TECHNISCHE UNIVERSITÄT DRESDEN

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ESP. SYSTEMS ENGINEERING

Integrated Clinical Pathways
A Model-based Holistic Method

by

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DOCTORAL DISSERTATION

submitted to

The Faculty of Business Management and Economics
Technische Universität Dresden

in partial fulfillment of the requirements for the degree of

Dr. rer. pol.

Date of submission: February 02, 2017
Date of defense: May 17, 2017

supervised by:
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Preface

Information Systems Research and accurately what we call *Wirtschaftsinformatik* in German, has become an independent and emancipated research discipline over the last decades. Not least, the increasing digitalization in nearly all areas of daily life fosters the discussion about information systems and provides a wide range of applications for theories, paradigms and methods, that are core subjects of Wirtschaftsinformatik. Therefore the nature of an applied science was the convincing reason for me, to decide for studies in this field.

Especially in health care, digitalization discloses various perspectives and prospects of re-engineering and improvement, that would affect essential aspects in human life. Nevertheless, during my research activities within the last 10 years I was often surprised and sometimes even disillusioned about these chances, being less and slowly seized. Already during my academic studies I was able to gain first experience doing IS research in health care, not least during the investigations made for my diploma thesis in the field of model-driven process management in health care. At once, this was the trigger for a more profound entry into this area, which I perceived as a fertile area of applied sciences at all times.

This work now consolidates essential investigations in this field and finishes a vital stage of my academic career, that was accompanied by various people who supported me in my research, making me infinitely grateful.

First of all, I would like to thank my supervisor, Prof. Dr. Werner Esswein, for providing the necessary freedom in the choice of my research focus, the plenary support of all research activities at all times and the empowerment of responsibility in academic teaching and research projects. Furthermore, I would like to express my sincere gratitude to Prof. Dr. Susanne Strahringer for the preparation of the second opinion on this doctoral dissertation as well as the constructive criticism in context of the doctoral consortia.

I am particularly thankful to my colleague and friend, Dr. Hannes Schlieter, for encouraging me to do research and for being a mentor of my work especially in the early stage. Our countless discussions and pleasant conversations during our daily business essentially shaped my work and often opened up new vistas and ideas, that enabled exciting research projects and publications. This equally applies to all my colleagues at the *WISE* chair, especially Martin Benedict, Dr. Richard Braun and Dr. Sina Lehrmann, to whom I am very grateful. For being a pleasant mentor and her unremitting assistance concerning various administrative issues in daily work, I am furthermore very thankful to Lisa Gerstenberger.

Finally, I would like to emphasize my family who always absolutely supported my academic education. I am especially grateful to my wife Susanne who is facing my work with sympathy and is keeping me grounded at all times. Moreover, the time with her and our lovely children, Mika and Magdalena, makes for life balance and great pleasure. To the three of you I dedicate this work.

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List of Abbreviations

AS	Application System
ATL	Atlas Transformation Language
BPMN	Business Process Model and Notation
CDA	Clinical Document Architecture
CIM	Computation Independent Model
CP	Clinical Pathway
CPG	Clinical Practice Guideline
DICOM	Digital Imaging and Communications in Medicine
DRG	Diagnosis Related Group
DSML	Domain-Specific Modeling Language
DSR	Design Science Research
EHR	Electronic Health Record
EPR	Electronic Patient Record
GPML	General-Purpose Modeling Language
HIS	Hospital Information System
HL7	Health Level 7
IHE	Integrating the Healthcare Enterprise
IS	Information System
IT	Information Technology
KPI	Key Performance Indicator
PIM	Platform Independent Model
PSM	Platform Specific Model

A. Synopsis of the Doctoral Dissertation

Contents

This synopsis corresponds to the ”gesonderte Abhandlung” according to §8(3) PromO 2010.

Synopsis of the Doctoral Dissertation

1. Introduction

1.1. Background

The textural change of the European health care systems, especially in Germany, does accelerate a permanently increasing multidisciplinarity of care. With the introduction of the Diagnosis Related Groups (DRG) system at the latest, the German health care system is facing various challenges. Growing competition and rising cost pressure are increasingly leading to economic constraints and stimulate health care organizations to improve performance and increase efficiency. In order to counter the steady rise in costs, health care providers are increasingly looking at their services from an economic point of view. To sustain their position in the competition for patients, as well as to increase the number of cases and thus the revenues, a shift away from conventional, function-oriented structures to a patient-centered treatment and thus an orientation towards the treatment process can be observed (Salfeld et al., 2009). Thereby, health care providers preferentially purpose the increase in (I) the quality of medical service, (II) the transparency of medical services, as well as (III) the economic efficiency of the entire health care system (Nagel, 2007).

On the one hand the significant demographic phenomenon of an aging population is facing an increasing concentration of medical care facilities in urban areas. Hence, the population in rural areas in particular has limited access to medical care. Ensuring an adequate medical care therefore requires an increasing degree of the mobility of care providers respectively the establishment of medical care networks, involving inpatient, outpatient and nursing service providers (Kronhardt, 2004). Additionally intensified by the overall social development of prevalently occurring multimorbidities, the care system is being provoked for specialization and division of labor along the treatment chain. This conveys the need for cooperation and coordination of all health care providers participating in the interdisciplinary, inter-organizational treatment process of a patient within in the care network.

1.2. Subject and Motivation

Against this background, clinical pathways (CPs) have been established as a promising tool at the organizational level in recent years (cf. Kinsman et al., 2010; Panella and Vanhaecht, 2010). They are primarily intended to ensure an adequate description of the care processes and to manage the balance between best treatment practice and economic viability (De Bleser

et al., 2006). CPs standardize the internal care services by explicating the institution-specific knowledge with regard to recommendations for action, service portfolio, organizational structures, infrastructure, etc. of a specific service provider. From the medical point of view, CPs are primarily intended to improve the quality of care through implementing disease-specific recommendations of clinical practice guidelines (CPGs) that represent the current state of the art of medical research. As a central repository of case-related treatment information, CPs are a suitable mean for a comprehensive documentation of the treatment but also for communication and cooperation in the context of inter-organizational care networks. At the same time, CPs offer prospects for planning and controlling with regard to the integration of key performance indicators (KPIs), to measure and evaluate the performance and particularly optimize the use of resources (Rotter et al., 2008). By establishing lean treatment processes and the attended decrease in economic expenses, the financial risk in the DRG system can be drastically reduced (Uerlich et al., 2009). Nevertheless, since the current utilization of CPs usually remains on an organizational level, CPs merely exist as textual, partly tabular treatment descriptions or documents. Thus, laborious document management systems are inevitable for version management and consistent provision of adequate process information. Moreover essential, informal CPs are neither operationalizable nor interpretable by appropriate information technology (IT) that maintain the primary care process by means of a treatment guide but also manage supporting business workflows for documentation or resource and quality management.

The development of hospital information systems (HIS) has so far been characterized by an evolutionary development of modules in the field of laboratory, radiology, nursing and picture archiving systems as well as in the area of administrative systems. As one result of this development, the HIS usually comprises a heterogeneous network of software systems of different types and manufacturers. In order to standardize the interaction and communication of individual HIS modules, data and communication standards such as Health Level 7[1] (HL7) or Digital Imaging and Communications in Medicine[2] (DICOM) exist in the field of medical informatics. The initiative Integrating the Healthcare Enterprise[3] (IHE) also ensures the coordinated use of defined standards by providing communication profiles for specific medical application scenarios. The inter-organizational IT-support has so far focused on the exchange of case and patient data through the development and implementation of data and communication standards such as the the electronic patient record (EPR) or the electronic health record (EHR) (cf. Boehm and Caumanns, 2007; Staemmler, 2010). However, the actual control of patients by means of evidence-based processes and integration of CPs into HIS was not addressed until the recent years, when HIS manufacturers started developing modules for CP modeling and workflow support (Raphael et al., 2009). Meanwhile, technical standards in the field of medical process

[1] see Health Level Seven® International (`http://www.hl7.org`)
[2] see Digital Imaging and Communications in Medicine (`http://dicom.nema.org/standard.html`)
[3] see Integrating the Healthcare Enterprise (`http://www.ihe.net`)

definition (e.g. Cross Enterprise Workflow (XDW)) began to emerge.

Combining the described potentials of CPs, merely used on organizational level, and the gradually emerging process-orientation of HIS, the lack of an holistic view and implementation of CPs can be perceived. This initially comprises the investigation of how CPs should be best described to fit the needs of medical terminology, understandability and accessibility for care professionals on the one hand, but also formalize the process definition to be accessible and interpretable for IT systems on the other hand. Therefore, conceptual models can provide a solution as a medium for the entire process knowledge (Heß et al., 2015). Conceptual models provide an adequate mean to describe and communicate complex matters in a comprehensible form (cf. Ferstl and Sinz, 2008; Frank, 1999). Schütte (1998) defines them as the result of a construction by a modeler, who declares a representation of an original to a model user as relevant with the help of a language (cf. Schütte, 1998, p. 59). On a strategic layer, conceptual models can be used to provide an adequate representation of the (process) knowledge of CPs. Beyond the provision of a consistent knowledge base, conceptual CP models enable the transformation and integration into the operational IT-layer due to the semi-formal nature of conceptual models. Hence, CP models can be used to configure application systems (AS) that support the daily care by means of various process instances for individual patients. This concept ensures an improved process alignment and compliance of the daily care to defined treatment standards. Prospectively, the accumulated data from documenting the daily care provides a valuable operational knowledge that could be aggregated and evaluated regarding the improvement of the strategic knowledge base. The outlined framework for an integrated CP modeling and management is illustrated in figure A.1.

The framework focuses on the documentation, guidance and management of the mostly manual, human-triggered care process and integrates administrative and management aspects to enable (semi-) automated support processes while delineating a continuous improvement cycle.

The objective of this work is to provide a holistic methodical support for the description of clinical pathways and their integration into a hospital information system to finally improve the compliance of daily care to standard process definitions. Hence, the subject of this work can be arranged at the upper and right part of figure A.1. The road map for achieving this objective is depicted by the following research design.

