered, such as the gender of the patient, the phase of the pathway, the HCP who performed the activity, the healthcare unit in which the activity performed or any clinical outcome. With multiple attributes, it is possible to filter the event log to study the compliance based on specific characteristics under analysis (e.g. filtering by the clinical cases for which mortality is observed). Nevertheless, it must be ensured that each activity has an unique identifier, such that the name of the activity recorded in the log match the same activity in the modelled CP and vice versa. Moreover, the log
may include different activities than those expressed in the model.

Figure 2: Architecture of the proposed model to assess the compliance to a care pathway.

As basis for the information’s architecture of this model, represented in Figure 2, the formalization of the concepts used follows the suggestion of Weidlich et al. (2011), but applied to medical treatment processes. Considering the authors’ preliminaries and an interpretation of the CP using BPMN modeling language, a CP and a patient case are defined as:

(1) Definition: Care Pathway.
A care pathway is defined as CP = (A, εp, ai, ao), in which

- A is a non-empty set of activities. An activity is considered the unit of care that must be delivered to the patient, such that should be executed and recorded, e.g. interventions, laboratory tests or prescriptions.

- εp is the set of valid executions sequences of activities.

- ai ∈ A is the initial activity and ao ∈ A is the final one, with no business semantics except initiating and ending a process instance.

(2) Definition: Patient Case.
Following the structure of an event log, the set of patient cases is represented by C = [c1, c2, c3, ...], where a patient case c is a list of ordered events, referring to the observed behaviours in a patient careflow, in the form c = ⟨e1, ..., en; fc⟩, in which n > 0 ∈ N is the number of events occurred, ej ∈ Ec ∀ 1 < j ≤ n and fc is the conformance value of the case. Each event has an associated timestamp.

Under the assumption of a well-defined CP execution semantics, the existence of the gateways construct in a BPMN representation is contemplated when declaring all the possible paths of the CP. Assuming the existence of such definition, the set of feasible sequences of activities according to the CP is presented in Definition 3. To note that an execution sequence refers to a sequence of activities considered valid in the CP. In contrast, the sequence of events of a case may not be completely replayed by the model.

(3) Definition: Execution Sequence.
Following the semantics of care pathway CP, the set of execution sequences for a CP is expressed by εp = [σ1, σ2, σ3, ...], which is the set of lists, each named execution sequence, of the form σ = ⟨ai, a1, ..., am, ao⟩ representing a feasible sequence of activities of the CP, in which m > 0 ∈ N, ai ∈ A ∀ 1 < j ≤ m, ai ∈ A is the initial activity and ao ∈ A is the final one.

Subsequently, to identify reasons for non-compliant executions, it has to be defined which possible deviations can occur. With respect to the non-compliant scenarios considered, taking inspiration on the work of Weidlich et al. (2011) and Günther (2009), it is possible to distinguish two main classifications: missing activities (or skipped activities) and inserted events.

- Missing activities: activities that should occur according to the CP but are not observed in the event log. The three different types considered are illustrated in Figure 3.

- Inserted events: events that occurred in reality but should not be executed according to the CP. See Figure 4 with the three types of these events, involving the wrong recording of an activity order, the wrong recording of an additional event or the recording of alien events (events not contemplated in the pathway).

3.2 Conformance Measurement
To measure the conformance value for each clinical case with the specifications in the CP, the model uses the Replay a Log on flexible model for conformance analysis plug-in in the ProM framework, developed by Adriansyah et al. (2011). The algorithm employs a replay analysis technique that defines a fitness metric for quantifying the extent of the deviations observed, considering the two possible causes of non-compliant scenarios – skipped activities and inserted events.

- Missing activities: activities that should occur according to the CP but are not observed in the event log. The three different types considered are illustrated in Figure 3.

- Inserted events: events that occurred in reality but should not be executed according to the CP. See Figure 4 with the three types of these events.

To achieve the conformance values, the event log as well as the modelled CP must be imported into the ProM framework. Through the help of conversion plug-ins available in ProM, the care pathway is converted from BPMN to Petri Net, which is the required modelling language of the algorithm. The output is a file (extracted
with the help of export plug-ins), in which each entry contains the patient case identifier and the corresponding fitness, i.e. the conformance value.

