# Process-Based Quality Management in Care: Adding a Quality Perspective to Pathway Modelling[1]

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**Abstract.** Care pathways (CPs) are used as a tool to organize complex care processes and to foster the quality management in general. However, the quality management potentials have not been sufficiently exploited yet, since the development, documentation, and controlling of quality indicators (QIs) for quality management purposes are not fully integrated to the process standards defined by CPs. To support the integration of a quality perspective in CPs, the paper addresses the questions which and how quality concepts can be integrated into the process documentation in order to support managers, health service providers, and patients. Therefore, we extended the widely accepted modelling language "Business Process Model and Notation" (BPMN) with a quality perspective. The conceptualization is grounded on a systematic literature review on (quality) indicator modelling. Together with previous work on the conceptualization of QIs in health care, it provided the basis for a comprehensive domain requirements analysis. Following a design-oriented research approach, the requirements were evaluated and used to design a BPMN extension by implementing the quality indicator enhancements as BPMN meta model extension. All design decisions were evaluated in a feedback workshop with a domain expert experienced in quality management and certification of cancer centres on national and international level. The approach is demonstrated with an example from stroke care. The proposed language extension provides a tool to be used for the governance of care processes based on QIs and for the implementation of a more real-time, pathway-based quality management in health care.

**Keywords:** care pathways, pathway modelling, quality management, integrated care, systematic literature review, conceptual modelling, BPMN extension.

## 1 Introduction

Care pathways are recognized as an appropriate tool for the organization and streamlining of complex integrated care processes for a well-defined patient population [1]. Especially against the background of demographic changes, skilled worker shortages, an increasing number of multimorbid people with chronic diseases, and economic effi-

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ciency efforts in Western countries, the management of the care process is of high importance [2]–[4]. Besides the organization of the core clinical process, i. e. interactions between patients and health service providers, care pathways are also important for process governance and compliance purposes as well as for the establishment of an integrated process management. However, the potentials of defined process standards by care pathways has not been sufficiently exploited so far. This is particularly apparent in quality management, which supports health care organizations be more pro-active, improves operational efficiency and outcomes, increases patient safety, and reduces errors [5], [6]. Although care pathways are an important means to this end, especially in integrated care settings [4], [7], the development, documentation and controlling of quality indicators (QIs) for quality management purposes are yet not based on the process standards defined by care pathways. On the one hand, there are process modelling languages for the conceptual representation of care pathways (e. g. [8]). On the other hand, the issue of conceptualizing and modelling indicators, especially for performance management purposes is comprehensively addressed in the literature (e. g. [9]). However, the integration of both is yet not sufficiently supported.

This isolated view on quality management and care pathways hampers the comprehensive, process-based quality improvement intentions of healthcare organizations, e. g. the pathway-based identification of activities which reduce or enhance quality and the real-time monitoring of quality levels in care provision [10]. Annual quality reports do not allow quick reactions based on current quality levels. To address this shortcoming, the objective of the paper at hand is the integration of a quality perspective in care pathways represented as conceptual process models. The focus of this paper is on design decisions, i. e. the questions of which and how quality concepts shall be integrated in care pathways in order to support managers of health institutions, health service providers, and patients in terms of quality information and management tasks. The presented approach contributes as a tool for the governance of care processes based on QIs and for the development of real-time process-based quality dashboards complementing the pathway view and supporting continuous quality management.

The remainder of the paper is structured as follows: In section 2 the applied methods are described. Section 3 addresses the current body of knowledge in the fields of indicator modelling in relation to process modelling. In section 4 the integration of a quality perspective in conceptual care pathway models is described by extending the widely accepted and used Business Process Model and Notation (BPMN). This involves the definition and expert evaluation of user requirements for the integration of QIs in pathway models, the development and description of a domain ontology, and, building upon that, the extension design of the modelling language. The approach is demonstrated with an example from stroke care in section 5. The paper closes with a conclusion and a discussion of open issues in section 6.

## 2 Methods

The presented work comprises both the design and development as well as the demonstration phase of a design-oriented information systems (IS) research project [11], [12].

The general focus of this design science research (DSR) genre is the instruction of the design and operation of IS and of innovative IS concepts [13]. The addressed DSR artefact is a method in terms of the extension of a modelling language [14], intended to be used for pathway-based quality management in healthcare settings. This approach is reasonable since the adaption of an existing modelling language with domain-specific concepts is expected to be less expensive than the invention of a new one [15]. The relevance for the language extension is reasoned in additional requirements from the environment which are yet not addressed, i. e. pathway-related QIs required in the context of quality management initiatives in the stroke and cancer care context [16] (supporting the DSR relevance cycle according to Hevner [17]). We conducted interviews with domain experts to gain insights into these two care domains and to validate requirements for the language extension. The presented research contributes to the current knowledge base with a quality-integrating pathway ontology and a corresponding BPMN extension. The work is grounded in the theoretical knowledge base regarding meta modelling, modelling language (esp. BPMN) extensibility, and indicator modelling (supporting the DSR rigor cycle according to Hevner [17]). The applied DSR approach and their relation in the DSR framework are shown in Figure 1. For the extension of an existing process modelling language with a quality perspective we follow the requirements-based extension procedure described by Braun and Schlieter [18]. This approach was chosen since it includes a deep consideration of the requirements resulting from the application domain, which is of high importance for design-oriented research. The extension procedure is outlined in Figure 1 and detailed in in section 4.1.