1.3. Research Design

In order to ensure the traceability and comparability of research, the explication of the criteria is required that are labelled by Becker et al. (2003) as the research design. Thus, research design is defined by the disclosure of the researcher's position regarding philosophy of science, the research objective pursued and the research methods applied (cf. Becker et al., 2003, pp. 307).

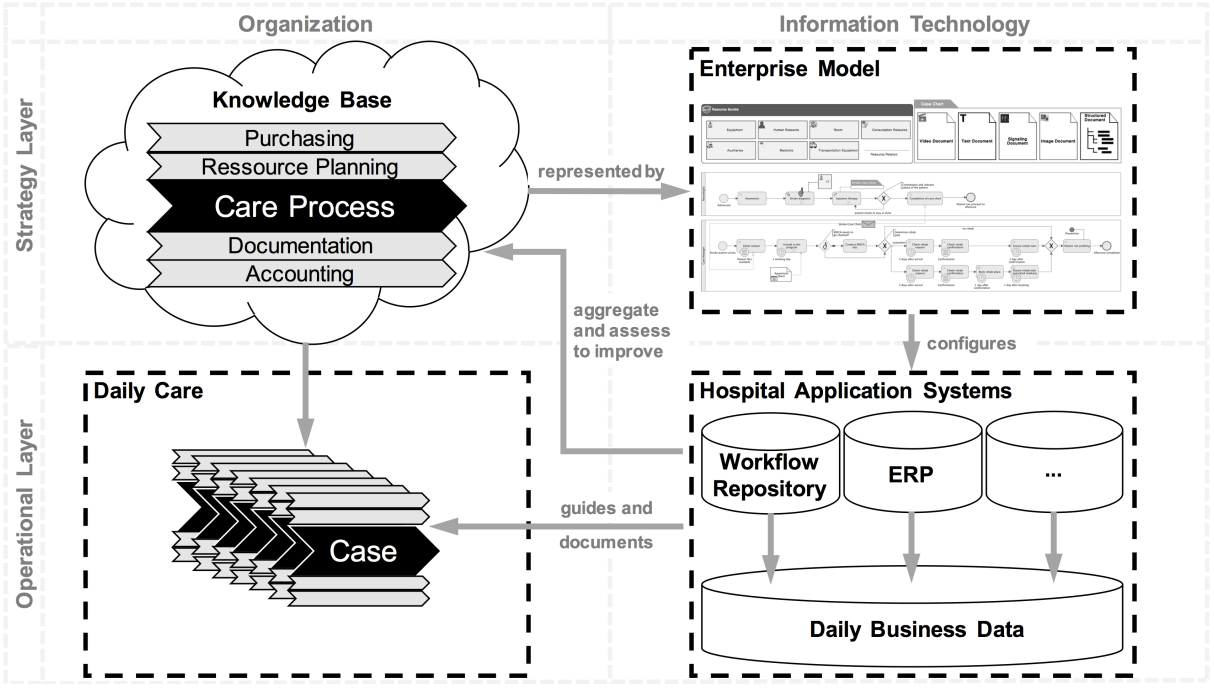

Figure A.1.: Framework for integrated CP modeling

Due to a close interdependence between these criteria, a random configuration is excluded. Accordingly, the research design of this work regarding these criteria is described as follows.

1.3.1. Philosophy of Science

According to Braun and Esswein (2006), the position regarding philosophy of science is characterized by the disclosure of the ontological and epistemological point of view as well as the determination of the concept of truth (cf. Becker et al., 2004b, p. 4; Becker et al., 2004a, p. 336) . Thus the researcher explains the manner in which a perceivable reality exists outside the notion of an individual subject (ontological position), the relationship between knowledge and the object of knowledge (epistemological position), and when knowledge can be regarded as true (the concept of truth) (cf. Hudson and Ozanne, 1998).

For the research of the present thesis, a constructivist position will be used regarding the subject-object relation, that is based on an open ontological point of view (Becker et al., 2004b). This implies a significant impact of the subject to the process of cognition (Schütte, 1998, p. 27) and an undetermined existence of a subject-independent reality (Gehlert, 2007, p. 23). Furthermore, the consensus theory as an adequate theory of truth will be followed. Hence, a community regards a statement as true if and only if in optimal and ideal conditions the community can accept it rationally (Becker et al., 2004b, pp. 7).

1.3.2. Research Objective

The next element of the research design is the definition of the research objective. The exploration of the research objective enables to derive the necessary research activities and thus provides a guideline that further allows to assess the objective achievement. In the field of IS research, there is a usual distinction between descriptive and design objectives. According to this, the focus of the research is either on theory level or rather on technology level. Both foci can be combined with either a methodical research assignment or a content-oriented, functional research assignment, that finally lead to the four types of research objectives illustrated in figure A.2.

	Theory (descriptive objective) theories/hypotheses	**Technology** (design objective) artifacts/technologies
Methodical Assignment	comprehension of methods and techniques for IS design	**development of methods and techniques for IS design**
Content-oriented Functional Assignment	comprehension of business IS and their applications	provision of IS reference models for several companies or industries

Figure A.2.: Classification of the research objective according to Becker et al. (2003)

As mentioned in section 1.2, the purpose of this research is to provide a holistic methodical support for the description of clinical pathways and their integration into a hospital information system to finally improve the compliance of daily care to standard process definitions. This is primarily to be classified as a design objective by means of the construction of a respective method. It is not the purpose to design a specific CP model in terms of a reference model. It is rather intended to develop a generally applicable artifact including its instructions for use, to enable health care stakeholders to semi-formally describe clinical pathways and to transform them into AS-configuring items. This results in a methodical research assignment. The corresponding classification of the research objective is illustrated in figure A.2. Summarizing these explanations, the research objective for this doctoral dissertation is named the following:

Research Objective. *The research objective is the design and construction of a method to functionally and technically describe clinical pathways and to support their integration into process-oriented application systems.*

Since conceptual models have been motivated as an adequate mean to describe and communicate complex matters in a comprehensible form and are able to bridge the gap between business and technology (see section 1.2), it is obvious to pursue a model-based approach to achieve

the depicted research objective. Thus, the objective can be subdivided into two main research questions as follows:

RQ 1. *How can clinical pathways be described adequately using conceptual models?*

RQ 2. *How can conceptual models of clinical pathways be used to configure process-oriented application systems?*

1.3.3. Research Method

The choice of an adequate research method to structure all research actions and to create reasonable and reproducible results should be derived from the respective research objective. According to the classification as a design objective (see section 1.3.2) the research work of the thesis follows the Design Science Research (DSR) paradigm, intending to elaborate and design innovative and relevant artifacts in a rigorous manner (Hevner, 2007; Hevner and Chatterjee, 2010). Among others, such artifacts can be methods, models general constructions and their application in practice (cf. March and Smith, 1995, pp. 251).

According to Hevner (2007), the central design task (Design Cycle) as an iteration between the core activities of designing and evaluating the artifact is surrounded by the contextual environment (Relevance Cycle), as well as the knowledge base of scientific foundations, experiences and expertise (Rigor Cycle) (Hevner, 2007, pp. 88). While the Relevance Cycle thus typically initiates a design project by providing a problem context as well as corresponding requirements and evaluation criteria, the Rigor Cycle ensures the innovative character of the artifact.

Peffers et al. (2007) and Alturki et al. (2011) further proposed more or less detailed procedures for conducting DSR by specifying particular activities. Nevertheless, each of the work does not determine the explicit decoration of these activities. It is hence presumed, that each part of the thesis' work, that contributes to the objective by representing several DSR activities, can apply any research method fitting the respective intermediate objective. This presumption is encouraged by the rationale of Frank (2007), who states the need for an individual configuration of (multiple) research methods according to the goals and needs of the researcher within design-oriented IS research.

2. Genesis of the Thesis

According to the two main research questions (see section 1.3.2), the work is subdivided into two corresponding research threads, each addressing one question. The first research thread pursues an answer for RQ 1, including the design of an adequate modeling language for clinical pathways. The second research thread analogously pursues an answer for RQ 2, including the design of an integration method of clinical pathways for application system configuration. Both

artifacts finally represent results of respective DSR projects, thus the internal structure of a research thread is aligned to the DSR activities of Peffers et al. (2007).

The entire research work was conducted as a cumulative research process where individual research essays (Chapters B - I) reflect respective stages of the work. Figure A.3 therefore illustrates the position of each essay within the research threads as well as their correlation and contribution to the DSR activities of Peffers et al. (2007).

