Functional Interdependencies between Quality Techniques reverting to Meta Models

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Abstract. Considering the digitalization of the economy, process-oriented quality management (PQM) has increasingly been gaining attention. In the course of a PQM project, quality techniques are applied to elicit employees' process knowledge and transform it into solutions to overcome process weaknesses. However, quality techniques may support each other during application or produce contradictory results, depending on the so-called "functional interdependencies (FIs)" between them. Little understanding exists of how such FIs can be properly identified, which is a prerequisite to exploit valuable synergies between quality techniques. To uncover the corresponding interdependencies, we revert to meta models in this paper, which allow to precisely describe a technique's functionality. Generally valid indicators on a meta model level are derived to unveil the existence of FIs.

Keywords: Process knowledge, meta model, quality technique.

1 Introduction

Many enterprises go through profound transformations these days triggered by the increasing digitalization of the economy [1]. Against this background, the improvement or redesign of business processes, in the context of process-oriented quality management (PQM) projects, is an important task [2], [3]. Only if the business processes are aligned with the expectations of internal and external customers, the purposeful definition of business services and the introduction of IT systems to beneficially support a company's value creation are possible [4].

However, the execution of PQM projects is challenging and many initiatives fall short of expectations [2], [5]. The success of PQM projects largely depends on the participation of employees from all cooperating partners in an inter-organizational business network and the goal-oriented elicitation [6] of their process knowledge to derive opportunities for process improvement (cf. [7]).

In this respect, the PQM discipline has brought forth a variety of methods (e.g., Six Sigma) that can be applied to improve or redesign business processes [3]. However, many employees do not have the time to become acquainted with such holistic methods (cf. [8]). Further, their application is increasingly perceived as too resource-consuming for projects with a limited scope (cf. [9]). Thus, enterprises often prefer a manageable

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and limited set of quality techniques (e.g., Ishikawa Diagram, etc.) instead of extensive quality management methods (cf. [9]), even though the selection of adequate quality techniques is time-consuming (cf. [10]). Further, there are "functional interdependencies (FIs)" between quality techniques, i.e., they may complement each other during application or pursue diverging goals, e.g., cost-orientation vs. customer-orientation [11]. The knowledge of these interdependencies is decisive to understand which quality techniques may be purposefully combined in a project. For example, the CTQ/CTB-Matrix (Critical-to-Quality/Critical-to-Business-Matrix) helps to define quality goals, which are the base for developing Key Performance Indicators (KPIs) to measure process performance, e.g., via the Measurement-Matrix (cf. [12]). However, little understanding exists on such fertile FIs between quality techniques in practice and literature (e.g., [8], [11]). This is a drawback because such knowledge is crucial for method engineers to develop enterprise-adapted PQM methods and the corresponding software support (e.g., [13]). Therefore, our research aims at finding indicators that point to valuable FIs between quality techniques. For that purpose, we revert to meta models (cf. [14]). Meta models are suitable to capture the core concepts of quality techniques and to explicate their functionalities to transform particular types of input information (e.g., customer requirements) to output information (e.g., project goals) (cf. [10]). Accordingly, meta models allow to describe the nature of quality techniques and to derive indicators as to whether quality techniques can be beneficially combined in the course of a project or not. Thus, the following research question (RQ) is posed: *How can indicators of functional interdependencies (FIs) between quality techniques be purposefully identified on a meta model level and what FIs do typically exist between quality techniques of a representative set?*

Based on the findings, quality techniques with beneficial synergies can be precisely identified by reverting to meta models. Individual PQM approaches and corresponding software tools may then be designed.

This paper is structured as follows: first, foundations of quality techniques and meta models are explained. Afterwards, the research procedure is described and the design of meta models is explicated. In the main part of the paper, the indicators of FIs are derived. Afterwards, their benefits are presented. The paper concludes with an outlook.

2 Foundations

2.1 Quality Techniques and Functional Interdependencies (FIs)

A quality technique is a guideline for the creation of results in PQM projects (cf. [12], [15]). In that context, a quality technique supports the elicitation of employees' process knowledge (cf. [6]), derives some type of input information that is transformed to output information and thus (partial) results (cf. [10]). This perception is similar to the definition of a "technique" in IS method engineering (cf. [15]). An example for a quality technique is the Ishikawa Diagram (Fishbone Diagram), which serves the classification of problem causes for insufficient process performance (cf. [16]). According to *Bruhn* [11], functional, temporal as well as hierarchical interdependencies exist between quality techniques. Temporal interdependencies refer to the chronological sequencing of quality techniques in projects [11]. Hierarchical interdependencies differentiate whether a quality technique pursues strategic (e.g., definition of business objectives) or operational goals (e.g., definition of KPIs) [11]. Regarding the identification of valuable synergies between quality techniques, however, FIs are of interest (cf. [11]). FIs analyze the conjoint application of quality techniques considering their individual functioning, i.e., the way each technique converts input to output information, as well as the nature of the input and output itself. By taking this detailed perspective on how information is processed, it becomes obvious whether techniques may complement each other, produce identical outcomes or even require their mutual application (cf. [11]). Considering this, FIs are suitable to describe the interplay between quality techniques in the course of a project, and different types can be distinguished (Table 1).