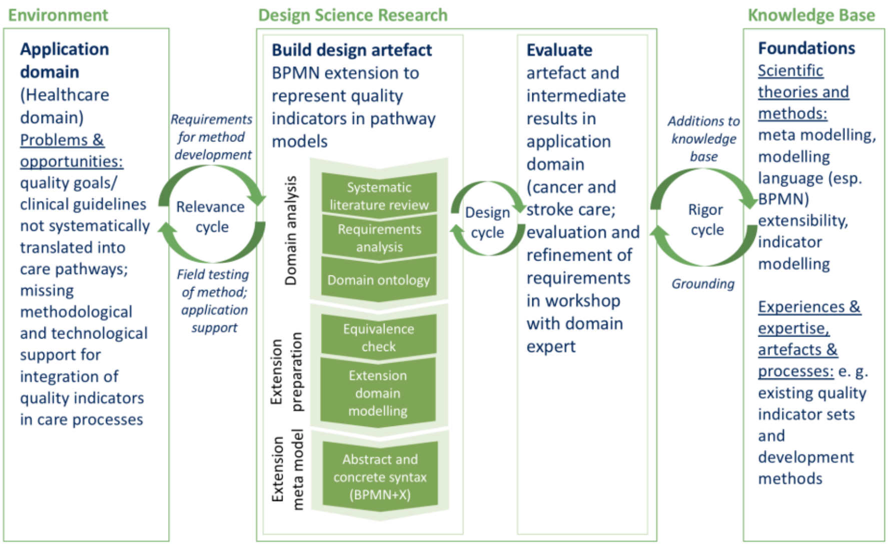


**Fig. 1.** Research methods in relation to DSR framework from Hevner et al. [14] and Hevner [17], artefact design applying the BPMN extension method proposed by Braun and Schlieter [18].

In order to reflect on the existing literature body in the field of indicator modelling as well as its feasibility and fitness in terms of the representation of QIs in care pathway models, we conducted a systematic literature review [19]. The search was based on the literature review on performance modelling conducted by Livieri et al. [9]. As represented in Table 1, we adapted their search string to also cover quality-related issues and the health care domain. The search was performed in February 2019. Only articles that described either a conceptual model of indicators or an approach (e. g. modelling language) to represent indicators in business process models or care pathways were included in the analysis. The database searches were complemented by backwards searches and hand search using google scholar.

**Table 1.** Search strategy (italic keywords taken from search string used by Livieri et al. [9]).

| Reporting item | Description |
|---|---|
| Databases | Web of Science, Academic Search Complete |
| Keywords searched in titles | ((“*enterprise monitoring*” OR “*performance monitoring*” OR “quality monitoring” OR “quality measurement” OR “*performance measurement*” OR *indicator* OR *KPI**) AND (*ontolog** OR *semantic* OR model* OR *formal**)) |
| | AND |
| Keywords searched in abstracts (Academic Search Complete)/ topic (Web of Science) | ((“health care” OR “care network” OR “integrated care” OR “care process” OR “clinical pathway” OR “care pathway” OR “care process”) OR (*enterprise* OR “*supply chain*” OR *organization* OR organisation OR “*collaborative network*” OR “*supply network*” OR “*alliance*” OR “*virtual enterprise*”)) |
| No. of initial results | Web of Science: 270<br>Academic Search Complete: 56 |
| No. of results without duplicates | 285 |
| No. of relevant articles | 18 |

## 3 State-of-the-Art Indicator Modelling

In relation to the objective of this work, the focus of the literature analysis was on existing indicator models describing key concepts of indicators and on existing approaches for the integration of indicators in process models, especially in care pathways. The literature was analysed accordingly. An overview of the main contributions in this field is given with Table 2. Although we included quality-related search terms, the search did not result in work specifically addressing the modelling of QIs. The focus of existing literature is on the modelling of business goals and of organizational- and process performance. However, this literature provides a useful basis for the conceptualization and modelling of QIs, since business goals can equal quality goals and thus be reflected with QIs. Also, performance is a quality aspect, focusing on the business processes as means to improve outcomes [20].

**Table 2.** Overview of main contributions in the field of indicator modelling.

| Reference | Indicator focus | Process model integration |
|---|---|---|
| Popova and Sharpanskykh 2011 [21] | Business goals, conceptualization of and relations between performance indicators | Not specified |
| Strecker et al. 2012 [22] | Modelling method METRICM for performance indicator systems; indicator meta model | Not specified |
| Staron et al. 2016 [23] | Quality model and relevant characteristics of key performance indicators | Not specified |
| Mate et al. 2016 [24] | Meta model for key performance indicators and key results indicators | Not specified |
| Amor and Ghannouchi 2017 [25] | Ontology model of key performance indicators in context of process improvement | Not specified |
| Ghahremanlou et al. 2017 [26] | Ontology design patterns to consistently represent indicators from multiple indicator sets | Not specified |
| del-Río-Ortega et al. 2010 [27] | Ontology defining process performance indicators | Ontology-based definition of relationships between indicators and BPMN elements |
| Silva and Weigand 2011 [28] | Monitoring metric ontology as part of an enterprise monitoring ontology | Not specified |
| Zeise 2010 [29] | Performance indicators | Proposal of graphic representation of indicators in BPMN |
| Ronaghi 2005 [30] | Performance management meta model including an indicator model | Not specified |
| Pourshahid et al. 2009 [31] | Extension of User Requirements Notation (URN) with key performance indicators to measure and align processes and goals | Relation between process models, goals and indicator models in URN |
| Rojas and Jaramillo 2013 [32] | Pre-conceptual schema for the representation of key performance indicators | Not specified |
| Braun et al. [33] | QIs and objectives in healthcare | BPMN extension, indicators and objectives annotated to clinical pathways |
| Jussupova-Mariethoz and Probst [34] | Ontology specifying business concepts for enterprise performance monitoring; focus: key performance indicators | Not specified |

There are several ontology-based conceptualizations of indicators described in the literature. They define key attributes of indicators as well as the relations to other organizational elements such as policy, goals, processes, or roles. The identified indicator ontologies were mostly developed and used for enterprise monitoring purposes. In addition, literature addressing indicator modelling in the health care domain is scarce. Pourshahid et al. [35] as well as Amor and Ghannouchi [25] apply their approaches with example case studies in healthcare. Braun et al. [33] integrated QIs in BPMN models of care pathways by representing them as labelled circles, annotated as properties to activities, gateways, and processes. Still, the QI element is not further specified. Another, but domain-independent proposal for the process integration of indicators was made by Zeise [29] by drafting a graphical representation of indicators in BPMN models. However, there is no technical integration of their proposal to the BPMN meta model. In summary, there is no fully defined healthcare domain-specific process modelling language integrating a detailed perspective on QIs yet.

