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Towards a Methodology and a Tool for Modeling Clinical Pathways

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Abstract

Nowadays hospitals face the problem of increasing quality and at the same time reducing costs of their services. Clinical pathways approach has established itself as an effective method of reorganization of medical practice in a process-oriented way. Since more than a decade, clinical pathways are being created and applied in hospitals in the USA, Australia, and European countries. Traditional text-based approach for documenting clinical pathways does not allow automatic analysis and makes the maintenance of the models inefficient. Recently, researchers started to apply generic modeling languages, such as UML activity diagrams, EPC or BPMN, as well as domain specific process modeling languages, in order to formalize the representation of clinical pathways. However, none of these languages sufficiently covers the requirements of clinical pathway models, and the choice of a suitable modeling technique remains a problem. In this paper, we propose a modeling methodology and a modeling tool for creating graphical semantically annotated models of clinical pathways. We take into account the characteristics and usage scenarios of clinical pathways and show, how the proposed approach addresses these requirements.

Peer-review under responsibility of the Program Chairs

Keywords: Clinical Pathway; Process Modeling Methodology; Process Modeling Tool

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1. Introduction

Nowadays the hospitals are experiencing a management paradigm shift and are forced to organize a process-based alignment of their care structures in order to increase efficiency and improve quality of healthcare services[1,2]. Since more than a decade clinical pathways (CPs) are used as an instrument for reorganization of clinical processes[2]. CPs are widely accepted in the USA, Australia, and European countries and are starting being applied in Asia, e.g. Singapore[3], and other developing countries.

The term clinical pathway is internationally accepted and can be defined as "a method for the patient-care management of a well-defined group of patients during a well-defined period of time"[2]. CPs are developed and utilized by multidisciplinary teams of clinicians, case managers, nurses, pharmacists, and physiotherapists for local use inside organizations[3]. CPs are used as a roadmap by patients and their relatives[4]. Application scenarios of the CPs include facilitation of the communication between various medical personnel and patients, standardization of medical treatment processes, training and education of young medical professionals, design and implementation of health information systems, automated analysis for the purpose of process optimization[1,2,4-6]. However, one of the main challenges in creating CPs is the selection of a modeling method.

At the moment, CPs are mostly created in a form of text documents or tables[1,2,4,7]. On the one hand, this allows capturing a wide range of relevant information. On the other hand, such a narrative, non-formalized form of documentation prevents automatic analysis of CPs and makes change and variance management inefficient[4]. Recently, conceptual modeling has established itself as a suitable technique for the documentation of CPs[1,5,6,8,9]. Generic modeling languages, such as Flow Charts, UML Activity Diagrams, EPC, and BPMN, as well as domain-specific languages have been used for modeling CPs. However, according to the analysis of Burwitz et al. all these methods have certain deficiencies and do not completely fulfil the requirements of the pathways[1]. Thus, for instance, it has been shown that plain BPMN methodology does not produce intuitive models and needs to be extended, e.g. to better represent the concept of shared responsibility for CPs activities[10,11]. Moreover, the introduction of BPMN as a modeling method is connected with huge time and manpower investments[7]. Therefore, despite the fact that BPMN is more efficient than textual descriptions of CPs, it is difficult to utilize this method as a part of daily clinical routine[7].

In this paper, we address this problem by presenting a business process modeling methodology and supporting web-based modeling tool, originally designed for a retail domain, to the context of CPs. The methodology and the tool are designed primarily for the documentation of information intensive clinical processes for the purpose of improving communication between medical personnel and patients, knowledge dissemination and education. The presented solution also addresses the problems of standardization and variance management in CPs. The proposed modeling method does not directly allow automation of CPs. We argue that this should not be the primary task of CPs models. Transfer of CPs models into workflow systems is a challenging task, which requires considerable IT efforts[7.12.13]. Creation of intuitively understandable and at the same time executable models is hardly possible even in structured domains, such as retail or manufacturing, and becomes even more difficult in the context of highly variable clinical processes. However, the translation of descriptive models to the executable ones might be possible using the presented approach.

The paper is structured as follows: in the next section we briefly present the design science research method, which was applied to the current study. By conducting a literature review we define objectives for the solution (section 3). In the section four we present design and development of the artifact according to the identified objectives. We demonstrate the artifact in section five and conclude the paper with a discussion and outline of future research steps

2. Research method

All For the current study, we have applied a design science research method (DSRM) as presented by[14]. The DSRM consists of six steps, starting with the identification of the problem and motivation of the research, which is followed by the definition of the research objectives, design and development, demonstration and evaluation of the created artifact and finally communication of the research results.