Table 1. Types of FIs

Interdependency type (derived from [11])	Examples
Conditional: A quality technique requires other techniques to be applied in a project in addition.	Creating a Data Collection Plan requires the definition of KPIs in advance, e.g., by means of the Measurement-Matrix (e.g., [12]).
Complementary: Two or more quality techniques support each other during application.	The Failure-Mode-and-Effects-Analysis (FMEA) is purposefully complemented by the KANO Model, as the severity of potential "defects" during process execution can be precisely quantified that way (e.g., [12], [32]).
Substituting: The application of two or more quality techniques leads to identical types of output information.	The CTQ/CTB-Matrix as well as the Driver Tree can be used for specifying process-related quality goals (CTQ/CTB factors) for instance (e.g., [12], [17]).
Rivalling: The application of particular quality techniques produces results that are contradictory to one another.	Applying the FMEA and the Value-Stream-Map (VSM) may generate contradictory suggestions on the should-be process design (e.g., [12]).
Note: *Bruhn* [11] also mentions "indifferent interdependencies" indicating that the application of certain techniques has no mutual influence on one another. However, this type is not further considered because the corresponding techniques are not interrelated in terms of above described specification.	

Against this background, the beneficial synergies between quality techniques are primarily determined by conditional and complementary interdependencies. In case of a conditional interdependency, the application of a quality technique produces output information (e.g., KPIs) that is taken up and further processed as input information by another technique. In case of a complementary interdependency, the combined usage of certain techniques leads to results that are more precise in nature (e.g., KPIs aligned with project goals), while inherent drawbacks of a quality technique can be mitigated at the same time (see Table 1).

2.2 Meta Models and Process Knowledge in PQM Projects

Meta modeling is a widely-established discipline in the field of model-driven design and development of IS and software, respectively [14], [18]. In this regards, the behavior of software or an IT system is specified via conceptual models [18]. The meta model defines the concepts that can be expressed in such conceptual models designed with the help of a modeling language, i.e., what modeling elements may be applied [14]. Hence, a conceptual model is created as an instance of the corresponding meta model [13]. In the research at hand, we use meta models to describe the constituting elements (core concepts) of a quality technique as well as the type of input information (e.g., project goal) that is transformed to a particular type of output information accordingly (e.g., improvement idea). In so doing, an unambiguous description of a technique's functionality is achieved. Applying quality techniques in the course of projects results in diagrams, tables or sketches (cf. [19]), allowing to capture emerging process knowledge as conceptual models, which are specified by meta models accordingly. Thus, the documented result (e.g., conceptual model) received by applying a particular technique represents an instance of the corresponding meta model. For the design of meta models, we generally revert to UML class diagrams, which have proven suitable for creating meta models in research and practice alike (e.g., [20]).

Process knowledge plays a decisive role in light of organizational learning (cf. [7], [21], [22]). In this regards, "learning" specifies a firm's efforts to "retain and improve competitiveness, productivity, and innovativeness in uncertain technological and market circumstances" [22, p. 378]. Process knowledge is a multi-dimensional construct, comprising knowledge about the process structure, the training and management efforts required for achieving desired outcomes or knowledge directly linked to process execution (e.g., factors impacting efficiency) amongst others [21]. The challenge in PQM projects is to elicit employees' tacit process knowledge and convert it into explicit knowledge (cf. [23]) that can be used to derive opportunities for process improvement. Quality techniques support this conversion because employees' ideas, which are based on their individual process knowledge, are used as input to be transformed into results visualized as diagrams or conceptual models for instance (e.g., [19]). Meta models are suitable to capture the core concepts of quality techniques and to explain how the aforementioned conversion is performed. Further, the combination of discrete pieces of explicit knowledge [23] to come to improvement suggestions is fostered by techniques since the information processed may stem from diverse sources such as reports or IT-systems (e.g., [12]). The research contributes to developing means to uncover FIs between quality techniques and thus to support the purposive externalization and use of process knowledge to improve process performance.

3 Procedure of the Research

The study at hand is part of a larger Design Science (DS) project (cf. [24]), which aims at the development of a modeling tool to document, communicate and analyze knowledge on process weaknesses and process improvement opportunities. A central requirement on the tool is to support users in the selection and combined application of quality techniques based on FIs. For the implementation, the meta modeling platform ADOxx *(www.adoxx.org)* will be reverted to, which has been successfully applied in industry for more than 15 years now [13]. However, prior to the implementation, indicators for FIs on a meta model level are to be identified that allow to unambiguously decide whether quality techniques complement one another or not. Our paper deals with the identification of corresponding indicators and follows a four-step procedure building on the principles of inductive logic (cf. [25]). Thus, based on a sample set of quality techniques, the corresponding meta models are analyzed to derive generally valid indicators explaining the occurrence of FIs (see Fig. 1).

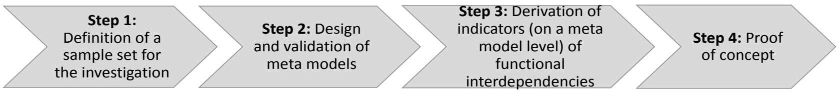

Figure 1. Procedure for identifying indicators

Considering the huge number of existing quality techniques (e.g., [12]), a representative set (sample set) is selected as a subject of investigation in a first step **(step 1)**. The techniques of our set along with the knowledge of the interdependencies between them represented the "instances" of the "phenomenon" [25] investigated. Afterwards, meta models for the quality techniques are generated and validated (**step 2**). Indicators explaining the occurrence of FIs between techniques are derived in **step 3**. Their applicability is demonstrated in **step 4** reverting to a prototypical realization.