# 4 Development of the Extension

## 4.1 Extension Procedure and Language Selection

According to the requirements-based extension procedure described by Braun and Schlieter [18], we conducted a domain requirements analysis to understand the domain in detail and to derive necessary requirements for the intended modelling approach (see section 4.2). Based on this, the next step was to select a modelling language to be used for the extension design. We decided on BPMN since it is a broadly accepted and established standard for business process modelling in economy and industry. Also, it provides a meta model, so that it can be modified and extended as needed for particular domain specificities. BPMN is already used for modelling care processes (e. g. [36], [37]) and thus, is a known approach in health care practice. Also, we include the existing BPMN extension for care pathway modelling (BPMN4CP) [38] and its revised version including a resource and document view [33] in our extension design. Within the step of language selection, a domain ontology based on the previously defined requirements is developed (see section 4.3). The next step contains an equivalence check to determine whether a domain concept is already covered by existing BPMN elements, resulting in extension requirements (see section 4.4). After this, Braun and Schlieter refer to the extension method of Stroppi et al. [39] for the domain modelling (see section 4.5) and definition of the abstract syntax of the extension. Finally, the concrete syntax (graphical representation) of the BPMN extension shall be specified. In this paper, we focus on the presentation of the Conceptual Domain Model of the Extension (CDME) functioning as the basis for the BPMN meta model extension. Also, the graphical representation (concrete syntax) in a BPMN pathway model is outlined (see sections 4.5 and 5).

### 4.2 Requirements for the Integration of a Quality Perspective in Pathway Models

In order to identify underlying requirements for the integration of a quality perspective in care pathways, we conducted a user-centred requirements analysis. In general, pathways are used for patient information, documentation, monitoring and evaluation purposes [40]. As part of health operations management, care pathways are utilized within the following five main activity areas [1]:

- care planning and documentation for individual patients
- care planning and -controlling for specific patient groups
- care resource capacity planning (e. g. providers, materials, space) and controlling
- patient volume planning and -controlling
- strategic planning with regard to long-term policy of a health organization

These imply that care pathways are used by different stakeholder groups with different purposes. For example, management uses QIs to monitor and direct the organization's care policies and practices [20]. Based on the described activity areas above, we distinguished between the main user groups patients, health service providers engaged in care provision along the care pathway (e. g. physicians, nurses), and managers (especially quality management, controlling). We presented an initial list of requirements to an expert in the field of cancer care and certification of comprehensive cancer centres. She reviewed and revised the requirements on the basis of her many years of experience on national and European level. For example, she pointed out that it should be identifiable whether a quality indicator was developed based on existing evidence or on an experts' consensus. Table 3 represents the final, validated set of requirements for the representation of a quality perspective in care pathway models.

**Table 3.** Requirements for an integrated quality perspective in care pathways (HSP – health service provider, M – manager, P – patient).

| No. | Requirement | User group |
|---|---|---|
| $R_1$ | Information about relevant quality aspects along the care pathway | HSP, M, P |
| $R_2$ | QIs as integrative part of the care pathway (represented at the relevant point in the pathway, i. e. decision point, activity, whole pathway or part of the pathway, time frame, outcome, structural unit) | HSP, M, P |
| $R_3$ | Representation of the source of a QI | HSP, M, P |
| $R_4$ | Representation of the recommendation level of a QI (e. g. evidence indicator or recommendation based on consensus report) | HSP, M, P |
| $R_5$ | Representation of relevant QI attributes to describe and measure them | HSP, M |
| $R_6$ | Representation only of those QIs to a user which are relevant for the user's work/purpose | HSP, M, P |
| $R_7$ | Representation of data sources used for data provision | HSP, M |
| $R_8$ | Representation of the relation of a QI to the corresponding quality- and business goals | M |

| | | |
|---|---|---|
| $R_9$ | Representation of deviations from defined QI target value and thus, of quality and process improvement potentials at corresponding points in the pathway | HSP, M |
| $R_{10}$ | Representation of current QI values (status) | HSP, M |
| $R_{11}$ | Representation of QI values over time to see quality development/trend | HSP, M |

The user-related requirements are complemented by theory-based requirements [41], i. e. $R_{12}$: base development on multi-perspective modelling theory [42], $R_{13}$: procedural transparency of extension design [33], [43], $R_{14}$: evolution of existing BPMN extension [44], $R_{15}$: base development on classification and characteristics of QIs in care [45]. This theoretical basis ensures the rigorousness within the followed DSR approach [17].

### 4.3 Domain Ontology

Ontologies are used to deepen the understanding of a domain by explicating the domain knowledge, core concepts and their relationships [46]. Informal ontologies are a means to that end, functioning as a terminological and conceptual basis [47]. In order to conceptualize the quality perspective in relation to care pathways, the pathway ontology proposed by Braun et al. [38] was extended. Therefore, the identified indicator ontologies as described in section 3, own previous research on the conceptualization of process quality in healthcare [16], and the user-centred requirements identified in section 4.2 were used. The evolved domain ontology is depicted in Figure 2.

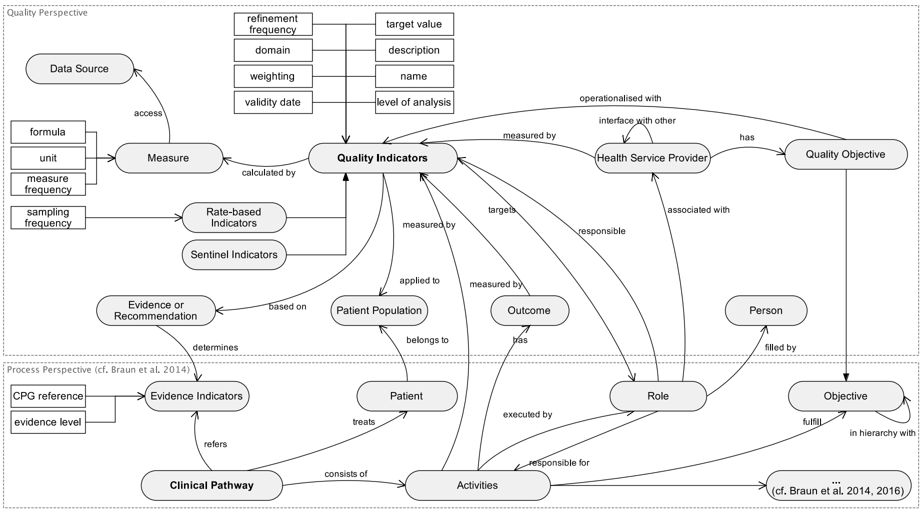


**Fig. 2.** Care pathway based on [38] and extended with a quality perspective, represented using the OWL Lite ontology [48].