We motivate our research in the introduction section of the current paper. In the section three we perform a literature review in order to derive research objectives. Based on the research objectives we design and implement a modeling methodology and a web-based modeling tool, which allows efficient creation of clinical pathways. This step is described in the fourth section of this paper. We demonstrate the proposed approach by applying the modeling method and the modeling tool in a CP modeling project. Evaluation is performed by comparing the characteristics of the modeling method and functionality of the modeling tool to the objectives for the solution. Further quantitative evaluation in of the artifact in the medical domain should follow in the future research steps. The last phase of the DSRM method – communication of the research results – is performed by the publication of the current paper.

3. Definition of the objectives for the solution

CPs are applied for coordinating activities of a multidisciplinary team of medical specialists in the process of patients' treatment. To allow efficient (semi-) automatic analysis, maintenance and re-use of the CPs, their representation should be performed using a formalized conceptual modeling notation[4]. Such a notation should allow to represent the relevant aspect of the CPs, namely treatment steps, process flow, parallel or exclusive execution logic of activities, integrate information objects and responsibilities[1].

CPs are created and used by domain experts with little experience in the information systems discipline, as well as patients themselves and patients' relatives[2-4]. Therefore, simplicity and clarity of pathways representation is of high importance[1,3]. CPs are based on the Evidence Based Medicine guidelines[2]. These guidelines offer a bunch of additional information, such as complications or guiding symptoms of a disease pointed out, which should be integrated in the pathways models[4]. This leads to a requirement of representing all the relevant evidences next to the process steps and flow, but at the same time keeping the models intuitively understandable[1].

One of the main problems of medical specialists nowadays is information overload[9]. An enormous number of medical articles, which are being published worldwide, requires the clinicians to read approximately 17 articles per day in order to keep their knowledge up to date[8]. Formalizing medical knowledge in a form of graphical diagrams with annotated sources of evidence and presenting this information on a relevant abstraction level can help to reduce the information overload and make the search of information effective and efficient.

Thus, we formulate the first objective of a solution as *"Obj.1. Modeling notation should allow (1) representation of activities and process flow, (2) annotation of relevant information and (3) representation of knowledge on the appropriate level of abstraction"*.

Standardization and variance management are essential tasks of CPs[8]. CPs should document, monitor and evaluate variations in the treatment practice and attempt to reduce these variations[2.3.6]. At the same time, pathways are continuously modified in order to reflect the current practices[3]. The maintenance process of CPs models should be as effective and efficient as possible. This means that the modeler should be able to quickly identify all places in the CPs models, which are affected by the changes, and apply the changes efficiently. Moreover, taking into account the multidisciplinary and distributed nature of the domain expert teams, who are working on the creation of the pathway models[2-4], the modeling methodology have to support the team in creation of standardized and comparable CPs models. This leads us to the second objective of a solution *"Obj.2. The modeling methodology should allow (1) standardization and (2) variance management of created models"*.

The interdisciplinarity of the team also poses certain requirements to the tool, which provides IT support to the modeling methodology. The tool should, first of all, allow access of different types of users to the models and control their access rights. Conflict-free collaborative work on the CP models should be possible. The models tool should be intuitive to use and prevent long learning time. Thus, we define the next objective for the solution as "*Obj.3. The modeling method should have a tool support, which (1) allows collaborative work (2) controls user access rights, and (3) is intuitive and easy to learn*".

CPs not only help to improve efficiency of the executed medical treatment processes, but are also used for training purposes of young medical professionals, as well as serve as a guidebook of treatment for patients and their relatives[1]. Therefore, it is necessary to provide an additional point of access to the models' content next to the web-based modeling tool. A static document with the current version of the models and related relevant information, which can be printed out and provided to the target audience, can be beneficial in this case. Thus, we define the fourth objective as "*Obj.4. The modeling tool should allow export of model information in a human readable form*".