4 Sample Set, Design and Validation of the Meta Models

4.1 Sample Set of the Investigation (Step 1)

On the one hand, the toolbox of quality techniques of a German automotive bank was reverted to for this research, comprising 30 techniques in total. This bank has a long tradition regarding the adaption and usage of methods for PQM (e.g., Lean Six Sigma, Total Quality Management, GE Work-Out) making it a suitable candidate for the investigation. Further, the author of this study participated in various PQM projects at the bank, taking the role of a "team member", over a period of three years. That way, profound insights into the beneficial combination of quality techniques were gained.

On the other hand, publications explicating FIs between quality techniques, e.g., in the form of an efficient further processing of results (conditional interdependency), were reverted to that were derived from a previously conducted literature review on the integration of quality methods and techniques (cf. [26]). Considering these findings, techniques not considered by the toolbox of the automotive bank were added to our sample set for the study, comprising 34 techniques in the end (see Appendix).

Next, the FIs between these quality techniques were specified according to the types as introduced in Table 1. That way, a complete overview of the FIs for the sample set emerged. For that purpose, the descriptions in literature were reverted to as well as the insights gained by actively participating in projects at the automotive bank. The Appendix exemplifies the results of this process for the CTQ/CTB-Matrix or the Driver Tree (cf. [17]) amongst others. The derivation of FIs was performed by two researchers, who consolidated the results afterwards. Further, the findings on FIs were validated in discussions with leaders of PQM initiatives at the automotive bank.

4.2 Design and Validation of the Meta Models (Step 2)

The subsequent design of meta models for the quality techniques of the set was done as follows: first, the core concepts of a quality technique were identified by analyzing its functioning. For example, the CTQ/CTB-Matrix supports the user in defining "Critical-to-Quality (CTQ)" and "Critical-to-Business (CTB)" factors based on customer (Voice of the Customer – VOC) and employee requirements (Voice of the Business – VOB), which are classified into core statements correspondingly (cf. [12]). Then, we considered the relations between the core concepts. For instance, each VOC or VOB statement in a CTQ/CTB-Matrix is assigned to one core statement at least. The core concepts and the relations were transformed into corresponding classes and relations of a meta model (MM) afterwards. Finally, the cardinalities of the meta model were to be set. Fig. 2 shows the meta model for the CTQ/CTB-Matrix.

A decisive aspect concerns the validation of meta models. In this context, formalization is an established means of uncovering inconsistencies, syntactical errors and incompleteness of the meta model design [27]. A generally valid formalization approach for domain-independent meta models is FDMM (Formalism for Describing ADOxx Meta Models and Models) (cf. [28]). Due to its general applicability across domains, differentiating FDMM from formalization approaches such as EMOF or KM3, which were developed for specifying software architectures in particular, it was chosen for the study at hand. All meta models established for the quality techniques of our sample set were formalized via FDMM making it possible to check them for inconsistencies (e.g., wrong cardinalities), syntactical errors (e.g., in case the meta model of the CTQ/CTB-Matrix would allow to connect instances of the class "VOC statement" to instances of the class "CTQ factor") and incompleteness (e.g., missing cardinalities). Generally, meta models in FDMM are represented as a tuple of a set of object types (O_i^T), data types (D_i^T) and attributes (A_j) [28], which is exemplified for the CTQ/CTB-Matrix in equation (1) (see [28] for details on FDMM).

$$\mathrm{MT}_{CTQ/CTB-Matrix} = \langle O^T_{CTQ/CTB-Matrix}, D^T_{CTQ/CTB-Matrix}, A_{CTQ/CTB-Matrix} \rangle \quad (1)$$

Further, the meta models were discussed with four researchers renowned for their expertise in the field of meta modeling and two practitioners who had a consultancy industry background and had been heavily involved in PQM projects for several years. The discussion partners were not involved in the development of the meta models and thus unbiased. Their feedback was gathered and modifications were made, if necessary. After these steps, the validity of the meta models was seen as sufficiently confirmed.

5 Indicators of Functional Interdependencies (Step 3)

Based on the meta models created in the prior step *(step 2)* and the FIs between the techniques of our sample set *(step 1)*, indicators of FIs on a meta model level were derived. Therefore, for each type of FI (see Table 1), we specified the synergies between the corresponding quality techniques of our sample set more profoundly and, if different forms of synergies could be distinguished, we defined subtypes of a FI *(step 3.1)*. Afterwards, each subtype (or form of synergy) was analyzed in detail by reverting to the meta models of the quality techniques, which allowed for explaining the FI by means of the meta models' classes *(step 3.2)*. Based on these findings, indicators on a meta model level could be derived characterizing each type of FI *(step 3.3)*. To reduce complexity, the indicators analyze quality techniques following a binary strategy (cf. [29]), i.e., it is determined whether two particular quality techniques considered hold an interdependency or not. The three steps were performed by two researchers – to reduce subjectivity – with the results being discussed and consolidated afterwards.