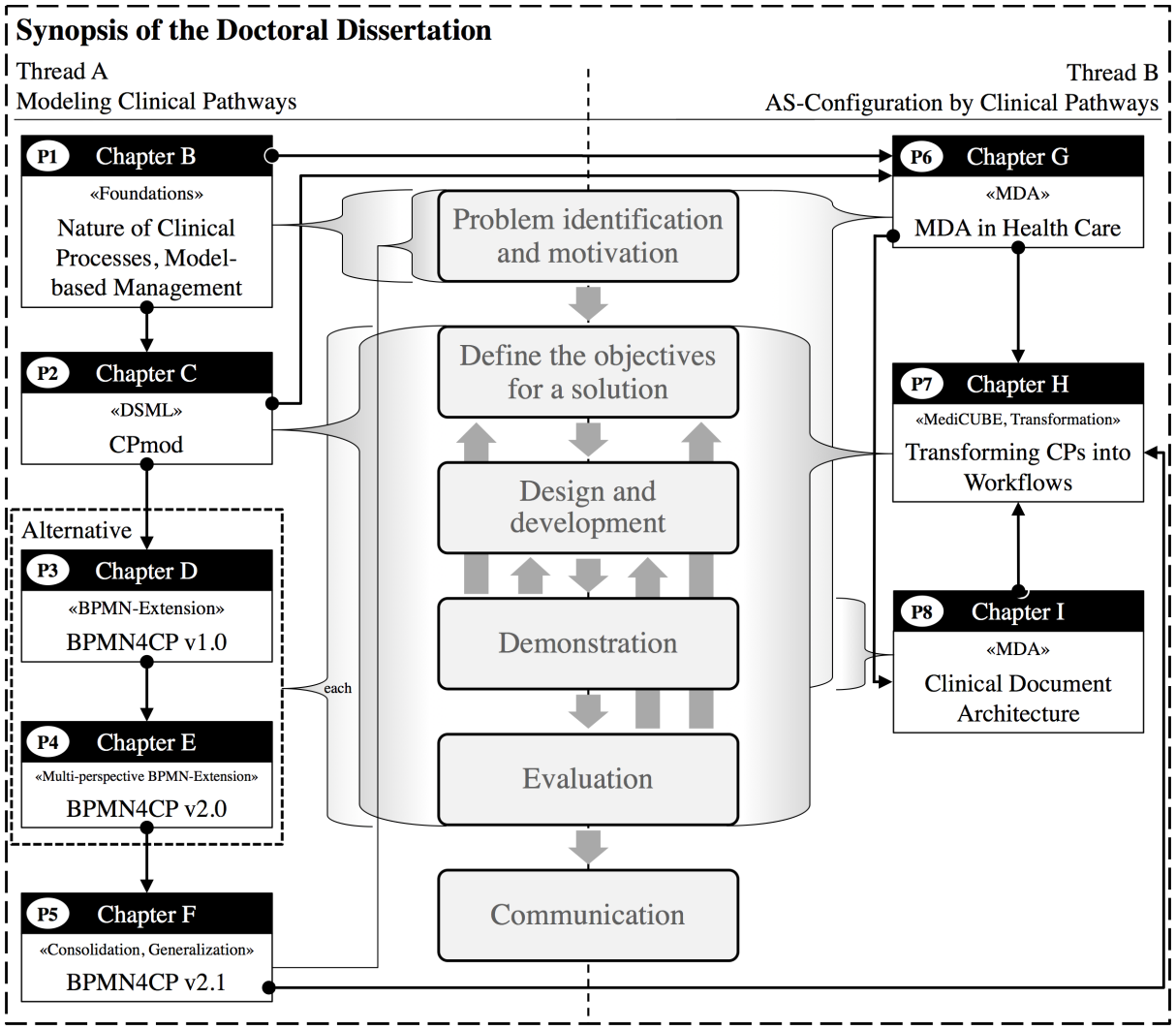

Figure A.3.: Structure of the cumulative thesis aligned to the DSR activities of Peffers et al. (2007)

2.1. Modeling Clinical Pathways

To find the answer for RQ 1, an initial investigation about the special nature of CPs and their characteristics was followed by several design iterations for an evolutionary design of CP modeling languages. The research in this field offered synergies with the investigations of Braun

(2016), concerning the extensibility of enterprise modeling languages. Hence, the initial design of a domain-specific CP modeling language was followed by a significant part of adapting and extending the Business Process Model and Notation (BPMN) for the CP domain. The development of each artifact itself was aligned to the general guidelines of Hevner et al. (2004) and Hevner (2007), indicating a constant interplay between relevance (reflecting practical needs and applicability) and rigor (reflecting methodical soundness and justification). The consecutive design process further followed the requirements-driven DSR approach proposed by Braun et al. (2015). Thus, two general classes of requirements can be simply divided: Problem-oriented requirements and rather solution-oriented requirements. The first class covers requirements that come from the relevance cycle of a DS project, i.e. the relevant environment, user expectations or problem characteristics. Therefore, user requirements, contextual requirements and feature-related requirements can be divided. The second class of solution-oriented requirements rather focuses on the rigor cycle of the common DS framework of Hevner (2007) and covers the scientific knowledge base. Hence, theory-based requirements and functional requirements can be divided in this class. Table A.1 briefly summarizes the stated requirement types.

Table A.1.: Types of DS-related requirements as base for artifact design (cf. Braun et al., 2015)

Requ. Type	Abbr.	Semantics	Example
Problem-oriented Requirements			
User	RU	(a) Functional expectations of stakeholders (b) Non-functional in the sense of qualitative artifact properties	(a) Modeling language for the representation of intersectoral care processes (b) Compliance with standards for modeling clinical algorithms (e.g. Pearson et al., 1992)
Contextual	RC	Constraints, regulations, laws, rules or conventions of a problem domain	Legal regulations in regard of medical products and software
Feature-related	RFe	Rather vague, high level specification of artifact features (behavior and properties)	Capabilities for resource modeling
Solution-oriented Requirements			
Theory-based	RT	(a) Design theories and kernel theories from associated disciplines (e.g. Kuechler and Vaishnavi, 2012; Baskerville and Pries-Heje, 2010) (b) Academic rigor, norms, guidelines (c) Representation of the knowledge base	(a) Defining the concrete syntax of modeling languages (e.g. Moody, 2009) (b) DSR guidelines (e.g. Hevner et al., 2004) (c) Reusing already existing artifacts
Functional	RFu	Detailed specification of artifact features	Provision of a resource perspective in a modeling language, which represents the concepts Resource, Resource Bundle and Resource Association

Consequently, each modeling language version was constructed, based on a set of different requirements, implicating possibly precise design goals. The concrete requirements of each version are summarized in table A.2. The particular requirements (e.g. user requirement RU_1) are further referred to in the respective summarizing figures A.4, A.5 and A.6 in the following sections.

Table A.2.: Originating requirements set for each modeling language artifact

Problem-oriented Requirements			Solution-oriented Requirements	
User (RU_i)	Contextual (RC_i)	Feature (RFe_i)	Theory-based (RT_i)	Function (RFu_i)
Requirements to the First Artifact (CPmod)				
RU$_1$: Representation of inter-sectoral medical processes for the coordination between different stakeholders **RU**$_2$: Usage of self-explanatory graphics **RU**$_3$: Ensure alignment with CPGs and modeling clinical algorithms	**RC**$_1$: Evidence-based medicine (EBM): Evidences for treatment decisions have to be documented (Sackett et al., 1996)	**RFe**$_1$: EBM aspects in CP models **RFe**$_2$: Concepts for clinical BPM **RFe**$_3$: Responsibilities **RFe**$_4$: Static objects **RFe**$_5$: CP-specific order relations and dependencies between tasks	*From theories:* **RT**$_1$: Meta model based language specification (e.g. Wand and Weber, 2002) **RT**$_2$: DSML design guidelines (Frank, 2013) **RT**$_3$: Design of the concrete syntax (Frank, 2013; Moody, 2009) *From knowledge base:* **RT**$_4$: e.g. classification of evidence types (Sackett et al., 1996)	*Contextual:* **RFu**$_1$: Patient state, treatment step, decision, process flow **RFu**$_2$: Information objects and responsibilities, variable flow, parallel flow, iteration **RFu**$_3$: Evidence indicator, evidence-based decision **RFu**$_4$: Time Event *Methodical* **RFu**$_5$: Abstract syntax as diagrammatic meta model; concrete syntax symbols from CP domain
Requirements to the Second Artifact (BPMN4CP 1.0)				
RU$_1$ **RU**$_2$ **RU**$_3$	**RC**$_1$	**RFe**$_1$ **RFe**$_2$ **RFe**$_3$ **RFe**$_4$ **RFe**$_5$	*From theories:* **RT**$_5$: Abstract syntax: using BPMN extension classes (Stroppi et al., 2011, p. 57) **RT**$_6$: Exploiting the vocabulary of BPMN **RT**$_7$: Concrete syntax in accordance to BPMN style guidelines (OMG, 2011, p. 8) *From guidelines etc.:* **RT**$_8$: Rigor, application of appropriate procedure models (Alturki et al., 2011) **RT**$_9$: Transparent design justification (semantic equivalence check in pre-design phase) *From knowledge base:* **RT**$_{10}$: BPMN extension procedure of Stroppi et al. (2011)	**RFu**$_1$ **RFu**$_2$ **RFu**$_3$ **RFu**$_4$ **RFu**$_5$
Requirements to the Third Artifact (BPMN4CP 2.0)				
RU$_4$: Each stakeholder group should only see modeling concepts, which are helpful for their work **RU**$_5$: Representation of CP-related resources and documents (structure and process allocation)	**RC**$_2$: Documentation obligations by law **RC**$_3$: CP-related resource types and document types	**RFe**$_6$: Complexity reduction by the creation of perspectives **RFe**$_7$: In-detail modeling of resource structures and document structures **RFe**$_8$: Integration with CPs	*From theories:* **RT**$_{11}$: Multi-perspective modeling (Frank, 2014) separation of concern and model coherence **RT**$_{12}$: Integration in modeling method (Wand and Weber, 2002) *From theories:* **RT**$_{13}$: Procedural transparency (c.f. Gleasure et al., 2012) *From knowledge base:* **RT**$_{14}$: Classification of resources and medical documents (HL7) **RT**$_{15}$: User-specific set of BPMN concepts	*Contextual:* **RFu**$_1$**; RFu**$_2$**; RFu**$_3$**; RFu**$_4$**; RFu**$_5$ **RFu**$_6$: Perspectives (resources and docs) **RFu**$_7$: Resources, resource types, bundles, resource associations, document types *Methodical* **RFu**$_8$: Extending BPMN meta model for specifying perspectives and integrating abstract and concrete syntax as well with DD **RFu**$_8$: Perspectives in extension methods

2.1.1. P1: Agility in medical treatment processes – A model-based approach

The first paper in this research thread provides a fundamental investigation about the specific nature of clinical processes and the role of CPs for clinical process management. Since care processes are typically characterized by a variety of decisions, that have to consider the individuality of the primarily participating actors (patient, professionals), standardization potentials as intended by CPs are limited, compared to common business or production processes. Therefore, the paper differentiates the terms *flexibility* and *agility* to reveal characteristics, that can be covered at design time of CPs, as well as characteristics, that have to be considered at execution time. While the first provides foundations for the requirements analysis for the modeling language design, the latter leads to eight agility mechanisms (types of agile modifications, that must be available) for a CP-configured application system to manage CP instances, motivating the IT-integration of CPs addressed in the research thread B.

Beyond these foundations, the paper furthermore proposes the model-based approach for CP description and argumentatively reveals the potential for a model-based management, covering the modeling, planing, execution and improvement of CPs. It therefore outlines the idea of a continuous interplay of an adequate CP modeling tool, as well as an application system, covering the planing, execution and analysis of pathway instances.