4. Design and implementation

The objectives for the solution, presented in the previous section, are addressed by design and implementation of two related artifacts: icebricks modeling methodology and a web-based modeling tool, with supports the modeling methodology. In this section, we briefly describe the underlying concepts of the modeling methodology and the primary functions of the modeling tool. Both artifacts are developed to support the guidelines of modeling[15,16], which allow efficient conduction of modeling projects and creation of conflict-free non-ambiguous models, which are ready for (semi-) automatic analysis and re-use.

The primary concept of the icebricks methodology is four predefined layers of abstraction as depicted in the Fig.1. The highest level, framework, depicts the landscape of main processes in the organization without temporal connection between them. One can imagine a framework as a graphical functional representation of the entire hospital or an organizational unit, responsible for the management of a particular disease. On the next level, the main processes are outlined using activities and temporal connection flow between them. Each of the elements can further be decomposed on the detail process level into process bricks. Process bricks are the atomic elements, which cannot be further decomposed, but can be annotated with attributes, as presented below. The modeling language used for the depiction of main and detail processes consists of activities and a connection flow between them. The processes are modeled from top to bottom, meaning that the upper activities occur earlier, than the lower activities. It is possible to depict parallel and exclusive execution of activities by creating branches. As no gateways are present in the language metamodel, the element labels and descriptions define the semantics of branches.

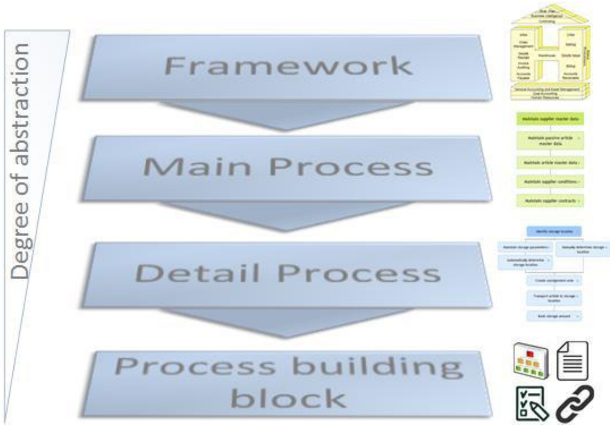

Fig. 1. Four layers of abstraction

Process steps on each level of abstraction can be annotated with additional information. For this purpose, the modeling language and the corresponding web-based modeling tool support the concept of semantic attributes of different types. Using attributes any information, from simple textual description, up to organizational units, document attachments or web links can be added to the elements. The attribute values can further be used for reporting purposes. For instance, by creating a report it is possible to automatically find all actions, performed by a particular person or organizational unit, calculate average execution time of a process, identify weaknesses and improvement potentials.

For the representation of organizational structure or IT system infrastructure, it is possible to create hierarchies. Hierarchies represent tree-like structures, where each element corresponds to e.g. an organization unit or a module in an IT system. Each hierarchy element can be annotated with additional information using different types of attributes. The hierarchy elements themselves can be used as attribute values for annotation of process elements or other hierarchy elements. E.g. an organization unit can be assigned as a performer of a process step. As it is possible to add several hierarchy elements to one processes steps, the proposed approach solves the problem of modeling shared responsibilities, which is not possible to depict using BPMN[10,11].

When the modeling is performed by a distributed team of modelers, it is important to prevent possible semantic naming conflicts already during the creation of CP models[17]. For this purpose a glossary, which consists of business objects (nouns) and activities (verbs), can be created in the icebricks tool and assigned to a modeling project. Each business object and activity have a description, which ensures common understanding of the terms by all model users. During the creation of the processes, modelers are enforced to use the glossary objects and phrase-structure conventions for labeling process elements. It was proven that the "verb-object" structure is the most intuitively understandable label form for the model users[18]. When modelers are creating a process element, they have to choose a business object and then a related activity from the glossary. The label is automatically constructed and assigned to the process element. It is later possible to automatically change the labels of all elements with glossary object assignment through management of the glossary objects. Standardization of element labels allows creation of comparable semantically unambiguous models and makes (semi-) automatic analysis of process models possible, as all the naming conflicts are eliminated already during the creation of the models.

To cope with variations of process models, variants can be created at each level of abstraction to depict specific cases of a particular process. In order to get rid of duplicated information, references can be used. Thus, a process element can be created and annotated with all the additional information only once, and later it can be re-used as a reference in other processes or process variants. All the possible changes, which occur later, should be performed only for the original element and will be automatically applied to all the reference objects.