5.1 Conditional Interdependencies

Conditional interdependencies exist in case two or more quality techniques presuppose their mutual application (cf. [11]).

Step 3.1: In our sample set, conditional interdependencies between techniques were characterized by one particular form of synergy. In this respect, a technique produced a certain type of output information, which represented a specific type of input information for another technique simultaneously. For instance, the CTQ/CTB-Matrix provides the "CTQ" and "CTB factors" as types of output information (cf. [12]). These are referred to by the Measurement-Matrix for the definition of KPIs (cf. [12]). The use of the Measurement-Matrix is thus bound to techniques enabling the derivation of CTQ and CTB factors, e.g., the CTQ/CTB-Matrix (a more comprehensive example can be found at: *http://tinyurl.com/zbctxt8*).

Step 3.2: On the level of meta models (MM), the aforementioned synergy between quality techniques is visually exemplified in Fig. 2 reverting to the CTQ/CTB-Matrix and the Measurement-Matrix. The dotted line highlights the common classes across the meta models. It becomes obvious that the classes "Critical-to-Quality (CTQ) factor" and "Critical-to-Business (CTB) factor" can be found in both meta models, while they represent output information types (colored "black") in MM_1 (meta model of the CTQ/CTB-Matrix) and input information types (colored "grey") in MM_2 (meta model of the Measurement-Matrix). In this regards, the CTQ or CTB factors captured by an instance of MM_1 (CTQ/CTB-Matrix) serve as input information for an instance of MM_2 (Measurement-Matrix). This kind of relation between classes was similarly observed for all other techniques of the sample set regarding conditional interdependencies.

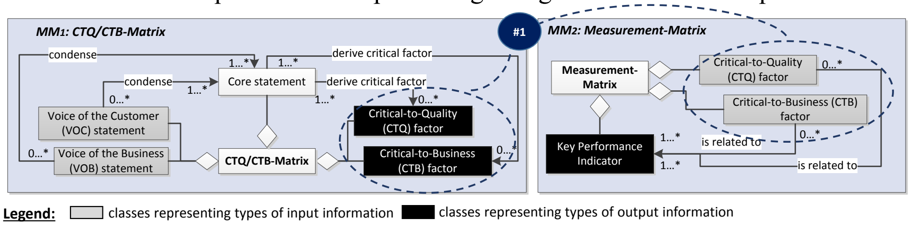

Figure 2. Example for conditional interdependencies (indicator #1)

Step 3.3: Based on these insights, the following indicator pointing to a conditional interdependency between two quality techniques, on a meta model level, was derived:

Indicator #1: A conditional interdependency between two *quality techniques i* and *j* is given, if the corresponding meta models (MM_i and MM_j) share identical classes while these represent types of output information of *quality technique i* in MM_i and types of input information of *quality technique j* in MM_j (or vice versa).[1] The results of the *technique i* thus represent decisive input information for *quality technique j* (or vice versa).

[1] In the following, *i* and *j* are continuous indices with the following assumptions: 1) $i \in \mathbb{N}$, 2) $j \in \mathbb{N}$ and 3) $i \neq j$. *Technique i* or *j* are thus representatives for any kind of quality technique.

5.2 Complementary Interdependencies

Generally, complementary interdependencies are observed for quality techniques that support each other during application (cf. [11]). Detailed examples of each subtype as described in the following can be found at: *http://tinyurl.com/zbctxt8*.

Step 3.1: In total, we identified four different subtypes (forms of synergy) of complementary interdependencies (A to D) between techniques based on our set.

Subtype A: The first subtype of complementary interdependencies builds on the use of common concepts, by different quality techniques, to transform input information to output information. For instance, both the KANO Model and the Driver Tree use the KANO categories "basic requirements", "breakthrough customer needs" and "core competitive requirements" [30], [31] to enable the prioritization of customer and employee requirements on process execution. The KANO Model prioritizes process-related VOC and VOB statements and its application thus clarifies which requirements are of particular interest to process stakeholders. Based on these insights, KPIs can be developed (Driver Tree) considering requirements with a high priority in special [17].

Subtype B: A second subtype of complementary interdependencies is given in case quality techniques contain core concepts that pursue a common purpose of transforming input information to output information (e.g., analysis, classification, comparison of information, etc.) [10], but are not identical per se. For example, the FMEA may be applied to identify potential "defects" during process execution and to judge their severity [12]. A classification of customer or employee requirements according to the KANO categories (cf. [30]) provides hints as to which potential "defects" will most probably affect customer satisfaction in a negative way [32]. Thus, a complementary interdependency between the KANO Model and the FMEA exists.

Subtype C: Further, a complementary interdependency exists, if the results gained by applying a particular quality technique help to specify the input information processed by another technique more precisely. However, the results produced by the first technique are not a mandatory prerequisite for applying the second one, which demarcates *subtype C* from a conditional interdependency. In a project for instance, the results generated via the CTQ/CTB-Matrix (CTQ and CTB factors) may trigger the purposeful search for causes of insufficient process performance reverting to the Ishikawa Diagram (cf. [16]). However, the process weaknesses to be investigated by means of the Ishikawa Diagram do not necessarily have to be derived from the CTQ or CTB factors but can also be defined "ad-hoc" in the course of a project (cf. [16]).