According to the defined structure of the thesis, this paper is part of the phase *problem identification and motivation* (see figure A.3), since it supplements the identification of the business problem and the motivation of the model-based approach (cf. section 1.2), that is targeted by the following research activities.

2.1.2. P2: Modeling Clinical Pathways – Design and Application of a Domain-specific Modeling Language

The objective of this first design paper of research thread A is the development of a modeling language, covering the requirements to CPs, that result from current challenges of hospital organizations. The paper therefore differentiates clinical pathways from clinical practice guidelines, picking up the considerations of Schlieter et al. (2012), who illustrated the inter-dependencies between CPGs, CPs and the IT layer of hospital organizations.

Based on this framework and the considerations conducted in paper P1, three scenarios for the use of conceptual models in health care are derived argumentatively:

- implementation and utilization of CPs
- integration of CPGs into CPs
- deriving executable clinical workflows

According to the process model of Peffers et al. (2007), these three scenarios provide the main objectives for the envisaged design artifact and hence justify the initial requirements set, which is also used to provide a compliance check of existing modeling approaches, that were identified in available literature.

The result of the compliance check further leads to the design decision of constructing a domain-specific modeling language (DSML) named *CPmod*. Through several design cycles, iteratively evaluating and revising the artifact using a practical case example of a medical process (therapy of wisdom tooth), relevant concepts of existing modeling approaches are adapted and extended to finally achieve a stable constitution of the artifact by complying with the entire initial requirements set and being applicable to the case. Figure A.4 illustrates the iterative design according to the DSR cycles of Hevner (2007) and referring the initial requirements, listed in table A.2. The requirements, that are introduced based on environmental demands (relevance side) or respectively required methodical consequences (rigor side), are presented in rectangles with a dark grey background.

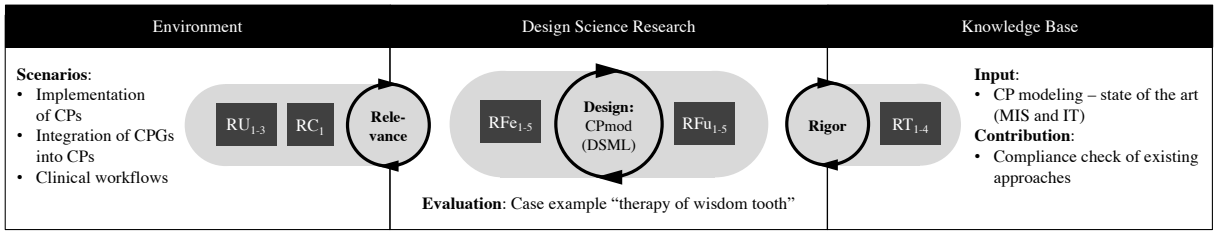

Figure A.4.: Initial design of the domain-specific modeling language *CPmod*

According to the defined structure of the thesis, this paper contributes to multiple DSR activities (see figure A.3). Initially, it picks up the motivation of the first paper and its investigations about the nature of CPs for the definition of the scenarios, the derivation of an initial requirements set for the modeling language artifact and the delineation to the current state of the art of CP modeling languages. Hence, it *defines the objectives* for the intended solution. Furthermore, the paper presents the *design and development* of CPmod, *demonstrates* its applicability using a practical case and *evaluates* the designed artifact according to the stated requirements set.

2.1.3. P3: BPMN4CP: Design and Implementation of a BPMN Extension for Clinical Pathways

The objective of this second design paper of research thread A is the development of a valid extension of the Business Process Modeling and Notation (BPMN) for CPs. Due to several environmental changes, esp. concerning multiple stakeholders and heterogeneous modeling tools, the previously defined requirements set is consecutively expanded by standardization and diffusion needs (see table A.2). Since there is a broad BPMN acceptance in research and

industry (e.g. Kirchner et al., 2014), the admission as an official ISO standard (ISO, 2013) and the provision of a well-defined meta model of the language, facilitating model exchangeability, this situation provokes an adaptation of the process modeling standard BPMN. Therefore, the problem-oriented requirements of the *CPmod* artifact are reused and provide the foundation for the design of the BPMN extension.

The paper emphasizes the basis for the requirements analysis (cf. scenarios of P2) by systematizing the available domain knowledge using an ontology. The BPMN extension itself is conducted using a customization of the BPMN extension method of Stroppi et al. (2011). The applicability of the constructed artifact, named *BPMN4CP*, is finally demonstrated, using the same case as introduced in Paper P2. From an external point of view, the evolutionary step leads to two separate design artifacts (*CPmod* and *BPMN4CP*) for an identical (problem-oriented) requirements set, which is only extended towards the specific concerns of fostering a broader diffusion and tool independence. According to this and the introduced structure of the thesis (see figure A.3), this paper contributes to the same DSR activities as paper P2 (*define the objectives, design and development, demonstration, evaluation*.

Analogously to the design of *CPmod* in P2, figure A.5 illustrates the iterative design according to the DSR cycles of Hevner (2007) referring to the adapted requirements listed in table A.2. The requirements, that are introduced based on environmental changes (relevance side) or respectively required methodical consequences (rigor side), are presented in rectangles with a dark grey background. Requirements, that are reused from the previous artifact version, are presented with a light grey background.

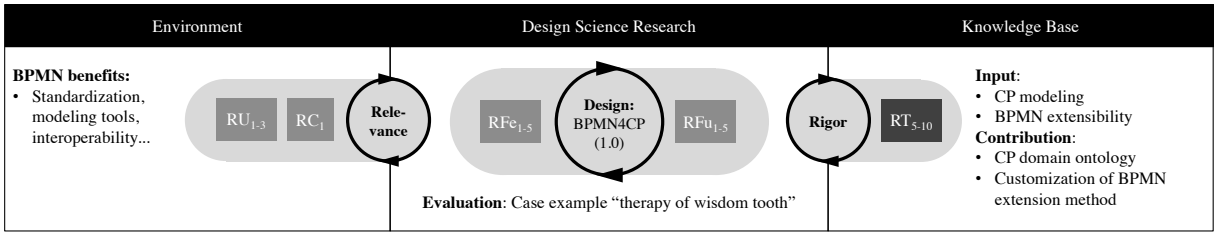

Figure A.5.: Design of the BPMN health care extension *BPMN4CP* as a variation of *CPmod*

2.1.4. P4: BPMN4CP Revised – Extending BPMN for Multi-Perspective Modeling of Clinical Pathways

The objective of this third design paper of research thread A is the advancement of the previously constructed BPMN extension for CPs. The practical application of the artifact in real-life projects, esp. on an e-health platform for telemedical purposes in the context of stroke aftercare services, disclosed valuable insights regarding the usefulness of the modeling language and aspects for its improvement. Hence, the change is primarily triggered by an impulse from

the problem context, that arises from the stated project (relevance aspect according to Hevner (2007)). Due to the characteristics of the mentioned e-health platform and the corresponding project, both user requirements and contextual requirements remarkably changed. Thus, it became necessary to integrate and specify process-relevant documents and medical resources as well as quality indicators, in order to measure the process quality of different treatment procedures. This finally led to the decision to revise and extend the initial *BPMN4CP* extension.

Therefore, the paper first enhances the domain knowledge of CP modeling by an extension of the domain ontology, as well as the requirement analysis regarding the additional user and contextual needs. The set of requirements further provokes the decision for a multi-perspective modeling approach (cf. Frank, 2014; Overbeek et al., 2015) to meet the contextual requirements for a detailed view on the structure of medical documents, as well as on medical resources. The language extension itself is again conducted using a customized method of Stroppi et al. (2011). The applicability of the constructed artifact (*BPMN4CP v2.0* is finally demonstrated end evaluated, using a sample process from the mentioned stroke care context. According to this and the introduced structure of the thesis (see figure A.3), this paper contributes to the same DSR activities as paper P2 and P3 (*define the objectives, design and development, demonstration, evaluation*.

Analogously to the design of the previous artifacts, figure A.6 illustrates the iterative design according to the DSR cycles of Hevner (2007) referring to the adapted requirements listed in table A.2. The requirements, that are introduced based on environmental changes (relevance side) or respectively required methodical consequences (rigor side), are presented in rectangles with a dark grey background. Requirements, that are reused from the previous artifact version, are presented with a light grey background.

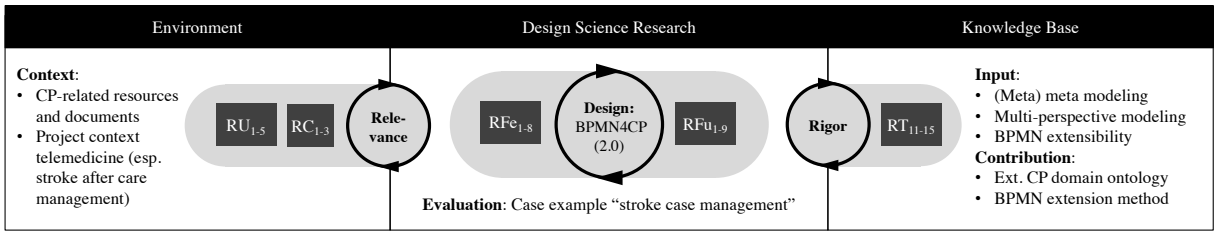

Figure A.6.: Extending BPMN for multi-perspective modeling of clinical pathways

2.1.5. P5: Clinical Processes from Various Angles – Amplifying BPMN for Integrated Hospital Management

The objective of this last paper of research thread A is to overcome the experienced shortcomings of the BPMN regarding multi-perspectivity and hence, to propose an adaptation of the Meta Object Facility (MOF, foundation of BPMN among others), that enables the definition of

perspectives for MOF-based modeling languages in general. To demonstrate this conceptual MOF-extension, *BPMN4CP v2.0* is used as exemplary case. The paper therefore rather provides the construction of another advancement of the CP modeling language, but contributes to the research of the thesis by a consolidation and generalization of the experiences and knowledge, gained through the previous design process. Thus, the paper explicates a summarized abstract syntax of the current BPMN extension and therefore condenses the least state of the art of conceptual modeling CPs. It further contemplates the framework for integrated hospital modeling (cf. figure A.1) as well as scenarios, in order to demonstrate the model application apart from pure documentation (e.g. semi-automatization in workflow-support, model-based analysis). Hence, the paper draws the link between research thread A and research thread B of this thesis. Thus, beside the consolidation and generalization of the previous design process as the main contribution to research thread A, this paper enhances the contribution to the (*problem identification and motivation*) in terms of research thread B (see figure A.3).