To ensure efficient re-use of models, they can be exported as an XML-based file. Later, the exported model can be used as a template or a reference model for future projects. The icebricks models can be imported into any modeling tool, which supports import and interpretation of XML files, for an extensive analysis or simulation purposes. Moreover, models or parts of the models can be exported in an MS-word format. This allows an automatic creation of project reports, which contain the full process documentation, including graphical diagrams and all annotated information, in a structured form.

The icebricks modeling tool is a web-based tool, which allows easy access from any place. For mobile access, a prototypical hybrid application was developed, which can be run using Android or iOS-based devices[19]. The icebricks tool supports collaborative work and allows simultaneous editing of the same process model by several users. The tool always ensures consistency of the changes independent of the number of modelers. The user access is controlled by an access control module. Thus, it is possible to define different groups of users, who have different access rights to the process models (e.g. a user may only view the models, edit models, or also export process documentation, etc.). The user interface of the tool is designed in such a way, that it is intuitively understandable and easy to learn. The usability study has shown that even users with low experience in process modeling are able to create high-quality models using the icebricks notation and the tool[20]. Exemplary screenshots of the user interface are shown in Fig. 2 and Fig. 3.

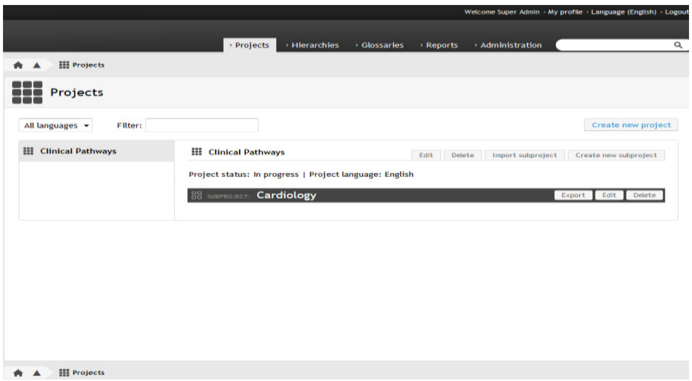

Fig. 2. Project page of the web-based modeling tool

Fig. 2 demonstrates the main page of the icebricks tool. On the top of the page, the links to the main functions (projects, hierarchies, glossaries, reports and administration), as well as the search field are located. The content part of the screen presents projects and subprojects, which are created in the system. One may create any number of projects and subprojects. Fig. 3 shows the modeling environment. The breadcrumbs on the top of the page show the current location, which allows efficient navigation through the model layers. The CP model occupies the central part of the screen. On the right side, in the attribute pane, the annotated information is shown for the selected process element. The presented model has two variants: standard, representing the normal execution scenario, and an additional variant, to depict possible deviations. The model can be edited in the same screen by switching to the edit menu in the attribute pane.

5. Demonstration and evaluation

The icebricks modeling methodology and web-based modeling tool were originally developed for process modeling in retail domain[21,22]. The artifacts were successfully applied for the purpose of business process documentation and optimization, employee training and ERP-software selection and customization. Later on, this method was unitized for a compliance-checking project in the banking industry.

Because of a generic nature of the notation it can be applicable for the tasks of CPs modeling. As proof of concept, we applied the icebricks method in a project for modeling treatment pathways of patients' with cardiac disease. The only changes we had to apply to the tool, in order to use it in a new domain, were the customization of the glossary and attribute groups. Fig. 3 shows an exemplary process created in the project. The purpose of the modeling project was to document well-established treatment procedures, based on the guidelines of German Association for Cardiology[22]. The created models were later used for the development of a web-based application for the cardiac patient management. The application is designed to be used by the patients themselves in order to control the treatment actions. The created models were used by both medical and IT-specialists and served as a basis for discussions between the two parties. The icebricks modeling tool and derived models were highly appreciated by both medical and IT Specialists. Both domain and IT experts were able to easily understand and use the created models during the discussion of the application business logic. Although the modeling experts created the models, the medical personnel have agreed that they can imagine using the methodology and the tool in their daily routine.