The set of skipped activities in the case are identified as $A_s$ over $A$. On the other hand, all inserted events are identified as a set $E_i \subseteq E_c$ ($E_c$ designates the set of events of a case $c$), where $c$ is the case identifier from the finite set of cases $C$ ($c \in C$). It is possible to take into account different costs for skipping and inserting individual activities, depending on the severity considered for each activity of the CP, which should be assigned by clinical experts (see Figure 1). Thus, $k_s$ and $k_i$ represent the cost functions for skipping and inserting activities, respectively. As a result, the fitness metric $f$ is defined as: one minus the ratio between the total cost of having inserted/skipped activities and the total cost of considering all events as inserted activities.

\[
f = 1 - \frac{\sum_{a \in A_s} A_s(a) \times k_s(a) + \sum_{e \in E_i} k_i(\alpha(e))}{\sum_{e \in E_c} k_i(\alpha(e))}
\]  

in which $\alpha$: $E \rightarrow A$ represents a function relating each event of the case to an activity of the process.

The rationale behind with this fitness metric is that the fitness values should decrease as more activities are skipped or inserted. In the worst scenario of evaluating the conformance to a process, all the events are inserted and that is used to normalize the fitness metric. Note that it is possible that $f$ becomes negative in cases where many activities are skipped and the skipping costs are high, for instance, a loop that happens repeatedly. However, generally, $f$ assumes values between 0 and 1 (for a feasible sequence according to the process model).

Equation 1 involves knowing up front which activities are skipped or inserted. For this reason, when identifying deviations to the CP, the focus is in discovering the inserted and skipped activities that return the minimal cost for a valid path of the process model, such that we obtain the maximum fitness value. Hence, identifying these activities in a case is formulated as finding the best matching instance of the process model based on the events of a case. To achieve this, the conformance calculation invokes the $A^*$ algorithm in order to identify the process instance that best matches a given case. The $A^*$ algorithm was originally developed to discover the shortest path between two nodes, the source and target nodes, in a directed graph with arc costs (distances associated to the arcs). These “arc costs” are related to the cost functions of skipping and inserting activities.

Accordingly to the proposal of Adriansyah et al. (2011), to replay a group of events on a process model, the instances of the process (process paths) are iteratively constructed using shares of the sequence of events of a case. The objective is to construct the process instance that shows the lowest cost of deviations, such that only in cases where the cost of skipping an activity is higher than the cost of assuming an inserted event, the event is considered as inserted.

### 3.3 Metrics to Examine the Compliance of Patient Cases

The model comprises the definition of the compliance metrics that assist in performing the comparison between the conformance achieved for the set of cases and the CP, which allows to extract diagnostic information for individual patient careflow as well as for the whole population of cases, based on the non-compliance criteria described. By implementing the concepts previously described and using the conformance values achieved, the following compliance metrics were computed:

- Compliance of a patient case, i.e. the fitness value achieved, including the patient careflow (sequence of events that was observed): $f_c$;
- Overall compliance of all patient cases (average compliance considering all cases): $\frac{\sum_{c \in C} f_c}{|C|}$.
• Frequency of the occurrence of an activity or set of activities, that is in how many patient cases HCPs performed that activity or set of activities: \[ \frac{\sum_{c \in C} \alpha(c)}{\sum_{c \in C} \mu(c)} \];

• Average compliance of the patient cases in which an activity or a set of activities has occurred, independent of the order: \[ \frac{\sum_{c \in C \setminus (a \cup b)} f_c}{\sum_{c \in C \setminus (a \cup b)} \mu(c)} \];

• Proportion of patient cases in which an activity occurred but another does not, independent of the order, and the corresponding average compliance of those cases: \[ \frac{\sum_{c \in C \setminus (a \cup b)} f_c}{\sum_{c \in C \setminus (a \cup b)} \mu(c)} \];