Subtype D: Yet another subtype addresses the usage of a quality technique to further refine the output information generated by another technique. An example would be the combined use of the Affinity Diagram and the Payoff-Matrix (cf. [12], [33]). By using the Affinity Diagram, suggestions for process improvement are purposefully classified (e.g., cost-oriented solutions, IT-related solutions) and this classification can be refined by a prioritization of the ideas via the Payoff-Matrix (e.g., Quick Win).

Step 3.2: Fig. 3 exemplifies the subtypes of complementary interdependencies on a meta model level. Considering the *subtype A*, the meta models of techniques (e.g., KANO Model and Driver Tree) share identical classes. This is indicated by the dotted line "#2", hinting at the common class "KANO category" in MM_1 and MM_2.

Concerning the *subtype B* on a meta model level, a relationship exists between core concepts of different techniques (e.g., KANO Model and FMEA), which are represented by dissimilar classes, e.g., "KANO category" and "severity number" (dotted line "#3"). However, the core concepts follow a common purpose (cf. [10]) of transforming input to output information. Regarding *subtype C*, the meta model of a quality technique has one or more classes representing types of output information that are related to classes representing input information types of another meta model. In so doing, the classes representing types of input and output information are not identical as exemplified for the CTQ/CTB-Matrix and the Ishikawa Diagram (see MM_4 and MM_5 – dotted line "#4"). Finally *(subtype D)*, core concepts of quality techniques supporting the transformation of input information to output information, e.g., by prioritizing or categorizing information, may cause a complementary interdependency. Such concepts, e.g., "payoff category", are explicitly represented by separate classes in the meta models and implicitly become evident in the labels of the classes representing types of output information. Further, identical classes representing types of input information are given (e.g., improvement idea). Fig. 3 and the dotted lines "#5" demonstrate this particular form of synergy (MM_6 and MM_7).

Step 3.3: Based on these findings, four indicators of complementary interdependencies on a meta model level, numbered #2 to #5, were derived:

Table 2. Indicators of complementary interdependencies on a meta model level

Indicator #2 *(subtype A):* Two *quality techniques i and j* have a complementary interdependency in case their corresponding meta models (MM_i and MM_j) share one or more identical classes representing common core concepts serving a particular purpose (e.g., prioritization) during the transformation of input to output information. The affected classes represent neither output nor input information types on a meta model level.
Indicator #3 *(subtype B):* Two *quality techniques i and j* have a complementary interdependency if the corresponding meta models (MM_i and MM_j) contain classes representing concepts serving a common purpose during the transformation of input to output information in a particular project (e.g., classification of information) but are not identical per se. In that context, the output information created by applying *technique i* creates knowledge that facilitates the use of *technique j*.
Indicator #4 *(subtype C):* Two *quality techniques i and j* with the corresponding meta models (MM_i and MM_j) have a complementary interdependency, if the output information represented by classes in MM_i on a type level facilitates the specification of input information for *technique j*, represented by classes indicating types of input information in MM_j. However, the output information produced by *quality technique i* is no mandatory prerequisite for applying *quality technique j* in a project.
Indicator #5 *(subtype D):* Two *quality techniques i and j* have a complementary interdependency, if the corresponding meta models (MM_i and MM_j) contain classes representing particular concepts to transform input to output information, whereas the general purpose of the concepts (e.g., prioritization, classification) varies for the *techniques i and j*. The nature of these concepts becomes evident by the classes representing types of output information in the meta models MM_i and MM_j. The combined use of the techniques allows to reflect results from complementary perspectives (e.g., classified and prioritized improvement ideas). MM_i and MM_j share identical classes for representing types of input information.