*Quality indicators* are in the centre of the quality perspective. They are measures to assess particular health care structures, processes or outcomes [45]. This corresponds to the traditional classification of care quality by Donabedian, who distinguishes between the quality of structures (e. g. infrastructure, environment, employee qualification), processes (e. g. interventions, diagnosis activities), and outcomes (e. g. patient's health status, patient satisfaction) [49] (for examples see Table 4). This division is also represented in the domain ontology with QIs measuring structures of *health care providers* (corresponding to structural quality), pathway *activities* (corresponding to process quality and analogous to the process relation of indicators described in [25] and [34]), and pathway activity *outcomes* (corresponding to outcome quality).

**Table 4.** Examples of QIs (identified from [45]).

| Quality dimension | QI example |
|---|---|
| Structure | access to specific technologies/ medical devices, proportion of specialists to other doctors |
| Process | proportion of patients assessed by doctor within 24h after referral |
| Outcome | blood pressure, mortality |

QIs operationalise *quality objectives*, being part of the goal hierarchy of a health care institutions [34]. Useful QIs need to be relevant, scientifically developed and feasible [50]. Thus, indicators are linked to *recommendation or evidence sources*. Typically, these are consensus reports, clinical studies, systematic literature reviews, or clinical practice guidelines (CPGs). The latter bundle the current evidence from clinical studies regarding the care for particular patient groups [51]. Mature CPGs already describe QIs to be used for assessing quality of care. If new evidence becomes available or the original source such as the corresponding CPG is updated, applied QIs may themselves need revision, updating or discontinuation. This lifecycle of QIs is specified by attributes such as a refinement frequency, responsible person and validity date. Other attributes of QIs as represented in the domain ontology are adapted from existing indicator-related meta models proposed in performance measurement literature (see [22], [52]). QIs are either *rate-based* (e. g. proportions, mean values) or *sentinel indicators* (identifying undesirable events such as number of patients who died during surgery) [45]. They are categorised with respect to their domain, e. g. the phase in care provision (prevention, diagnosis, treatment, follow-up), symptoms, comorbidities, side effects, documentation and communication, service availability and access, or teamwork (examples for QI domains in [27], [53], [54]). Thus, they are generic or disease-specific, on patient level or institutional level [45].

QIs are used by *health service providers*, e. g. in a hospital, nursing home, or care network, and they refer to a specific *patient population*. Therefore, it needs to be specified for whom a QI is applicable, e. g. by detailing clinical situation, age, gender, comorbidities of the targeted patient group. However, QIs are applied to groups, not individuals and thus, there may occur exceptions.

To measure quality, QIs use particular *measures*, having a calculation formula depending on the type of the indicator. Rate-based indicators are represented as If-Then-statements, resulting in ratio calculations (with the then-part as numerator and the if-part as denominator) [45]. However, sentinel indicators are for example operationalised into volumes, yes/no statements or time periods, e. g. waiting times for an appointment. The QI measurement results in an actual value for the analysed setting. It might deviate from a specified target or threshold value. It is possible to apply a weighting scheme to a QI set to differentiate the importance of the QIs. To assess a QI, the necessary *data sources* need to be accessible. These might be electronic or paper-based medical records, accounting databases, e. g. DRG (diagnosis related group) reporting systems, health insurance claims data, additional documentation on in- and outpatient care, or patient surveys.

## 4.4 Equivalence Check

In this section, we compare the identified domain concepts to original BPMN elements in order to identify the need for extension, adaption or reuse of elements. If applicable, the domain concepts are also compared to the already existing language extension BPMN4CP in order to reuse extension concepts. The results of the equivalence check are shown in Table 5. It includes the classification of the equivalence type for each domain concept and correspondingly, the classification either as *BPMN Concept* or *Extension Concept*. Therefore, each domain concept is analysed regarding semantic equivalence to existing BPMN elements as specified in [55] and BPMN4CP elements as described in [33], [38]. In case of equivalence, a domain concept is either represented by a valid composition of original BPMN elements (equivalence by composition) or as specification of original BPMN elements, i. e. adding domain-specific properties or semantics (equivalence by specification) [34].

**Table 5.** Equivalence check.

| Req. | Concept | Description | Equivalence check | CDME |
|---|---|---|---|---|
| $R_1$, $R_2$, $R_5$ | **Quality Indicator** | Measurement of quality bound to activities, decisions, process parts, entire processes, structural units, or outcomes | **Conditional equivalence:** BPMN4CP extension concept *Quality Indicator* (specification of BPMN *Property* element) but without further structuring or parametrization according to domain ontology attributes | Extension concept and specified BPMN4CP concept |
| $R_8$ | **Quality Objective** | Quality goal of activities, decisions, process parts, entire processes, structural units, or outcomes in relation | **Conditional equivalence:** see *Quality Indicator*; BPMN4CP extension concept needs reference to *Quality Indicator* | Extension concept and specified BPMN4CP concept |
| $R_5$ | **Measure** | Specification of how and when to calculate the value of a QI | **No equivalence** | Integrate as complex data type in *Quality Indicator* concept since |

| | | | | |
|---|---|---|---|---|
| | | | | each QI has one measure (1:1 relation) |
| R7 | **Data Source** | Data source used for the provision of data to calculate value of a QI | **Conditional equivalence:** BPMN concept *Data Input* as mechanism to retrieve data; needs reference to *Quality Indicator* | Extension concept and specified BPMN concept |
| R6 | **Interest group** | Group of people (roles) for whom a QI is relevant | **No equivalence** | Integrate as complex data type in *Quality Indicator* concept |
| R3 | **Recommendation source** | Reference to specific source which was used to reason and derive the QI from | **Conditional equivalence:** BPMN4CP extension concept *CPG Reference* is too restricted since CPGs are not the only source for QIs | Extension concept and specification of BPMN and BPMN4CP concepts |
| R4 | Recommendation | Statement of recommendation that a QI refers to | **Conditional equivalence:** see Quality Indicator; BPMN4CP extension concept Evidence Indicator needs reference to Quality Indicator; if QI is not evidence-based the recommendation strength shall be represented | Extension concept and specified BPMN4CP concept |

It was assessed to be unnecessary to include the domain concept *Patient Population* in the quality perspective of a pathway model since it is already covered by patient inclusion and exclusion criteria of a pathway. Instead, the relevant patient population for ratio-based QIs is represented in the formula (e. g. "percentage of patients with postoperative radiation of the remaining breast/chest wall among all patients with breast-conserving surgery for invasive carcinoma"). Furthermore, the domain concepts Health Service Provider and Outcome are not specifically included in the language extension. The type of a QI (structural, process-, and outcome-oriented) is represented by the QI domain, which is an attribute of the *Quality Indicator* concept. Understandably, the focus of QI representation in pathway models is on process-related QIs.