• Proportion of patient cases in which the order of two activities (not necessarily adjacent) was followed as imposed in the pathway, and the corresponding average compliance of those cases: \[ \frac{\sum_{c \in C \setminus \{a \rightarrow b\}} f_c}{\sum_{c \in C \setminus \{a \rightarrow b\}} \mu(c)} \];

• The set of alien events, with the set of patient cases for which each inserted event occurred and the corresponding average compliance of those cases: \[ \frac{\sum_{c \in C \setminus \{a \rightarrow b\}} f_c}{\sum_{c \in C \setminus \{a \rightarrow b\}} \mu(c)} \];

• Proportion of patient cases and the corresponding average compliance given a particular characteristic, e.g. a clinical outcome: \[ \frac{\sum_{c \in C_x} f_c}{\sum_{c \in C_x} \mu(c)} \];

4 Colorectal Cancer Compliance Analysis

The dataset assessed consists of data on colorectal cancer patients from Hospital da Luz Lisboa entering in the hospital in the year of 2017. In the dataset, each instance/entry represents a clinical case and presents information considering the three phases of the pathway: diagnosis, staging and treatment.

For multiple reasons, as expressed by van de Klundert et al. (2010), the data required to measure the conformity between the actual treatment behaviours and the guidelines or care pathways is often incomplete or incorrect, which makes compliance checking a difficult task. In fact, only about 27% of the CRC dataset is complete and more than half of the variables are empty (not considered in this CP analysis). Considering the CRC dataset, 60.3% of the patients are male (39.7% female patients), thus reflecting a higher incidence of men than in women. The average age for the patients population is 69 years old, within the range of ages in which CRC is frequently observed.

The dataset reflects information about 18 key performance indicators (KPI) the hospital is collecting on CRC CP. Therefore, the dataset represents the activities of the pathway that the hospital has interest in monitoring. However, the data under analysis does not reflect the data recorded in the EHR system, since it does not include all medical behaviours. For each patient case, I considered only the activities of the pathway matching available events recorded in the dataset. Based on these activities, I modelled two pathways with the BPMN modelling language, one for the colon and another for the rectum. Accordingly, the dataset was split into two subsets of patients cases, for the colon (246 cases) and rectum cancer patients (99 cases).

Since the CRC CP of Hospital da Luz Lisboa is confidential, the set of activities that form the CP and their sequence cannot be revealed. Due to the nature of the dataset, for the whole CRC pathway, I considered a total of 15 activities (based on available events), each labeled from A to O. Each activity of the pathway was assigned to a clinical category, including: registries, exams, laboratory tests, surgery, treatment and time constraints. The costs assigned to skipped activities were twice the costs for inserted activities considering than skipping a mandatory activity should be more penalized than inserting one (wrong order or alien event). These costs were chosen to carry an objective analysis, not contemplating any severity level for different activities.

4.1 Overall Compliance Results

Table 1 details the alignment results, considering the number of events observed and the skipped and inserted activities, for each subset of patient cases. Considering the 99 rectum patient cases, a total of 522 events were observed. On the other hand, the 246 patients with colon cancer revealed 1394 events. As expected, due to the nature of the dataset available for this study, the number of skipped activities is considerably higher than that of inserted events. With respect to the inserted events and considering the assumptions made, they concern only the timestamped activities and alien events. The average events per case for the colon subset was 5.67, which represents 56.7% of the number of events for the shortest valid sequence according the colon pathway (10 activities), showing that on average only half of the CP is completed. Similar results were obtained for the rectum subset, with an average of 5.27 events per patient case, which corresponds to 52.7% of the number of events for the shortest valid sequence according the rectum pathway (10 activities).

Figure 5 presents the distribution of the overall scores obtained for the compliance of the HCPs in the treatment of CRC. The values range from 0, in case of complete lack of conformance (skipping or inserting all activities), and 1, for feasible sequences of events according to the pathway. The overall compliance score observed was 58.5% and 57.3% for the colon and rectum patient cases, respectively. Both subsets recorded a maximum compliance of 93.1%, in cases where only one activity is missing, and
Table 1: Overall alignment results.