2.2. Integrating Clinical Pathways into Hospital Information Systems

Immediately after generating first results of CP modeling language development, the research simultaneously investigated the practical use of the CP models beyond process definition and documentation. Thus, the research was predominantly induced by practical experiences on CP modeling in different care scenarios, as well as practical demands for further integration of CP process knowledge into daily operational care. The following sections therefore illustrate the activities of research thread B, conducted to find an answer for RQ 2, how conceptual models of clinical pathways can be used to configure process-oriented application systems. As an advanced summary, three papers in different manner investigate the design of a model-based method, that enables a consecutive transformation of CPs into technical (workflow) specifications.

2.2.1. P6: Towards Model Driven Architecture in Health Care Information System Development

The first paper in the second research thread initializes the bridging of a gap between medical care professionals and information technology and therefore addresses the Business-IT alignment in health care. This investigation has a specific project background, concerning software development in context of an open telehealth platform. Various analysis workshops and multiple revisions of designed and implemented software confirmed the supposed relevance of a more intensive and systematic integration of domain knowledge into the entire development process. Furthermore, the telehealth platform was intended to provide a service infrastructure,

open for future extension by third party developers, that are supposed to face similar development challenges. Hence, the implicated practical need for a systematic methodical support of the development of software artifacts for the platform, strongly considering the business knowledge, fostered the idea of using conceptual business models. It was assumed, that the domain knowledge of these business models might provide the best possible foundation for the business-aligned development of IT artifacts.

Regarding related work in the field of model-based software development, the paper identified the Model Driven Architecture (MDA, Mellor, 2004) to be a suitable framework. Based on the MDA foundations, the project background and the current work on CP modeling, the paper illustrates the *MediCUBE* framework. The framework combines the idea of multi-perspective modeling (cf. Frank, 2014), the principle of metaization (cf. Strahringer, 1998) as a foundation for conceptual modeling and the consecutive transition from business to IT, delivered by the MDA modeling layers. Based on these principles, that form the three dimensions of the *MediCUBE*, the paper demonstrates the idea of conceptual business modeling and model transformation, outlining the application scenario of a model-driven CP execution.

The investigations especially revealed the challenge at the relation between the pure business model (CIM) and the technical, platform-independent model (PIM), concerning a diffuse separation of both layers, the choice of adequate modeling languages for the respective model purposes, as well as the model transformation between both layers. This was additionally restricted, since current literature in this field mostly investigated the modeling of software artifacts and transformation on PIM and PSM layer. To generalize the experiences gathered, the paper formulates four lessons learned, intended to structure and simplify the future application of the *MediCUBE* and the MDA in general.

According to the introduced structure of the thesis and in terms of research thread B, this paper can be arranged as a first DSR iteration for the design of a model-based method for CP-IT-integration (see figure A.3). Initially, it enhances the previous *motivation* for an integrated CP modeling by the introduction of a real case and *identifies* the need for methodical support. The defined superior *objective* of the development of a model-based method is tackled by the *design* of the *MediCUBE* and its *demonstration* using a practical case. Hence, the paper provides the basic method corpus, that is further revised and extended with special regard to clinical pathways, model transformation and procedural method support.

2.2.2. P7: Transforming Clinical Pathways into Care Workflows

For further justification of the developed artifact, conforming to the method term, this paper combines the previous findings, concerning CP modeling and the structural foundations of the *MediCUBE*, and adapts and extends the method by a concrete specification of modeling languages, a transformation rule set and the definition of a procedure and role model, to instruct

the method application for transforming CPs into workflow specifications.

According to the DSR activities for artifact design research (see figure A.3), the paper initially investigates the relevant knowledge base regarding the current potential of workflow support in health care IT and the foundations of model transformation. In combination with the previous work on conceptual CP modeling and the introduced scenario of stroke care, the paper presents the identification of seven method requirements and thus *defines the objectives* of the intended artifact. The requirements especially demand for a more general method application, independent of a specific care scenario, and thus claims flexibility with regard to the used modeling languages and target application systems.

It further presents the *design* of the method (*CP2WF*), focusing on the process view of the *MediCUBE*. It explains the purpose and relevance of each model layer and illustrates a setting of modeling and transformation languages. To provide method guidance in practice, the experiences from method application in the current project are condensed in a procedure model, describing the sequence of modeling and transformation tasks. To abstract the responsibilities for the different tasks from the specific project, the procedure is enhanced by an appropriate role model.

The paper finally *evaluates* the artifact by a *demonstration* of the application of the designed method in context of the case of stroke care, as well as an assessment of the fulfillment of stated requirements. In their entirety, the papers P6 and P7 provide essential contributions for the operationalization of clinical pathways with a systematic integration into the hospital information system. The *CP2WF* method is supposed to foster the further diffusion of clinical pathways in practical use, independent of the actual care profession, and thus presumably contributes to standardization, transparency and hence quality of care processes. First practical experiences already proved this assumption.

2.2.3. P8: CDA Templates – Utilizing the MediCUBE

The last paper, that contributes to research thread B, provides a first demonstrative approach to transfer the principle of the *MediCUBE*/*CP2WF* method to another perspective in the action system of health care (see figure A.3). It introduces the Clinical Document Architecture (CDA; Dolin et al., 2005), being a widely used standard for structurally and semantically define clinical documents. Nevertheless, the definition of according CDA document templates is a highly communication-demanding process, especially due to the purpose of inter-organizational document exchange between different care specialists. The XML-based CDA specification fostered the idea of adapting the *MediCUBE* for the generation of CDA templates based on conceptual business models of clinical documents.

The paper therefore shortly presents a CIM modeling language for modeling relevant medical documents and especially their internal structure. According to the lessons learned presented in

P6, the metamodel of the language is closely related to the Refined Message Information Model (R-MIM), which is a foundation of the CDA. The application is demonstrated by an exemplary model, taken from the case of stroke care.

At publication time, the development of the *CP2WF* method had not yet advanced to the current level. Hence, the published demonstration remains focused on the CIM modeling and an outline of the purpose and the potential for CDA generation by model transformation. With regard to the later findings in P7, the CDA generation has been tested in the meantime, using the *CP2WF* in the following configuration (for comparison see figure 2 in P7):

- designed document modeling language on CIM
- UML classes of the CDA XML specification as Platform Model
- UML object diagram of the document structure on PSM
- Atlas transformation rules to define transformation from CIM to PSM
- JAXB processor for XML generation

The application of the method in this configuration let to valid CDA templates, complying to the CDA reference specification. The coordination between specific document stakeholders and the development of the actual document structure was completely conducted on the basis of the business model. Due to the comparatively fix technical CDA standard, and the closely related modeling concepts, the definition of the Atlas transformation rules was an almost singular task. Hence, the method in this configuration is supposed to be stable in terms of modeling languages and transformation rules in the near future. Thus, it can essentially contribute to the efficiency and effectiveness of the creation of CDA templates, especially by ensuring specification compliance and reducing time.

3. Conclusion

The conducted research describes profound investigations in the field of process management and IS design in health care. Predominantly driven by problems in current medical practice, that are supposed to be solved by IS-optimizing solutions, the work delivers various contributions of practical relevance. Simultaneously it also considers the potential for generalization and the enrichment of respective knowledge, to contribute to research. The process of achieving the depicted research objective of a method, to functionally and technically describe clinical pathways and to support their integration into process-oriented application systems, methodically represents extensive Design Science Research and was structured into two threads.

The first consecutive thread of work investigated the potential of conceptual modeling for clinical pathways. This essentially includes a domain-specific approach, as well as the adaptation and extension of a general-purpose approach. All designed modeling languages were especially adjusted to domain-driven, practical demands and resulting requirements. The consecutive design process permanently reflected the respective current demands and reacted to requirement changes with adequate revisions.

The second thread of work addressed pragmatics in terms of using conceptual clinical pathway models beyond process documentation, for configuring and guiding the actual care process. For this purpose, a model-based method was developed, that especially enables a consecutive modeling and transformation of clinical pathways into workflow specifications, based on the principles of the Model Driven Architecture. The basic method approach is the separation of different concerns, regarding the position in the range between care business and IT, as well as the specific perspective on the health care action system.

3.1. Results and Contributions

Combining both research threads, the work provides a general contribution to the method spectrum of IS research. At the same time, the work discloses the application potential of knowledge and theories in IS research, especially regarding the field of conceptual modeling and Model Driven Architecture in health care. Table A.3 summarizes the contributions of the research, regarding practical and scientific relevance.

The developed artifacts and method fragments are of equal relevance for research and practice. Regarding the scientific contribution, the work delivers a new method for an application context, which has been rarely considered so far. Especially the holistic character of the method, concerning adequate model construction and similarly model pragmatics, is a notable peculiarity. The comprehensive requirements analysis for the artifacts enables the assessment of the results and provides evaluation criteria for comparable artifacts. The individual research papers are based on a respective consolidation of previous research and practical solutions. Thus, the work presents a rework of relevant knowledge in the contexts of conceptual modeling, care processes and model transformation. With research thread B, the work presents the application of the Model Driven Architecture in the health care domain, which has been likewise rarely considered. Especially the profound focus on the computation-independent modeling layer is almost unique.

The investigations extend the current practical state of the art, by unifying and standardizing the description of clinical pathways and thus enable a continuous construction of a care process knowledge base, that is equally accessible for care professionals and information technology. This holistic characteristic further enables and fosters the improvement of process compliance.