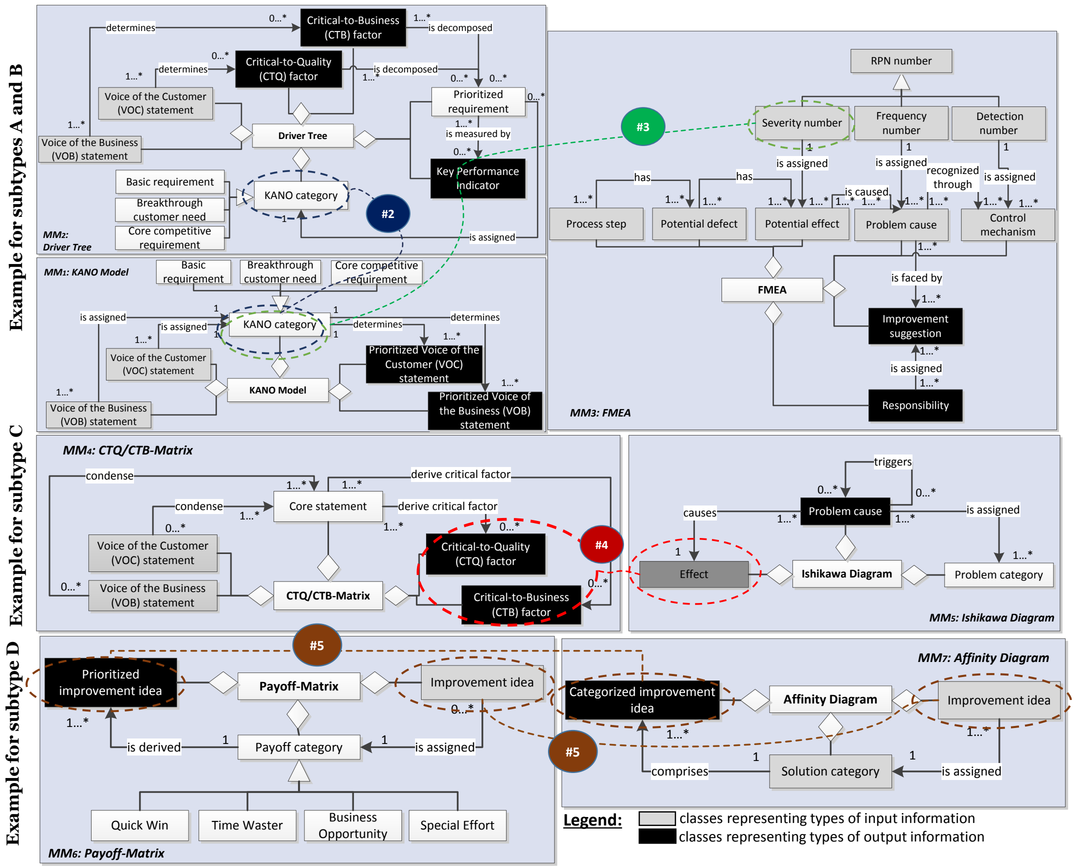

Figure 3. Example for complementary interdependencies (indicators #2 to #5)

5.3 Summary of Substituting and Rivalling Interdependencies

As mentioned, beneficial synergies between quality techniques are primarily determined by conditional and complementary interdependencies. However, further types exist (see Table 1) for which we will briefly summarize the results.

Substituting interdependencies are given in case two or more quality techniques follow the same purpose and produce an identical type of output information (e.g., improvement ideas) (cf. [11]). Substituting interdependencies were given for those quality techniques in our sample that shared a common purpose (e.g., identification of problem causes) and aimed at the production of identical types of output information. An example would be the interdependency between the Measurement-Matrix and the Driver Tree (cf. [12], [17]), with both techniques sharing the purpose of defining KPIs. Accordingly, on a meta model level, substituting interdependencies become obvious by common output information type classes of the techniques. The classes representing types of input information may be different though because the information processed by the techniques may vary. The following indicator was thus derived:

Indicator #6: Two *quality techniques i* and *j* have a substituting interdependency in case the corresponding meta models (MM_i and MM_j) have identical classes representing types of output information, with the *techniques i and j* sharing a common purpose within a project. The classes representing types of input information may be identical or different from one another.

Rivalling interdependencies exist, in case the combined application of quality techniques might lead to results that are contradictory to one another (cf. [11]). On a meta model level, rivalling interdependencies cannot be identified unambiguously. Generally, the types of output information generated are decisive, which is similar to substituting interdependencies. Thus, there is the danger of producing identical types of output information (e.g., improvement ideas), which, however, may contradict each other (cost-oriented vs. customer-oriented improvement ideas) (cf. [11]). Nevertheless, an unambiguous characterization by means of classes of a meta model cannot be done and thus no indicators were derived.

In summary, six indicators were defined pointing to FIs on a meta model level allowing to identify synergies between techniques. No further indicators or subtypes of a FI, allowing to specify the interplay between techniques in a generally valid manner, were found by the researchers performing steps 3.1 to 3.3. More, any interplay between quality techniques in the sample set could be expressed by the indicators as introduced.

6 Proof of Concept (Step 4)

The applicability as well as the usability of the indicators were to be validated. For that purpose, we created a prototype of the aforementioned modeling tool (see section 3) building on FIs in a first step. The prototype served as a proof of concept (cf. [24]) evidencing that the concept of indicators of FIs as well as the corresponding meta models could be realized in the form of an executable software tool. This was important considering the feasibility of the aforementioned DS project (see section 3).

In a second step, a usability study was conducted, reverting to the prototype and two case studies, to prove the beneficial impact of FIs between quality techniques on the development of process improvement suggestions.

Our prototype contains the 14 quality techniques of the sample set that were most frequently applied by the said automotive bank *(tool download as an MS Windows installation package: http://tinyurl.com/zc9rpnp)*. The quality techniques were realized as model types based on the corresponding meta models (see section 4.2). The receipt of an executable prototype demonstrated the validity of these meta models once again in terms of consistency, syntactical correctness and completeness. The model types could be used by project participants straight away for creating results and documenting outcomes in PQM initiatives. The indicators, which specify beneficial interdependencies between the techniques, enabled the development of algorithms that either allow the user to automatically transfer results between particular quality techniques (conditional interdependencies) or to specify and refine the outcomes of a technique by using complementary techniques in addition (complementary interdependencies). In the prototype, conditional interdependencies are automatically exploited whereas complementary interdependencies can be drawn upon optionally. Fig. 4 gives an example for conditional interdependencies. The model on the left shows an excerpt of the CTQ/CTB-Matrix designed as a model type, codifying customer statements (VOC statements) stemming from a project to improve the document management process at the aforementioned automotive bank. From these, the CTQ factor *"reduction of cycle time (...) to two working days"* is derived. Because of a conditional interdependency (indicator #1), the CTQ factor as defined is automatically referenced by the Measurement-Matrix straight away without the data having to be re-entered from the user side. Accordingly, KPIs such as the "overall cycle time" or the "number of errors in archiving" are specified to measure the goal achievement.