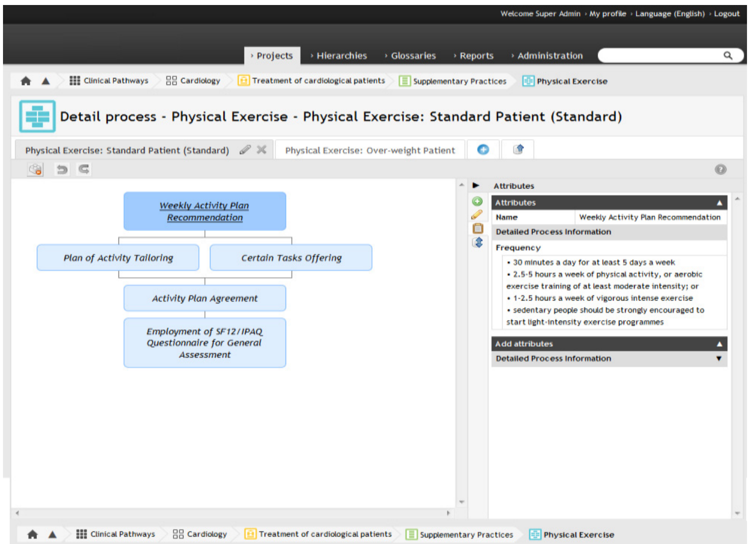

Fig. 3. Detail process modeling screen.

Because of a limited scope of the project it was not possible to perform an extensive quantitative evaluation. Thus, we conduct the evaluation by analyzing, to which extent the presented artifact supports the objectives for the solution, defined in the third section of the paper. In the Table 1 we summarize the objectives and present the corresponding characteristics of a modeling language and functionality of the modeling tool. We confirm that the constructed artifact fulfills all the defined objectives.

Table 1. Fulfillment of objectives for the solution.

Objectives	Corresponding methodology characteristics and modeling tool functionality
Obj 1.1 Modeling notation should allow representation of activities and process flow.	• Activities and control flow • Possibility to model parallel and exclusive execution of activities
Obj 1.2 Modeling notation should allow annotation of relevant information	• Attributes of different types • Assignment of attribute values to any process element
Obj 1.3 Modeling notation should allow representation of knowledge on the appropriate level of abstraction.	• Four levels of abstraction: framework, main process, detail process and process bricks
Obj.2.1 The modeling methodology should allow standardization of created models.	• Concept of variants and references • Analysis of variance via attribute-based reporting • XML-export of the models for future re-use
Obj. 2.2 The modeling methodology should allow variance management of created models	• Glossary and "verb-noun" phrase structure for naming process elements
Obj. 3.1 The modeling method should have a tool support, which allows collaborative work.	• Conflict-free simultaneous work of several modelers on the same model is possible
Obj. 3.2 […] tool support, which controls user access.	• User rights and access control module
Obj. 3.3 […] tool support, which is intuitive and easy to learn.	• Intuitive user interface design
Obj. 4 The modeling tool should allow export of model information in a human readable form.	• Export of the models in MS-Word format

6. Conclusion

CPs are being widely used in the medical domain for improving quality and reducing costs of treatment processes. Conceptual modeling techniques are being applied for formalized CP representation to allow (semi-) automatic analysis and re-use of CP models. The main problem, however, is the choice of an appropriate modeling technique. Generic modeling languages, such as Flow Charts, UML Activity Diagrams, EPC, and BPMN, do not completely fulfill the requirements of the CPs. In this research paper, we present the icebricks modeling methodology and a web-based modeling tool, which improve the current situation. We formulate four research objectives and show how the created artifacts support them. The presented artifacts were successfully applied in a CP modeling project. Although the models were created by the modeling experts, and not by the domain experts, we can still confirm the general applicability of the modeling method and the modeling tool to the tasks of CPs modeling. It is possible to create understandable semantically annotated CPs models, analyze and export them in a human-readable form. The modeling methodology ensures elimination of semantic conflicts already during the modeling. The problem of duplicated information storage is solved by the references concept, which ensures efficient variance management and model maintenance. Easy-to-use web-based icebricks modeling tool allows collaborative work of a multidisciplinary modeling team.

Unfortunately it was not yet possible to perform a complete extensive evaluation of the artifacts. The modeling methodology and the tool were successfully applied in the research project, however, because of its limited scope it was not possible to let the domain experts create the CPs and interact directly with the tool themselves. Although the general feedback on the created models was positive, it is still necessary to continue the evaluation by applying the tool in real-life settings. Thus, future research should focus on the evaluation of the artifacts and improving them according to the evaluation results.

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