Table A.3.: Contributions of the doctoral dissertation regarding research and practice

Contributions to Research	**Contributions to Practice**
• Extension of the method spectrum (see last row) • Requirements engineering for CP modeling and transformation • Consolidation of the current knowledge on conceptual modeling and model transformation in medical care • Application of the Model Driven Architecture in health care	• Standardization of CP descriptions • Tooling for establishing a process knowledge base • Improvement of process compliance • Improvement of effectiveness and efficiency of process definition
Contributions to Research and Practice	
• Identification of agile process modification types • Domain-specific CP modeling language *CPmod* • Extended general-purpose modeling language *BPMN4CP* for CP modeling • *MediCUBE* framework for MDA-based development of IT artifacts in health care • *CP2WF* as an adaptation of the *MediCUBE* framework for the model-based development of CP workflows • Procedure model for the generation of workflow specifications using *CP2WF* • Role model for the generation of workflow specifications using *CP2WF* • CDA-related modeling language for clinical documents • Demonstration of artifacts' applicability	

The methodical support is supposed to open out into improvements of effectiveness and efficiency in process definition tasks and hence provides a foundation for process management. Finally, the demonstration of the developed artifacts proves their applicability and illustrates existing potentials of conceptual models and model-based methods in health care.

3.2. Critiques and Prospects

This closing section provides a critical reflection of the conducted research and therefore summarizes the respective final considerations of each paper. The development of the conceptual modeling languages for CP modeling has been significantly affected by the care scenarios in practice, regarding the identification of requirements, as well as the application and evaluation. Hence, the modeling languages do not claim to be totally universal and independently applicable in every care scenario. It is significant and recommended, to consider the language design an infinite process of revision and application and hence a customization for the respective scenario. Therefore, the language artifacts and the conducted design process provide valuable foundations for both, a tool for adequately describe clinical process from a care provider view, as well as a methodical example for its design and adaptation.

Although not claiming to be universally applicable, the designed artifacts are supposed to be

suitable for a wide range of care processes, not least to the characteristic of a general purpose of the BPMN. Potential weaknesses might be disclosed in care scenarios, where processes are usually not characterized by sequential tasks and the possibility of their ex ante definition. For instance in psychological care, almost no prediction of the care process is possible due to the extremely individual response of patients to medications or therapy. A potential solution might be achieved by a general revision of the concept of clinical pathways, especially regarding the predictability of the process in non-standardized care. Such care scenarios are obviously out of the focus of the current work.

Furthermore, the languages do not prescribe specific types of tasks to be modeled, providing flexibility for the individual modeler and enable the combination of tasks of actual care, nursing or administrative tasks. Otherwise, the daily practice, especially in hospitals, is characterized by general supporting processes (e.g. ward rounds, provisions, discharge etc.) that run independently of the specific patient. For an optimized process execution, further investigations should be labored on the separate definition of care processes, nursing processes and administrative processes and an optimization of their interfaces (e.g. individual medication coupled with general provisions). This could reveal valuable knowledge for a more detailed process measurement and raise process and quality management to a new level.

With regard to the initially illustrated vision of integrated hospital modeling, the work is currently limited to process definition and execution. The overall artifacts' impact on the quality of medical care, especially through the proclaimed improvement of process compliance, have to be verified by further method application and case studies. Therefore, the diffusion of the usage of care workflows in practice requires a further process-orientation of the hospital IT and a standardization of workflow specifications and implementations of respective workflow engines. The theoretical considerations made on the agility of medical processes have to be reflected for the implementation of respective workflow-supporting IT systems, that must be empowered to allow agile adaptations of process instances. Additionally to these technical prerequisites, the chances of digitalization in health care must be seized more powerfully, which firstly needs a more open minded approach of the health care community towards information technology and digital transformation.

This is also a prerequisite to stand to benefit from experiences from daily care for process improvement. Therefore, investigations are further needed concerning the interface between the operational data, that is produced by CP workflow execution, and process measurement and management. Knowledge in the field of process mining should provide a suitable foundation for adequate aggregation and assessment of conducted workflows to reveal potential weaknesses and enable a long term establishment of a continuous process improvement cycle. This process management again will have impact on the modeling of CPs, at least by revealing needs for modeling performance indicators, quality goals or economic figures. Therefore, the designed

multi-perspective approach is well prepared. Altogether, this work provides essential contributions as a solid foundation to foster digitalization in health care as well as bridging the gap between care professionals and health care information technology.

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Appendices

Table A.4: Papers of the doctoral dissertation and declaration of authorship

P1	***Agility in medical treatment processes – A model-based approach***
Authors	Martin Burwitz (MB), Hannes Schlieter (HS), Werner Esswein (WE)
Publication	Sinz, E. J., Schürr, A. (Eds.): Modellierung 2012. Conference Proceedings, March 14-16, 2012, Bamberg, Germany, 267–279
Authors' contribution	MB: agile processes in health care, model-supported process management, recommendations for implementation, types of agile adaptation HS: model-based management, types of agile adaptation, conclusion WE: research concept
P2	***Modeling Clinical Pathways – Design and Application of a Domain-specific Modeling Language***
Authors	Martin Burwitz (MB), Hannes Schlieter (HS), Werner Esswein (WE)
Publication	Alt, R., Franczyk, B. (Eds.): Proceedings of the 11th International Conference on Wirtschaftsinformatik (WI 2013) - Volume 2, February 27 - March 1, 2013, Leipzig, Germany, 1325–1339
Authors' contribution	MB: scenarios, related work, requirement analysis, language design, demonstration HS: introduction and scenarios, conclusion WE: research concept
P3	***BPMN4CP: Design and Implementation of a BPMN Extension for Clinical Pathways***
Authors	Richard Braun (RB), Hannes Schlieter (HS), Martin Burwitz (MB), Werner Esswein (WE)
Publication	Zheng, H. J., Dubitzky, W., Hu, X., Hao, J., Berrar, D. P., Cho, K., Wang, Y., Gilbert, D. R. (Eds.): 2014 IEEE International Conference on Bioinformatics and Biomedicine (BIBM), November 2-5, 2014, Belfast, United Kingdom, 9–16
Authors' contribution	RB: method, domain analysis, extension design, further research HS: introduction, contributions MB: motivation, domain analysis, demonstration, tool implementation WE: research concept

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Table A.4: Papers of the doctoral dissertation and declaration of authorship [continued]

P4	***BPMN4CP Revised – Extending BPMN for Multi-Perspective Modeling of Clinical Pathways***
Authors	Richard Braun (RB), Hannes Schlieter (HS), Martin Burwitz (MB), Werner Esswein (WE)
Publication	Bui, T. X., Sprague Jr., R. H. (Eds.): Proceedings of the 49th Annual Hawaii International Conference on System Sciences (HICSS 2016), January 5-8, 2016, Kauai, USA, 3249–3258
Authors' contribution	RB: research approach, consequences for extension evolution, extension design, tool implementation HS: introduction and motivation, conclusion MB: requirement analysis, concrete syntax, tool implementation, demonstration WE: research concept
P5	***Clinical Processes from Various Angles – Amplifying BPMN for Integrated Hospital Management***
Authors	Richard Braun (RB), Martin Burwitz (MBu), Hannes Schlieter (HS), Martin Benedict (MBe)
Publication	Huan, J., Miyano, S., Shehu, A., Hu, X.T., Ma, B., Rajasekaran, S., Gombar, V.K., Schapranow, M., Yoo, I., Zhou, J., Chen, B., Pai, V., Pierce, B.G. (Eds.): 2015 IEEE International Conference on Bioinformatics and Biomedicine (BIBM), November 9-12, 2015, Washington D.C., USA, 837–845
Authors' contribution	RB: adapting and extending BPMN for hospital modelling, BPMN extension definition MBu: integrated hospital modeling, concrete syntax HS: conclusion and further research MBe: demonstration
P6	***Towards Model Driven Architecture in Health Care Information System Development***
Authors	Hannes Schlieter (HS), Martin Burwitz (MBu), Martin Benedict (MBe), Oliver Schönherr (OS)
Publication	Thomas, O., Teuteberg, F. (Eds.): Proceedings of the 12th International Conference on Wirtschaftsinformatik (WI 2015), March 4-6, 2015, Osnabrück, Germany, 497–511
Authors' contribution	MBu: potentials of model-driven software development, development of the MediCUBE method, lessons learned HS: project background, conclusion and outlook, lessons learned MBe: demonstration OS: MDA knowledge base

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Table A.4: Papers of the doctoral dissertation and declaration of authorship [continued]

P7	***Transforming Clinical Pathways into Care Workflows***
Author	Martin Burwitz (MB)
Publication	currently unpublished
Author's contribution	Complete paper: MB
P8	***CDA Templates – Utilizing the MediCUBE***
Authors	Martin Burwitz (MBu), Martin Benedict (MBe), Hannes Schlieter (HS)
Publication	Hoerbst, A., Hackl, W.O., De Keizer, N., Prokosch, H.U., Hercigonja-Szekeres, M., De Lusignan, S. (Eds.): Exploring Complexity in Health: An Interdisciplinary Systems Approach. Proceedings of MIE2016, August 28 - September 2, 2016, München, Germany, 481–485
Authors' contribution	MBu: foundations, demonstration MBe: design of the document perspective HS: introduction, discussion

Table A.5: Complete list of publications

Publication	**Ranking[4]**
2017	
Martin Benedict, Hannes Schlieter, and **Martin Burwitz** 2017. Nachhaltigkeit von E-Health-Projekten. In Müller-Mielitz, S. and Lux, T. (eds), E-Health-Ökonomie, pages 99–116. Springer-Gabler.	–
2016	
Martin Benedict, Hannes Schlieter, **Martin Burwitz** and Werner Esswein 2016. ISO 11354-2 for the Evaluation of EHealth Platforms. In Proceedings of the Pacific Asia Conference on Information Systems 2016 (PACIS 2016), Chiayi, Taiwan.	VHB: C WKWI: A
Richard Braun, Hannes Wendler, Martin Benedict, **Martin Burwitz**, Kai Gand, Peggy Richter, Richard Rößler, Hannes Schlieter, Jeannette Stark and Werner Esswein 2016. Integrated Enterprise Modeling Lectures for Master Classes. In Proceedings Modellierung 2016, Lecture Notes in Informatics (LNI), 255, Karlsruhe, Germany, pages 53–62.	VHB: C WKWI: B
Richard Braun, Hannes Schlieter, **Martin Burwitz**, and Werner Esswein 2016. BPMN4CP Revised – Extending BPMN for Multi-Perspective Modeling of Clinical Pathways. In Bui, T. X., and R. H. Sprague Jr. (eds), Proceedings of the 49th Annual Hawaii International Conference on System Sciences (HICSS2016) Kauai, Hawaii. pages 3249–3258.	VHB: C WKWI: A