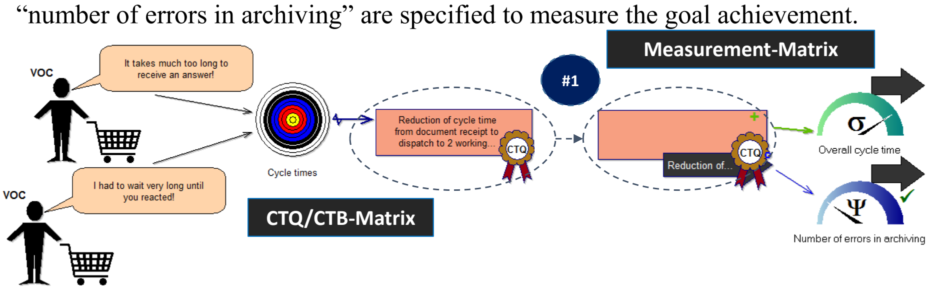

Figure 4. Example from the prototype

An example of a complementary interdependency would be the use of the "payoff categories" in the Affinity Diagram (see the following link for a detailed example: *http://tinyurl.com/zbctxt8*). As an additional proof of the beneficial impact of FIs in terms of project conduction, a usability study of the prototype by means of the SUMI questionnaire (Software Usability Measurement Inventory) *(http://sumi.ucc.ie/)* was performed with 32 Master degree students of a German university. The SUMI questionnaire is a well-established standard for measuring software usability and builds on the five dimensions "efficiency", "affect", "helpfulness", "control", and "learnability" [34]. The intention was to investigate whether users perceived the synergetic use of quality techniques (with complementary and conditional interdependencies) as beneficial for developing process improvement ideas or not. For that purpose, two case studies were drawn upon. The first case study was based on a real life project conducted in cooperation with the mentioned automotive bank to improve the end-of-terms process. The second case study described a fictitious check-in process at an airport. 17 students worked on the first case study and 15 dealt with the second one. Based on given problem statements, the students were supposed to develop suggestions to overcome process weaknesses using the prototype *(material download and detailed results of the study: http://tinyurl.com/zb5r5lk)*. Afterwards, they were asked to fill out the SUMI questionnaire, and an aggregated usability rating was received across both case studies. Taking into account two case studies enabled a more nuanced assessment of usability, because the results were not imprinted by one particular scenario only. In our context, the ratings for the dimension "efficiency" were of particular interest, because it captures the degree as to which the software supports a user in conducting tasks (cf. [34]). Considering the reference score of "50" as proposed by the SUMI reference database (cf. [34]), the users felt well supported by the prototype in deriving improvement suggestions, as indicated by the efficiency ratings *(mean: 51,56; median: 53)*. Making use of the references between the quality techniques, due to beneficial FIs, definitely had a huge share in that, which becomes evident by the SUMI item consensual analysis [34] and the user comments. Users highly appreciated the tool's functionality to easily move from one task to another and, hence, to further refine or process results by using beneficial combinations of techniques (see also: *http://tinyurl.com/zb5r5lk*).

7 Discussion

First, referring to our RQ, it was shown that meta modeling allows researchers to precisely assess the essence of quality techniques and to identify FIs on the base of indicators, respectively. The indicators foster knowledge creation regarding those quality techniques that may be beneficially combined in a project and, thus, help to develop methodological support for quality initiatives. Hence, synergetic quality techniques can be logically arranged and integrated by method or software engineers to come to an enterprise-adapted PQM method (cf. [13], [35]) that meets a firm's specific needs (cf. [9]). In this respect, the combined use of synergetic quality techniques backs the goal-oriented elicitation of process knowledge and its transformation into improvement opportunities, with process knowledge being a key factor to influencing project success (cf. [7]). Considering the toolbox of the automotive bank, which was part of our sample set, we found all FIs as introduced in Table 1 with the corresponding subtypes, which we were able to delineate in this study. However, especially conditional and complementary interdependencies were encountered particularly often.

Second, software support for practitioners for systematically eliciting, documenting and communicating results in the course of a PQM project – even across company borders – can be established as indicated in sections 3 and 6. On that base, project data may be further analyzed by means of reports promoting the querying and capitalization of process-related knowledge generated in PQM projects (cf. [36]). In the paper at hand, the indicators on a meta model level, specifying beneficial FIs, enabled to create algorithms for the automated transfer of project data between quality techniques to be further processed (see section 6).

However, as a restriction, meta modeling requires particular skills and knowledge from the user side. Thus, identifying and exploiting FIs on the base of indicators on a meta model level is an approach, which is most likely interesting for method or software engineers but probably only of little interest to employees who are less of an expert.

8 Conclusion

This research dealt with the question of how to purposefully identify FIs between quality techniques by reverting to their meta models. We learned that meta models, widely established in IS research, are helpful to explicate the functionality of quality techniques and to generally explain the occurrence of FIs. However, there are limitations to this study: the set of techniques analyzed for the derivation of indicators was restricted to the toolbox applied at an automotive bank and to those techniques derived from literature. Thus, further subtypes of FIs may potentially exist, building on fruitful combinations of techniques neither literature nor practice is yet aware of.