### 4.5 Extension Modelling – CDME and BPMN extension model

The CDME model is part of the extension preparation and was created based on the detailed analysis of the required quality concepts. The quality-related extension parts were embedded in the existing BPMN4CP CDME model and are depicted in Figure 3. As assessed during the equivalence check (see Table 5), we added relevant QI concepts to be represented in BPMN pathway models. Extension elements are marked with the *Extension Concept* stereotype. For easier visual distinguishability all new, i. e. quality-related extension concepts, are coloured white whereas BPMN concepts and previous BPMN4CP extension concepts from [33], [38] are coloured grey. The CDME model

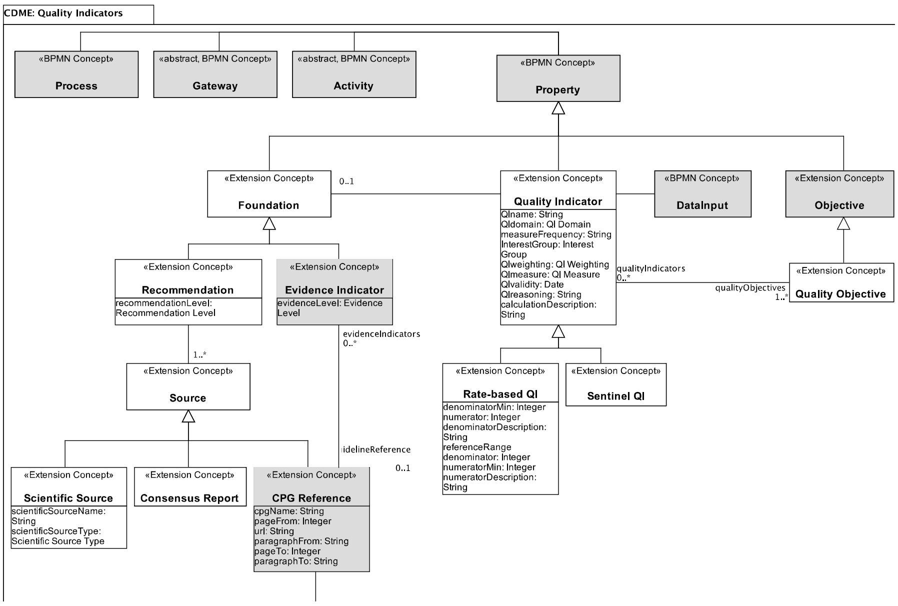


**Fig. 3.** Conceptual Domain Model of the Extension (CDME).

shows the integration of the *Quality Indicator* concept, a detailed specification of the BPMN *Property* concept, in pathway models. The CDME informs the extension of the BPMN meta model, which we developed according to [18]. Therefore, new concepts were marked as *Extension Definitions* and *Extension Elements* and new relationships as *Extension Relationship* (example see Figure 4a). An outline of the graphical representation (concrete syntax) of the added quality concepts is given in Figure 4b. Picking up on the introduced symbols of circled *Quality Indicators* and *Objectives* in the revised BPMN4CP version [33], we detailed *Quality Indicators with Measures* and added QI *Data Inputs*.

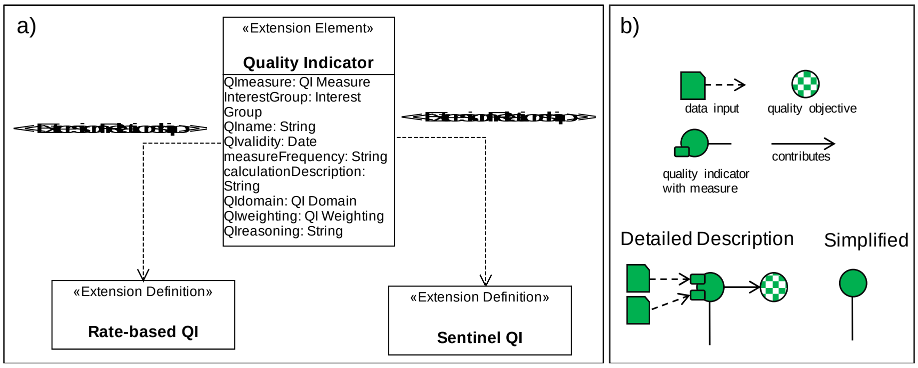


**Fig. 4.** a) Example part of the BPMN extension model (BPMN+x), b) extension of the concrete syntax by new graphical representations.

## 5 Demonstration

To demonstrate the application of the BPMN modelling language extension, we use a case example from integrated stroke care. Stroke is one of the most common causes of death globally. It holds a high risk of causing life-long, chronic disabilities in adults [56]. A coordinated stroke care, from acute care to rehabilitation and aftercare, aims to enable a quality-assured and evidence-based treatment to control risk factors and reduce recurrence rates, the need for long-term care and mortality [57]. Thus, managing quality in stroke care is an important issue and the proposed approach of integrated QIs in care process models shows high applicability for this case.

We gained insights to the process of stroke acute and aftercare via an expert interview with an experienced case manager. In the current flow chart-like integrated care pathway, objectives are already associated with QIs and individual pathway steps. They are depicted as circles near the corresponding process step [58]. The relation between a QI and an objective is shown by coherent numbering. A closer linkage between these concepts and their attributes shall be provided by applying the proposed BPMN extension.