<table>
<thead>
<tr>
<th>Subset</th>
<th>Patient Cases</th>
<th>Total Events</th>
<th>Avg.</th>
<th>Max.</th>
<th>Min.</th>
<th>Std. Dev.</th>
<th>Skipped Activities</th>
<th>Inserted Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colon</td>
<td>246</td>
<td>1394</td>
<td>5.67 (56.7%)</td>
<td>9 (90.0%)</td>
<td>2 (20.0%)</td>
<td>1.75</td>
<td>1210</td>
<td>141</td>
</tr>
<tr>
<td>Rectum</td>
<td>99</td>
<td>522</td>
<td>5.27 (52.7%)</td>
<td>9 (90.0%)</td>
<td>2 (20.0%)</td>
<td>1.63</td>
<td>507</td>
<td>34</td>
</tr>
<tr>
<td>Total</td>
<td>345</td>
<td>1916</td>
<td>5.56</td>
<td>9</td>
<td>2</td>
<td>-</td>
<td>1717</td>
<td>175</td>
</tr>
</tbody>
</table>

Table 2: Frequency of occurrence for each activity of the CRC care pathway

<table>
<thead>
<tr>
<th>Activity</th>
<th>Category</th>
<th>Colon Patient Cases</th>
<th>Frequency</th>
<th>Rectum Patient Cases</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Registry</td>
<td>100.0%</td>
<td>100.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Registry</td>
<td>100.0%</td>
<td>100.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Exams</td>
<td>21.1%</td>
<td>6.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Time</td>
<td>13.8%</td>
<td>10.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Exams</td>
<td>-</td>
<td>13.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Exams</td>
<td>18.3%</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Lab. Tests</td>
<td>47.2%</td>
<td>31.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Registry</td>
<td>37.4%</td>
<td>56.6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Time</td>
<td>68.3%</td>
<td>68.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>Appointment</td>
<td>87.4%</td>
<td>86.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Surgery</td>
<td>70.3%</td>
<td>46.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Treatment</td>
<td>-</td>
<td>1.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Treatment</td>
<td>-</td>
<td>4.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Treatment</td>
<td>-</td>
<td>1.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>Treatment</td>
<td>1.2%</td>
<td>2.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5: Distribution of the compliance values for each patient case.

a minimum of 27.3%, for cases in which only two activities were observed. Therefore, no patient case has data evidencing full compliance with the CP.

4.2 Compliance Evaluation and Interpretation

The patients cases were arranged according to their group of compliance value, defined as equally divided groups within the observed range of compliance values (max. and min. observed) of the total patient cases.

- Low compliance group \([min, \min + \frac{\max - \min}{3}\] = [0.273, 0.492]: 23.2%.
- Moderate compliance group \([\min + \frac{\max - \min}{3}, \min + 2 \cdot \frac{\max - \min}{3}\] = [0.493, 0.712]: 60.9%.
- High compliance group \([\min + 2 \cdot \frac{\max - \min}{3}, \max]\) = [0.713, 0.931]: 15.9%.

One can conclude that the larger proportion of patient cases have moderate compliance values, but there is still much room for improvement in increasing the compliance to the CRC pathway, since only 15.9% of the patient cases fall into the high compliance group.

When inspecting the compliance to a care pathway, several cases where a mandatory activity of the process is often skipped possibly indicate that the CP must be adjusted to include such skipping. Otherwise, the hospital should impose new mechanisms to enforce the best clinical practice, expressed in the CP. Table 2 reports on the relative frequency of occurrence for each activity of the pathway, for both subsets of patient cases. Some activities are only included in one of the pathways, marked in the table with “-”.

The activities where higher frequencies were observed are in the categories of Registries, followed by Appointment, Time and Surgery. On the other hand, lower frequency categories involved Treatment, Exams and Lab Tests. Activities under the category of Treatment are involved in alternative paths of the pathway, which explains the lower compliance values obtained. Note that, it is not unusual for some patients to move to different healthcare units to perform CP activities, which is not being considered in this analysis. Activity “G” is a mandatory activity in the pathway and a relevant KPI monitored by the hospital that refers to the solicitation of the Carcinoembryonic Antigen (CEA), a laboratory test that must be requested before the treatment to define the basal value to monitor recurrence signs, in the post-treatment period. Although it is not confirmed, there has been recorded an association between higher levels of CEA and a worst prognosis (Destri et al., 2015). In the dataset, the activity is observed only in 47% colon patient cases and 31% in the rectum cases, which may indicate a lack of awareness of the pathway. Another example is that only 70% of the cases recorded the surgery activity, which is mandatory according to the colon cancer pathway.