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[4]VHB: VHB-JORQUAL 3 (2015);
(http://vhbonline.org/vhb4you/jourqual/vhb-jourqual-3)
WKWI: "WI-Orientierungsliste der WKWI" (2008);
(http://www.kaifischbach.net/wkwi/orientierungslisten.pdf)

Table A.5: Complete list of publications [continued]

Publication	Ranking
2016	
Hannes Schlieter, **Martin Burwitz**, Oliver Schönherr and Martin Benedict 2016. Modellgestützte Softwareentwicklung im Gesundheitswesen. Business-IT-Alignment: Gemeinsam zum Unternehmenserfolg, page 252.	–
2015	
Richard Braun, **Martin Burwitz**, Hannes Schlieter and Martin Benedict 2015. Clinical Processes from Various Angles – Amplifying BPMN for Integrated Hospital Management. In Huan, J., S. Miyano, A. Shehu, X. T. Hu, B. Ma, S. Rajasekaran, V. K. Gom- bar, M. Schapranow, I. Yoo, J. Zhou, B. Chen, V. Pai, and B. G. Pierce (eds), 2015 IEEE International Conference on Bioinformatics and Biomedicine (BIBM), Washington D.C., United States. pages 837–845.	–
Martin Benedict, **Burwitz, Martin** and Hannes Schlieter 2015. Certification of Service-oriented eHealth Platforms – Derivation of Structured Criteria for Interoperability and Expandability. In Verdier, Christine, Marta Bienkiewicz, Ana Fred, Hugo Gamboa, and Dirk Elias (eds), Proceedings of the International Conference on Health Informatics 2015, Lisboa, Portugal, SCITEPRESS.	–
Hannes Schlieter, **Martin Burwitz**, Oliver Schönherr and Martin Benedict 2015. Towards Model Driven Architecture in Health Care Information System Development. In Thomas, O., and F. Teuteberg (eds), Proceedings of the 12th International Conference on Wirtschaftsinformatik 2015 (WI 2015), Osnabrück, Germany, pages 497–511.	VHB: C WKWI: A
Richard Braun, Hannes Schlieter, **Martin Burwitz** and Werner Esswein 2015. Extending a Business Process Modeling Language for Domain-Specific Adaptation in Healthcare. In Thomas, O., and F. Teuteberg (eds), Proceedings of the 12th International Conference on Wirtschaftsinformatik 2015 (WI 2015), Osnabrück, Germany, pages 468–481.	VHB: C WKWI: A
Sina Lehrmann, Hannes Schlieter, and **Martin Burwitz** 2015. Conceptual Modeling for Cooperation-Based Evolution of Medical Treatment. In Gurtner, Sebastian, and Katja Soyez (eds), Challenges and Opportunities in Health Care Management, pages 15–26.	–
Hannes Schlieter, **Martin Burwitz** and Steffen Greiffenberg 2015. Verwaltung und Modellierung klinischer Prozesse im Krankenhaus. Krankenhaus-IT, page 26.	–
2014	
Martin Burwitz, Hannes Schlieter, and Steffen Greiffenberg 2014. Clinical Process Management in the Future – Standard Operation Procedures on Mobile Devices. In Proceedings MobileMed 2014. Praha, Czech Republic.	–
Richard Richard, Hannes Schlieter, **Martin Burwitz** and Werner Esswein 2014. BPMN4CP: Design and Implementation of a BPMN Extension for Clinical Pathways. In Zheng, J. H., W. Dubitzky, X. Hu, J. Hao, D. P. Berrar, K. Cho, Y. Wang, and D. R. Gilbert (eds), 2014 IEEE International Conference on Bioinformatics and Biomedicine (BIBM). Belfast, United Kingdom, pages 9–16.	–

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Table A.5: Complete list of publications [continued]

Publication	Ranking
2014	
Martin Burwitz and Werner Esswein 2014. Modellbasierte Gestaltung und Entwicklung von Informationssystemen im Gesundheitswesen: Motivation und Potenziale. In Online-Proceedings des Workshops "Modellierung im Gesundheitswesen" im Rahmen der Konferenz Modellierung 2014. Vienna, Austria.	–
Michael Heß, Hannes Schlieter and **Martin Burwitz** 2014. Konzeption ausgewählter Sprachererweiterungen zur Ressourcenmodellierung in Modellen klinischer Behandlungspfade – Am Beispiel der Koronarangiographie. In Kundisch, Dennis, Leena Suhl, and Lars Beckmann (eds), Tagungsband Multikonferenz Wirtschaftsinformatik 2014 (MKWI 2014). Paderborn, Germany, pages 735–748.	VHB: D WKWI: C
Hannes Schlieter, **Martin Burwitz**, Oliver Schönherr and Martin Benedict 2014. Modellgestützte Softwareentwicklung im Gesundheitswesen. HMD Praxis der Wirtschaftsinformatik, 51(5): 669–684.	VHB: D WKWI: B
2013	
Jeannette Stark, **Martin Burwitz**, Richard Braun and Werner Esswein 2013. Cognitive Effective Modeling Using Tablets. In Proceedings of Enterprise Modelling in Information Systems 2013 (EMISA 2013), Lecture Notes in Informatics (LNI), St. Gallen, Switzerland.	VHB: C WKWI: B
Martin Burwitz, Hannes Schlieter and Werner Esswein 2013. Modeling Clinical Pathways – Design and Application of a Domain-Specific Modeling Language. In Alt, R., and B. Franczyk (eds), Proceedings of the 11th International Conference on Wirtschaftsinformatik (WI 2013). Leipzig, Germany, Volume 2, pages 1325–1339.	VHB: C WKWI: A
2012	
Hannes Schlieter and **Martin Burwitz** 2012. Ableitung Klinischer Pfade aus Medizinischen Leitlinien. In Online-Proceedings des Workshops "Wissensbasierte Systeme und Leitlinienmanagement in der Medizin" im Rahmen der GMDS-Jahrestagung 2012. Braunschweig, Germany.	–
Martin Burwitz, Hannes Schlieter and Werner Esswein 2012. Agility in medical treatment processes – A model-based approach. In Sinz, E. J., and A. Schürr (eds), Modellierung 2012, Lecture Notes in Informatics (LNI), 201, Bamberg, Germany. pages 267–279.	VHB: C WKWI: B
Richard Braun, Werner Esswein and **Martin Burwitz** 2012. Fachkonzeptionelle Modelle als Basis der Integration und Bewertung. In Großmann, Knut (ed), Tagungsband zum 2. Kolloquium zum SFB/TR 96. Chemnitz, Germany.	–
Werner Esswein, **Martin Burwitz** and Hannes Schlieter 2012. Modellgestüztes Prozessmanagement in Krankenhausinformationssystemen. Krankenhaus-IT, 1:20–22.	–

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Table A.5: Complete list of publications [continued]

Publication	Ranking
2011	
Martin Burwitz, Hannes Schlieter and Werner Esswein 2011. Modellgestütztes Management in Krankenhausinformationssystemen am Beispiel der Klinischen Prozesssteuerung. In Proceedings Informatiktagung 2011, Lecture Notes in Informatics (LNI). Berlin, Germany.	VHB: C WKWI: B

Table A.6: Complete list of conference presentations

Title, Conference	Date	Venue
ISO 11354-2 for the Evaluation of EHealth Platforms. *2016 Pacific Asia Conference on Information Systems, PACIS 2016*	27.06.-01.07.2016	Chiayi, Taiwan (ROC)
Towards Model Driven Architecture in Health Care Information System Development. *12th International Conference on Wirtschaftsinformatik, WI 2015*	04.-06.03.2015	Osnabrück, Germany
Clinical Process Management in the Future – Standard Operation Procedures on Mobile Devices. *MobileMed 2014*	20.11.2014	Praha, Czech Republic
Modellbasierte Gestaltung und Entwicklung von Informationssystemen im Gesundheitswesen: Motivation und Potenziale. *Workshop "Modellierung im Gesundheitswesen", Modellierung 2014*	19.-21.03.2014	Vienna, Austria
Modeling Clinical Pathways – Design and Application of a Domain-Specific Modeling Language. *11th International Conference on Wirtschaftsinformatik, WI 2013*	27.02-01.03.2013	Leipzig, Germany
Ableitung Klinischer Pfade aus Medizinischen Leitlinien. *Workshop "Wissensbasierte Systeme und Leitlinienmanagement in der Medizin" at the Annual GMDS Conference 2012*	18.09.2012	Braunschweig, Germany
Agility in medical treatment processes – A model-based approach. *Modellierung 2012*	14.-16.03.2012	Bamberg, Germany
Modellgestütztes Management in Krankenhausinformationssystemen am Beispiel der Klinischen Prozesssteuerung. *41st Annual GI Conference, Informatiktagung 2011*	04.-07.10.2011	Berlin, Germany

B. Agility in Medical Treatment Processes

Title	Agility in medical treatment processes – A model-based approach
Authors	Martin Burwitz (martin.burwitz@tu-dresden.de) Hannes Schlieter (hannes.schlieter@tu-dresden.de) Werner Esswein (werner.esswein@tu-dresden.de)
Publication	Sinz, E. J., Schürr, A. (Eds.): Modellierung 2012. Conference Proceedings, March 14-16, 2012, Bamberg, Germany, 267–279
Available at	`http://cs.emis.de/LNI/Proceedings/Proceedings201/256.pdf`

Abstract

The economic view on today's health care organizations insists on the integration of standardized process descriptions by Clinical Pathways and information technology (IT). The individuality of several treatments then again requires mechanisms for a flexible and agile alignment oft a treatment process at any time. This paper delineates an IT-system for an agile execution of medical treatment processes based on process models of Clinical Pathways. It will be shown which information occurs and where it can be used in terms of an agile process management and a continuous process improvement.