**Table 6.** Exemplary quality indicators, related quality objectives and data inputs.

| Quality objective | Quality indicator | Data input |
|---|---|---|
| O1: Increase the proportion of patients with stroke symptoms who receive adequate treatment within 3 hours | QI1.1: proportion of patients admitted within 3 hours after onset of symptoms in all patients with stroke or transient ischemic attack (TIA) | time interval stroke to admission (time_adm) |
| | QI1.2: proportion of patients with duration "admission - 1st imaging" under 30 minutes in all patients with | time interval admission to first imaging (time_imag) |

| | | |
|---|---|---|
| | stroke and duration of symptoms at the time of admission < 4h | |
| O2: Guideline compliant thrombolysis | QI2.1: percentage of patients with symptomatic cerebral haemorrhage in all patients with thrombolysis | complication: intracerebral hemorrhage (compl_intrahem); intravenous thrombolysis (iventhrom); intraarterial thrombolysis (iartthrom) |
| O3: Discharge management | QI3.1: Completely structured treatment plan aftercare in the set of all case charts | Treatment plan aftercare complete (tplan_compl) |

For demonstration purposes, we use a high-level process description of acute care in the care pathway for stroke patients and four exemplary QIs as described in Table 6. The example representation in Figure 5 shows the specification of QIs and their relation to activities in the care process. Also, it shows the connection to quality objectives and the input of data for measurement of a QI. QIs can either be represented in a simplified or more detailed description in the pathway. To not overload the process model, the QIs in the care process are further detailed in separate QI diagrams, representing a distinct view on the care pathway (see Figure 5). Continuing to use the concrete syntax of the language extension BPMN4CP [33], the orange index finger now not only represents the evidence level of activities but also of quality indicators.

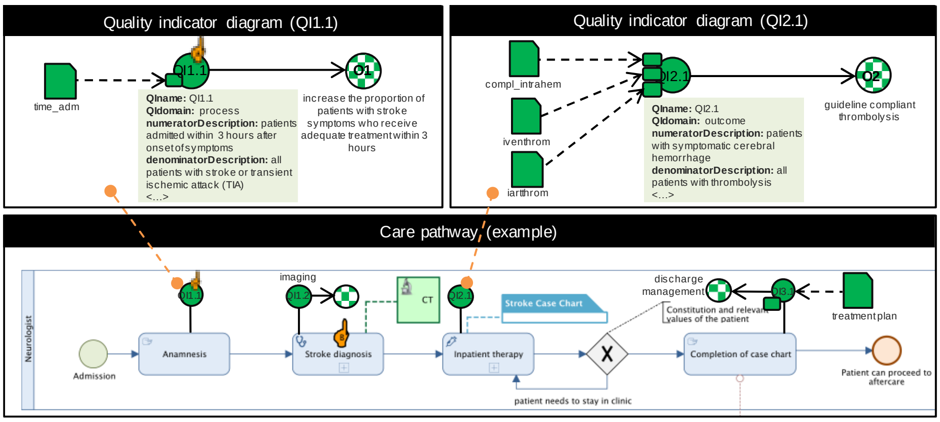


**Fig. 5.** Extended BPMN4CP demonstration model exemplarily presenting the integration of QIs in a process from stroke care.

## 6 Conclusion

Although care pathways are a commonly used tool to organize complex care processes and to increase care quality, their potentials in terms of quality management have not been sufficiently exploited yet. The development, documentation and controlling of QIs for quality management purposes are not fully integrated to the process standards defined by care pathways. Such integration could contribute to the governance of care processes and support continuous process-based quality management.

The purpose of this paper was to advance a common and widely used process modelling notation in order to integrate quality management information such as quality objectives, related QIs, and measure inputs. Therefore, we consolidated the characteristics of QIs as concept and QI modelling as method by conducting a systematic literature review. The results were implemented into an ontology connecting the concepts of care pathways with quality-related concepts such as QIs. This ontology served as mean to assess and describe the domain knowledge. For other researchers, the ontology provides an instrument to extend existing modelling approaches with that quality information. Based on the literature-based requirements analysis and a validation from a domain expert in the field of integrated cancer care, we developed a BPMN language extension to integrate a quality perspective in care pathway models. A separate QI view allows the description of structure-related information of the quality concepts. It also helps to inform and use the simplified QI description in the pathway diagram.

Critically reflecting on our own work, the validation of requirements for the BPMN language extension could be improved by interviewing more domain experts also outside of the cancer care domain. For example, discussing the requirements in a focus group would allow experts' interaction [59] and might result in additional or revised requirements. Also, the literature review could be broadened to also include work from other research fields. For example, Quality of Service literature provides modelling approaches of quality and quality indicators in process models. How such approaches could be adapted to the modelling of care pathways is a question to be addressed in future research.

Nowadays the interoperability between modelling tools is still not sufficient. Therefore, we concentrated our work on the specification of a meta model extension (abstract syntax) that can be incorporated in various tools or meta case tools and which can also be used to compare the proposed modelling extension with similar approaches. In addition, with the outline of the concrete syntax and the modelling example, the general applicability and utility of the approach were illustrated. However, for a better integration into the daily work processes the approach shall be linked to a documentation system (or to the clinical information system) so that the quality related documentation is directly derived and triggered by the pathway. The direct linkage of QIs to the process may also help to assess the documentation efforts in the process and can help the automated generation of quality-related data, e. g. to use inhouse tracking to collect time stamps that can be used to determine waiting times. Our approach is also a starting point for the integrated monitoring of QIs, which combines the quality performance of a concrete medical treatment process with historical data. In sum, the work contributes to an integrative quality management approach on the basis of care pathways. We showed how an existing general-purpose modelling language can be systematically extended to integrate the scope of quality information within care process models.