Table 3 presents the compliance observed for each phase of the colorectal cancer pathway: diagnostic, staging and treatment. Results show that the critical phase is staging, for both patient subsets, since it has the low-
Table 3: Average relative frequency of occurrence for completing any of the activities of each phase of the colorectal cancer pathway.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Colon</td>
<td>73.7%</td>
<td>29.2%</td>
<td>56.8%</td>
</tr>
<tr>
<td>Rectum</td>
<td>68.7%</td>
<td>27.8%</td>
<td>30.0%</td>
</tr>
</tbody>
</table>

Table 4: Compliance results on the alien events observed for the colon cancer patients.

<table>
<thead>
<tr>
<th>Alien Event</th>
<th>Frequency</th>
<th>Avg. Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>0.4%</td>
<td>0.679</td>
</tr>
<tr>
<td>M</td>
<td>0.8%</td>
<td>0.518</td>
</tr>
<tr>
<td>N</td>
<td>0.4%</td>
<td>0.643</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.6%</strong></td>
<td><strong>0.589</strong></td>
</tr>
</tbody>
</table>

With regards to inserted activities, in particular to alien events, i.e. events that occurred in the treatment of these CRC patients but are not contemplated in the pathway, their importance is essential in assessing the performance and resources management but also in redesigning the CP. Considering an alien event with high frequency of occurrence with low average compliance on those cases, it indicates a possible systematic mistake that must be addressed. On the other hand, if the alien event has high frequency with high compliance values, it probably indicates that it is an activity that should be contemplated in the CP. Due to the nature of the information in the dataset and considering the assumptions made, the alien events were found exclusively in the colon subset because only the events that can be observed in the rectum pathway but not in the colon one were considered to be alien events. Table 4 presents the compliance results on the alien events observed.

Although we have an extremely reduced number of alien events, some conclusions can be drawn from the content of the Table 4. Firstly, the total average compliance obtained for these cases with alien events is above the median which sets the ground for further analysis, and also no patient case belong to the low group of compliance values. With the help of the metrics defined, the details on the careflow of these patient cases were discovered. The three alien events observed correspond to treatment alternatives of the CP. According to the pathway, the treatment plan of the colon and rectum patients must always be discussed in the multidisciplinary appointment (MDA). Additional inspection on the sequence of events occurred revealed that there was not a MDA in the treatment with the “L” activity. Considering the other cases, although the MDA occurred, the treatment of colon cancer with “M” or “N” bypassed the decision process of a MDA, which indicates that the plan was not formally discussed. One of these patient cases is part of the group of patients that contains both cancers, therefore, the alien event can be justified by the rectum pathway. Although the number of alien events is reduced, more than one violation was found, which, can indicate a misunderstanding between the pathways of the colon and rectum. Either way, a closer monitoring should be given to the way the treatment for colon cancer is being performed.

When analyzing the frequency of occurrence for which the surgery occurred after the treatment plan discussed in the MDA, as described in the pathway, it is possible to conclude that:

- For the colon cancer patient cases, the MDA and surgery occurred in 64.3%, where only 13.8% have performed those activities in the correct order.
- For the rectum cancer patient cases, both activities were observed in 41.4%, where only 22.0% have performed them in the correct order.