C. Domain Specific Modeling Language – *CPmod*

Title	**Modeling Clinical Pathways – Design and Application of a Domain-specific Modeling Language**
Authors	Martin Burwitz (martin.burwitz@tu-dresden.de) Hannes Schlieter (hannes.schlieter@tu-dresden.de) Werner Esswein (werner.esswein@tu-dresden.de)
Publication	Alt, R., Franczyk, B. (Eds.): Proceedings of the 11th International Conference on Wirtschaftsinformatik (WI 2013) - Volume 2, February 27 - March 1, 2013, Leipzig, Germany, 1325–1339
Available at	`http://aisel.aisnet.org/wi2013/83`

Abstract

Networking and collaboration in clinical care are increasingly entailing new requirements on supporting medical processes. The information technology (IT) in public health accordingly earns strategic relevance and encounters new potentials as well as challenging demands. The application of conceptual models in health care domain is almost entirely restricted to documentation tasks. Approaches like Model-Driven-Architectures or Workflow Management Systems have shown that the application of models, e.g. transformation, execution and formal interpretation, has huge potential. This article presents a modeling language for modeling clinical pathways. Three scenarios show the potential of conceptual models in health care domain and provide foundations for language requirements. Presenting a state-of-the-art of modeling languages for clinical domain and evaluating existing approaches to the requirements provide the gap to develop a domain-specific language. The potentials of the language and the use of corresponding models in medical treatment are demonstrated exemplarily including a discussion on model-driven management.

D. BPMN4CP - Version 1.0

Title	BPMN4CP: Design and Implementation of a BPMN Extension for Clinical Pathways
Authors	Richard Braun (richard.braun@tu-dresden.de) Hannes Schlieter (hannes.schlieter@tu-dresden.de) Martin Burwitz (martin.burwitz@tu-dresden.de) Werner Esswein (werner.esswein@tu-dresden.de)
Publication	Zheng, H. J., Dubitzky, W., Hu, X., Hao, J., Berrar, D. P., Cho, K., Wang, Y., Gilbert, D. R. (Eds.): 2014 IEEE International Conference on Bioinformatics and Biomedicine (BIBM), November 2-5, 2014, Belfast, United Kingdom, 9–16
Available at	`http://ieeexplore.ieee.org/document/6999261/`

Abstract

The Business Process Model and Notation (BPMN) is a standard for business process modeling that is very common in professional practice due to its expressiveness, the well defined meta model and the possibility of workflow integration. This research article aims to apply the BPMN for the representation of clinical pathways in order to utilize its benefits in the clinical context. BPMN provides a set of generic process modeling elements what makes it necessary to extend the language by domain-specific concepts from the field of clinical pathways (e.g. evidence indicators). Therefore, the extension method of Stroppi et al. (2011) was applied and extended in order to facilitate a systematic design and development. This research article provides the analysis of requirements and relevant concepts for modeling clinical pathways. Based on a domain ontology, the need for extension is identified and the valid BPMN extension meta model is designed by the construction of a conceptional domain model and the corresponding BPMN extension model. The evolved extension "BPMN4CP" is demonstrated by an example process of wisdom tooth treatment.

E. BPMN4CP - Version 2.0

Title	BPMN4CP Revised – Extending BPMN for Multi-Perspective Modeling of Clinical Pathways
Authors	Richard Braun (richard.braun@tu-dresden.de) Hannes Schlieter (hannes.schlieter@tu-dresden.de) Martin Burwitz (martin.burwitz@tu-dresden.de) Werner Esswein (werner.esswein@tu-dresden.de)
Publication	Bui, T. X., Sprague Jr., R. H. (Eds.): Proceedings of the 49th Hawaii International Conference on System Sciences (HICSS 2016), January 5-8, 2016, Kauai, USA, 3249–3258
Available at	`http://ieeexplore.ieee.org/document/7427590/`

Abstract

Clinical Pathways (CPs) can be seen as business processes of hospitals or clinical institutions. Modeling these pathways is an emerging field of research, as it provides promising benefits for systems integration, quality management and documentation. The Business Process Model and Notation (BPMN) provides a range of process-related concepts but naturally lacks in representing specific aspects from the CP domain. Therefore, the BPMN extension BPMN4CP was designed in a previous research project. In accordance with research guidelines from Design Science, the extension ran through an iteration based on its practical application within a telemedical project. Based on several new requirements, the extension was revised regarding the integration of resources, documents, objectives and quality indicators. These concepts were assigned to particular perspectives and diagrams in order to support model complexity management and provide appropriate diagrams for respective stakeholders. In order to provide a commonly usable extension, these enhancements were implemented as a BPMN meta model extension.

F. BPMN4CP - Version 2.1

Title	Clinical Processes from Various Angles – Amplifying BPMN for Integrated Hospital Management
Authors	Richard Braun (richard.braun@tu-dresden.de) Martin Burwitz (martin.burwitz@tu-dresden.de) Hannes Schlieter (hannes.schlieter@tu-dresden.de) Werner Esswein (werner.esswein@tu-dresden.de)
Publication	Huan, J., Miyano, S., Shehu, A., Hu, X.T., Ma, B., Rajasekaran, S., Gombar, V.K., Schapranow, M., Yoo, I., Zhou, J., Chen, B., Pai, V., Pierce, B.G. (Eds.): 2015 IEEE International Conference on Bioinformatics and Biomedicine (BIBM), November 9-12, 2015, Washington D.C., USA, 837–845
Available at	`http://ieeexplore.ieee.org/document/7359794/`

Abstract

The design and management of information systems is driven by model-oriented approaches on different levels of abstraction. For instance, enterprise models link the organizational action system and corresponding information systems. Enterprise models are generally perceived as measures to close the gap between business and IT, as it is in the healthcare domain. Clinical Pathways (CPs) represent value-added processes of hospitals and are typically described by respective process modeling languages like BPMN. However, a solitary focus on processes is insufficient for utilizing the potential of the model. Instead, it is rather advisable to consider various perspectives in order to completely represent the organizational action system of a hospital. We therefore propose to extend clinical process models with accordingly required perspectives for the representation of satellite objects, e.g. medical resources. Based on previous work, this paper motivates the approach of (process-based) integrated hospital modeling and presents the architecture and design of a revised BPMN extension for multi-perspective modeling. The applicability of the proposed BPMN extension is demonstrated by modeling a CP part for the treatment of stroke patients, which explicitly integrates the process and resource perspective.

G. MDA in Health Care IS Development

Title	Towards Model Driven Architecture in Health Care Information System Development
Authors	Hannes Schlieter (hannes.schlieter@tu-dresden.de) Martin Burwitz (martin.burwitz@tu-dresden.de) Martin Benedict (martin.benedict@tu-dresden.de) Oliver Schönherr (oliver.schoenherr@tu-dresden.de)
Publication	Thomas, O., Teuteberg, F. (Eds.): Proceedings of the 12th International Conference on Wirtschaftsinformatik (WI 2015), March 4-6, 2015, Osnabrück, Germany, 497–511
Available at	`http://aisel.aisnet.org/wi2015/34`

Abstract

Failed software projects are often the result of an unsystematic transfer of business requirements to the implementation. This deficit led to the specification of the Model Driven Architecture (MDA). It claims a consistent use of conceptual models for the software development process from requirement analysis to technical specification of software. The MDA reduces the gap between the business level and the information technology (IT) level by defining a methodological framework to link these levels (Business-IT alignment). We will present the use of an MDA in health care domain. For this purpose, we show how the paradigm of MDA can be configured to implement medical application software based on a telemedical IT platform (telehealth platform). Additionally to the conceptual structure of the developed approach and the domain-specific alignment, lessons learned from the experiences gathered during design process will be formulated as an assistance for similar projects and substantiated with an exemplary application.

H. Transforming Clinical Pathways into Care Workflows

Title	Transforming Clinical Pathways into Care Workflows
Author	Martin Burwitz (martin.burwitz@tu-dresden.de)
Publication	Working Paper on Research Gate
Available at	https://www.researchgate.net/publication/313164885

Abstract

In the context of increasing economic competition between health care providers, the concurrent trend to specialization and inter-disciplinary and inter-organizational care as well as the effort to transparency and standardization of care services, a process orientation has become a central perspective in health care management. Therefore, clinical pathways (CPs) have been established as a promising tool, addressing evidence-based expertise of clinical practice guidelines and describing organization-specific recommendations for action and best practices. Mostly used for task definition and documentation, CPs furthermore provide the potential for actual process guidance, demanded in practice and technically available to some extent, but currently less implemented. This paper therefore proposes a model-based method as the result of a design-science process, providing holistic methodical support for CP description by conceptual models and their consecutive transformation into technical workflow specifications, to be interpreted by process-oriented hospital application systems. The method application in practice is demonstrated using a real care scenario and is intended to systematize the design of clinical pathways and to ease the definition of care workflows to further contribute to the alignment between process definition and execution.

I. CDA Templates – Utilizing the MediCUBE

Title	CDA Templates – Utilizing the MediCUBE
Authors	Martin Burwitz (martin.burwitz@tu-dresden.de) Martin Benedict (martin.benedict@tu-dresden.de) Hannes Schlieter (hannes.schlieter@tu-dresden.de)
Publication	Hoerbst, A., Hackl, W.O., De Keizer, N., Prokosch, H.U., Hercigonja-Szekeres, M., De Lusignan, S. (Eds.): Exploring Complexity in Health: An Interdisciplinary Systems Approach. Proceedings of MIE2016, August 28 - September 2, 2016, München, Germany, 481–485
Available at	`http://ebooks.iospress.nl/publication/44658`

Abstract

The specification and customization of clinical document types are tasks that need a strong collaboration between domain experts and IT specialists. However, these collaborators are often faced with difficulties due to different interpretation of domain knowledge. Therefore, an adequate method for sharing domain knowledge about documents is necessary. Even though there are some tools that help to define medical document types, there is a lack of approaches that focus on the understandability of the specification for the domain experts. This paper proposes a modeling approach based on the Clinical Document Architecture to address this gap.