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## References


1. Schrijvers, G., van Hoorn, A., Huiskes, N.: The care pathway: concepts and theories: an introduction. International Journal of Integrated Care 12, Special Edition Integrated Care Pathways (2012).
2. Antunes, V., Moreira, J.: Approaches to developing integrated care in Europe: a systematic literature review. *Journal of Management & Marketing in Healthcare* 4(2), 129–135 (2011).
3. Nolte, E., Pitchforth, E.: What is the evidence on the economic impacts of integrated care?. World Health Organization (2014).
4. Vanhaecht, K.: The impact of Clinical Pathways on the organisation of care processes. Katholieke Universiteit Leuven, Leuven (2007).
5. Sánchez, E., Letona, J., González, R., García, M., Darpón, J., Garay, J.: A descriptive study of the implementation of the EFQM excellence model and underlying tools in the Basque Health Service. International Journal of Quality in Health Care 18(1), 58–65 (2006).
6. Stoimenova, A., Stoilova, A., Petrova, G.: ISO 9001 certification for hospitals in Bulgaria: does it help service?. Biotechnology & Biotechnological Equipment 28(2), 372–378 (2014).
7. Minkman, M., Ahaus, K., Fabbricotti, I., Nabitz, U., Huijsman, R.: A quality management model for integrated care: results of a Delphi and Concept Mapping study. International Journal of Quality in Health Care 21(1), 66–75 (2009).
8. Burwitz, M., Schlieter, H., Esswein, W.: Modeling Clinical Pathways - Design and Application of a Domain-Specific Modeling Language. In: Proceedings of the 11th International Conference on Wirtschaftsinformatik, pp. 1325-1339. Leipzig, Germany (2013).
9. Livieri, B., Cagno, P. D., Bochicchio, M.: A Bibliometric Analysis and Review on Performance Modeling Literature. Complex Systems Informatics and Modeling Quarterly 2, 56–71 (2015).
10. Richter, P., Burwitz, M., Esswein, W.: Conceptual Considerations on the Integration of Quality Indicators into Clinical Pathways. Studies in Health Technology and Informatics 228, 38-42 (2016).
11. Österle, H. *et al.*: Memorandum on design-oriented information systems research. European Journal of Information Systems 20(1), 7–10 (2011).
12. Peffers, K., Tuunanen, T., Rothenberger, M. A., Chatterjee, S.: A Design Science Research Methodology for Information Systems Research. Journal of Management Information Systems 24(3), 45–77 (2007).
13. Peffers, K., Tuunanen, T., Niehaves, B.: Design science research genres: introduction to the special issue on exemplars and criteria for applicable design science research. European Journal of Information Systems 27(2), 129–139 (2018).
14. Hevner, A. R., March, S. T., Park, J., Ram, S.: Design science in information systems research. Management Information Systems Quarterly 28(1), 75–106 (2004).
15. Mernik, M., Heering, J., Sloane, A. M.: When and How to Develop Domain-specific Languages. ACM Computing Surveys 37(4), 316–344 (2005).

16. Richter, P.: Bringing Care Quality to Life: Towards Quality Indicator-Driven Pathway Modelling for Integrated Care Networks. In: Proceedings of the 27th European Conference on Information Systems. Stockholm-Uppsala, Sweden (2019).
17. Hevner, A. R.: A Three Cycle View of Design Science Research. Scandinavian Journal of Information Systems 19(2), 87–92 (2007).
18. Braun, R., Schlieter, H.: Requirements-based development of BPMN extensions: The case of clinical pathways. Proceedings of the IEEE 1st International Workshop on the Interrelations between Requirements Engineering and Business Process Management (REBPM), pp. 39–44. (2014).
19. vom Brocke, J. et al.: Reconstructing the Giant: On the Importance of Rigour in Documenting the Literature Search Process. In: Proceedings of the 17th European Conference of Information Systems. Verona, Italy (2009).
20. McLellan, A. T., Chalk, M., Bartlett, J.: Outcomes, performance, and quality: what's the difference?. Journal of Substance Abuse Treatment 32(4), 331–340 (2007).
21. Popova, V., Sharpanskykh, A.: Formal modelling of organisational goals based on performance indicators. Data & Knowledge Engineering 70(4), 335–364 (2011).
22. Strecker, S., Frank, U., Heise, D., Kattenstroth, H.: MetricM: A modeling method in support of the reflective design and use of performance measurement systems. Information Systems and e-Business Management 10(2), 241–276 (2012).
23. Staron, M., Meding, W., Niesel, K., Abran, A.: A Key Performance Indicator Quality Model and Its Industrial Evaluation. New York: IEEE (2016).
24. Mate, A., Trujillo, J., Mylopoulos, J.: Key Performance Indicator Elicitation and Selection Through Conceptual Modelling. In: ComynWattiau, I., Tanaka, K., Song, I. Y., Yamamoto, S., Saeki, M. (eds.) Conceptual Modeling - ER 2016, vol. 9974, pp. 73–80. Cham: Springer International Publishing (2016).
25. Amor, E., Ghannouchi, S. A.: Toward an Ontology-based model of key performance indicators for business process improvement. In: IEEE/ACS 14th International Conference on Computer Systems and Applications (aiccsa), pp. 148–153. New York: IEE (2017).
26. Ghahremanlou, L., Magee, L., Thom, J. A.: Using Ontology Design Patterns to Represent Sustainability Indicator Sets. In: Dragoni, M., PovedaVillalon, M., JimenezRuiz, E. (eds.) Owl: Experiences and Directions - Reasoner Evaluation (Owled 2016), vol. 10161, pp. 70–81. Cham: Springer International Publishing (2017).
27. del-Río-Ortega, A., Resinas, M., Ruiz-Cortés, A.: Defining Process Performance Indicators: An Ontological Approach. In: Proceedings of On the Move to Meaningful Internet Systems: (OTM 2010), pp. 555–572. Crete, Greece (2010).
28. Silva, P. de A., Weigand, H.: Enterprise Monitoring Ontology. In: Proceedings of Conceptual Modeling – ER 2011, pp. 132–146. (2011).
29. Zeise, N.: Modellierung von Kennzahlensystemen mit BPMN. In: *Software Engineering*, (2010).
30. Ronaghi, F.: A modeling method for integrated performance management. In: Proceedings of the 16th International Workshop on Database and Expert Systems Applications (DEXA'05), pp. 972–976. (2005).
31. Pourshahid, A. *et al*.: Business process management with the user requirements notation. Electronic Commerce Research 9(4), 269–316 (2009).
32. Rojas, L. F. C., Jaramillo, C. M. Z.: Executable pre-conceptual schemas for representing key performance indicators. In: Proceedings of the IEEE Computing Colombian Conference (8CCC) (2013).