4.3 Clinical Outcomes Analysis

With respect to clinical outcomes, the dataset provided includes information on post-operative days until hospital discharge and mortality. The first refers to the number of days a patient was hospitalized after surgery. From the dataset of 345 patient cases, 219 were submitted to surgery, although only 94 have records of post-operative days until discharge. The 18 patients containing the colon and rectum cancers were excluded from this analysis since they have two compliance values, due to the assumption made. Therefore, from the 94 patient cases, only n=88 were considered for this outcome. To discover the actual association between the variables, statistical tests were conducted. The post-operative days until hospital discharge per case, for both subsets and the corresponding compliance group (low, moderate, high) were submitted to the Shapiro test to find if the variables follow a normal distribution, where p-value=0.018<α=0.05 (CI=95%), the significance range considered (Panagiotakos, 2008). Proved otherwise, the non-parametric test Kruskal-Wallis was applied, where p-value=0.013<α=0.05 (CI=95%). By rejecting the null hypothesis of the equality of the distribution between the three groups under analysis, there is an association between the compliance level and the number of post-operative days, for at least one of the groups. It is possible to conclude that there is statistical significance that the number of post-operative days is lower for patient cases that showed higher levels of compliance.

The second outcome analyzed was the mortality. From the sample of patient cases, the patients with both can-
The model devised to assess the compliance between the clinical practice and care pathway was motivated by the current gap that exists between the clinical practice and the recommendations in a care pathway, which can lead to lower quality levels. Therefore, this model emerged as a solution to evaluate how the reality conforms to a pathway, supporting its compliance analysis and process improvement.

Care pathways and clinical practice guidelines have been proven to be beneficial structured processes about the appropriate healthcare and, therefore, are widely used around the healthcare organizations. However, they are often idealized processes that are not always followed by HCP, such that implementing a care pathway and its adoption represent a critical challenge to the healthcare organizations. In fact, scientific literature revealed that simply implementing a CP itself is not enough. Much attention must be paid to the design and improvement of these pathways. The need to monitor all the activities executed and to identify the main non-compliant events is constantly increasing as an attempt to deliver treatment excellence, reduce unjustified deviations and leverage cost-efficiency in the quality of care services.

Given the modelled CP using BPMN (along with its executions sequences), the event log and the activities’ costs, the model outputs the conformity value (a fitness metric) for each patient case in line with computed metrics based on non-compliant scenarios defined to support the compliance analysis. There are some difficulties in the conformance checking for medical treatment processes mainly introduced by the richer diversity of medical behaviours over other business processes. However, the model proved to be a robust approach once it allowed to deliver valuable information of a dataset that was recognized as highly incomplete. It is important to understand that one can not mislead on the subjectivities involved in the treatment interventions, as the complexity of the patients cases, which can interfere with the results obtained.

With respect to the compliance analysis, there are multiple possibilities for future work. Depending on the characteristics of individual activities in the CP, the severity should also be addressed. As future improvements, based on the input of clinical experts, defining different “costs” for skipping and inserting each activity explores the real-life scenario in measuring how the clinical executions comply with the model. Further improvements also rely on a method to address and classify the complexity of patients cases, such that it can be contemplated in the compliance measurement, as an attempt to have a closer approach for the actual healthcare environment. Process mining techniques seldom provide measurements on temporal information that are often contemplated in the CP. As an added topic for further analysis, compliance checking on the time intervals enables to perceive the temporal impact in CPs that differ in time spreadings (Huang et al., 2012).

I ascertain that data quality is essential for the success of an optimal alignment search and the main limitation of this study is related with the availability of event logs that record the executions of patients cases. In this work, the patient data considered manifested information around the key performance indicators (KPI) the hospital is collecting on CRC, rather than the actual medical interventions along or around the CP. In addition, not all events had the date of occurrence which does not allow to consider the correct order of events. Judging by the high percentage of empty field values in the CRC dataset, considering that an activity has not occurred if a field value is empty influences the results because, in reality, the activity could have been performed but not recorded. In further studies, a larger population of patient cases containing all clinical behaviours and their timestamps (complete event logs) should be considered, in order to contemplate all activities of the pathway and all variabilities.

The proposed model is suitable to assess the compliance between any care pathway and corresponding medical executions. This model provides a proper monitoring of the clinical practice that can work as an auditing model for process improvement and quality care assurance. To scale to the set of care pathways of an hospital, all deviations can be measured and effortlessly gather insights on the HCPs performance (according to the CP). In fact, in conducting such analysis, the value is not in the compliance measurement itself, but in the improvements in the care provided.
References