33. Braun, R., Schlieter, H., Burwitz, M., Esswein, W.: BPMN4CP Revised - Extending BPMN for Multiperspective Modeling of Clinical Pathways. In: Proceedings of the 49th Hawaii International Conference on System Sciences. Koloa, HI, USA (2016).
34. Jussupova-Mariethoz, Y., Probst, A.-R.: Business concepts ontology for an enterprise performance and competences monitoring. Computers in Industry 58(2), 118–129 (2007).
35. Pourshahid, A., Amyot, D., Chen, P., Weiss, M., Forster, A. J.: Business Process Monitoring and Alignment: An Approach Based on the User Requirements Notation and Business Intelligence Tools. In: WER (2007).
36. Zerbato, F., Oliboni, B., Combi, C., Campos, M., Juarez, J.: BPMN-Based Representation and Comparison of Clinical Pathways for Catheter-Related Bloodstream Infections. In: Proceedings of the International Conference on Healthcare Informatics, pp. 346–355. (2015).
37. Scheuerlein, H. *et al.*: New methods for clinical pathways-Business Process Modeling Notation (BPMN) and Tangible Business Process Modeling (t.BPM). Langenbeck's Archives of Surgery 397(5), 755–761 (2012).
38. Braun, R., Schlieter, H., Burwitz, M., Esswein, W.: BPMN4CP: Design and implementation of a BPMN extension for clinical pathways. In: Proceedings of the IEEE International Conference of Bioinformatics and Biomedicine, pp. 9–16. (2014).
39. Stroppi, L. J. R., Chiotti, O., Villarreal, P. D.: Extending BPMN 2.0: Method and Tool Support. In: Dijkman, R., Hofstetter, J., Koehler J. (eds.) Business Process Model and Notation. BPMN 2011. Lecture Notes in Business Information Processing, vol. 95. Springer, Berlin, Heidelberg.
40. Richter, P., Schlieter, H.: Understanding Patient Pathways in the Context of Integrated Health Care Services - Implications from a Scoping Review. In: Proceedings of the 14th International Conference on Wirtschaftsinformatik, pp. 997–1011. Siegen, Germany (2019).
41. Braun, R., Benedict, M., Wendler, H., Esswein, W.: Proposal for Requirements Driven Design Science Research. In: Donnellan, B., Helfert, M., Kenneally, J., VanderMeer, D., Rothenberger, M., Winter, R. (eds.): New Horizons in Design Science: Broadening the Research Agenda, pp. 135–151. Springer International Publishing (2015).
42. Frank, U.: Multi-perspective enterprise modeling: foundational concepts, prospects and future research challenges. Software & Systems Modeling 13(3), 941–962 (2014).
43. Braun, R., Esswein, W.: A Generic Framework for Modifying and Extending Enterprise Modeling Languages. In: Proceedings of the 17th International Conference on Enterprise Information Systems, Barcelona, Spain (2015).
44. Schlieter, H., Stark, J., Burwitz, M., Braun, R.: Terminology for Evolving Design Artifacts. In: Proceedings of the 14th International Conference on Wirtschaftsinformatik, Siegen, Germany (2019).
45. Mainz, J.: Defining and classifying clinical indicators for quality improvement. International Journal for Quality in Health Care 15(6), 523–530 (2003).
46. Happel, H. J., Seedorf, S.: Applications of Ontologies in Software Engineering. In: Proceedings of 2nd International Workshop on Semantic Web Enabled Software Engineering (SWESE 2006) held at the 5th International Semantic Web Conference (ISWC) 2006.
47. Uschold, M.: Building Ontologies: Towards a Unified Methodology. In: Proceedings of the 16th Annual Conference of the British Computer Society Specialist Group on Expert Systems (1996).
48. W3C: OWL 2 Web Ontology Language - Document Overview; W3C Recommendation. (2012), http://www.w3.org/TR/owl2-overview, last accessed 2018/11/19.
49. Donabedian, A.: The quality of care: How can it be assessed?. Journal of the American Medical Association 260(12), 1743–1748 (1988).

50. Reiter, A. *et al.*: QUALIFY: Ein Instrument zur Bewertung von Qualitätsindikatoren, Zeitschrift für ärztliche Fortbildung und Qualität im Gesundheitswesen. German Journal for Quality in Health Care 101(10), 683–688 (2008).
51. Woolf, S. H., Grol, R., Hutchinson, A., Eccles, M., Grimshaw, J.: Potential benefits, limitations, and harms of clinical guidelines. British Medical Journal 318(7182), 527–530 (1999).
52. Frank, U., Heise, D., Kattenstroth, H., Schauer, H.: Designing and Utilising Business Indicator Systems within Enterprise Models-Outline of a Method. In: Proceedings of Modellierung betrieblicher Informationssysteme (MobIS), Saarbrücken, Germany (2008).
53. Khare, S. R. *et al.*: Quality indicators in the management of bladder cancer: A modified Delphi study. Urologic Oncology: Seminars and Original Investig. 35(6), 328–334 (2017).
54. Ludt, S. *et al.*: Evaluating the quality of colorectal cancer care across the interface of healthcare sectors. PLoS One 8(5), e60947 (2013).
55. Object Management Group: OMG BPMN Version 2.0. (2011), https://www.omg.org/spec/BPMN/2.0/PDF/, last accessed 2019/07/01.
56. Busch, M. A., Kuhnert, R.: 12-Month prevalence of stroke or chronic consequences of stroke in Germany. Journal of Health Monitoring 2(1), 64-69 (2017).
57. Barlinn, J. *et al.*: Koordinierte Schlaganfallnachsorge durch Case Management auf der Basis eines standardisierten Behandlungspfades. Nervenarzt 87(8), 860–869 (2016).
58. SOS-NET. Das Neurovaskuläre Netzwerk Ostsachsen und Südbrandenburg: SOS-Care - Hilfe nach Schlaganfall. Akuttherapie bis Nachsorge, https://www.sos-net.de/das-netzwerk/struktur/sos-care/data/sos-care_behandlungspfad.pdf, last accessed 2019/02/25.
59. Morgan, D. L.: Focus Groups. Annual Review of Sociology 22(1), 129–152 (1996).