Therefore, further research to consider additional techniques is required, although our sample set comprises techniques that are widespread in practice and frequently used in PQM projects across different industries (cf. [10], [12]), which contributes to the general validity of the results. Generally, subjectivity cannot be entirely excluded considering the derivation of FIs as well as the definition of indicators. However, by the discussion between researchers and the consolidation of results, subjective imprints were to be minimized as far as possible. Nonetheless, further indicators for subtypes of FIs not unveiled by this research may occur. Yet, the indicators proved suitable to fully explain the interplay between techniques in the sample set at hand. In future, the indicators will be used for developing guidelines for practitioners explicating which techniques can be beneficially used in combination. More, the prototype will be revised considering practitioners' feedback and designed to run on different platforms.

Appendix

The following list presents the sample set of the quality techniques of our study. Due to page restrictions, the FIs are only exemplified for four techniques. More details on the techniques and interdependencies can be found at: *http://tinyurl.com/zbctxt8*

Technique	FI with other techniques (no.)	Technique	FI with other techniques (no.)
1) CTQ/CTB-Matrix	*CoI:* supported by no. 3, 5	18) Brainwriting	*CoI:* supports no. 16; supported by no. 9, 10, 11, 12, 13, 14, 15; *SI:* substitute for no. 17, 19, 21, 22
2) Driver Tree	*CoI:* supported by no.3; *SI:* substitute for no. 7	19) RAMMPP-Matrix	*CoI:* supports no. 16; supported by no. 9, 10, 11, 12, 13, 14, 15; *SI:* substitute for no. 17, 18, 21, 22
3) KANO Model, 4) Process Map, **5) SIPOC Diagram**, 6) Project Charter, **7) Measurement-Matrix, 8) Data Collection Plan, 9) Descriptive Statistics, 10) As-Is Process Modeling, 11) Value-Stream-Map, 12) Ishikawa Diagram**, 13) Relation Diagram, **14) FMEA**, 15) Time Analysis, **16) Should-Be Process Modeling, 17) Brainstorming**		**20) Affinity Diagram**, 21) SCAMPER Technique, 22) Lean for Service, 23) Place Cipher Approach, 24) Prioritization-Matrix, 25) Cost-Benefit Analysis, 26) Payoff-Matrix, 27) Town Meeting Worksheet, 28) Roll Out Plan, **29) Process Documentation, 30) Reaction Plan**, 31) QFD, 32) SERVQUAL, 33) Service Quality Map, 34) Design of Experiments	
Techniques no. 1 to 30: quality techniques derived from the toolbox at the automotive bank; no. 31 to 34: derived from literature; techniques considered by the prototype are printed in "bold". **Legend:** *CoI:* complementary interdependencies; *SI:* substituting interdependencies; *CdI:* conditional interdependencies; *RI:* rivalling interdependencies			

References

1. CapGemini, www.de.capgemini.com/it-trends-studie (Accessed: 17.08.2016)
2. Harmon, P.: The State of Business Process Management – 2016. BPTrends (2016)
3. Stracke, C.: Process-oriented quality management. In: Ehlers U-D, Pawlowski JM (eds.) Handbook on Quality and Standardisation in E-Learning, pp 79-96. Springer (2006)
4. Harmon, P.: Business Process Change. 2nd edition. Elsevier LTD, Oxford (2007)
5. Chakravorty, S.S.: Where Process-Improvement Projects Go Wrong. Wall Street J. (2010)
6. Erdani, Y., Hunger, A., Werner, S., Mertens, S.: Ternary grid as a potentially new technique for knowledge elicitation/acquisition. In: IEEE Conference on Intelligent Systems (2004)
7. Seethamraju, R., Marjanovic, O.: Role of process knowledge in business process improvement methodology: a case study. BPM Journal 15, 920-936 (2009)

8. Gijo, E.V., Rao, T., S.: Six Sigma Implementation – Hurdles and More Hurdles. Total Quality Management & Business Excellence 16, 721-725 (2005)
9. Davis, D.: 3rd Biennial PEX Network Report: State of the Industry – Trends and Success Factors in Business Process Excellence (2013)
10. Hagemeyer, C., Gershenson, J., K., Johnson, D., M.: Classification and application of problem solving quality tools: A manufacturing case study. TQM Mag. 18, 455-483 (2006)
11. Bruhn, M.: Operative Gestaltung des Qualitätsmanagements für Dienstleistungen. In: Bruhn, M. (ed.) Qualitätsmanagement für Dienstleistungen, pp. 251-354. Springer (2013)
12. Meran, R., John, A., Roenpage, O., Staudter, C.: Six Sigma+Lean Toolset. Springer (2013)
13. Fill, H.-G., Karagiannis, D.: On the Conceptualisation of Modelling Methods Using the ADOxx Meta Modelling Platform. EMISA – An International Journal 8, 4-25 (2013)
14. Seidewitz, E.: What models mean. IEEE Software 20, 26-32 (2003)
15. Gutzwiller, T.A.: Das CC RIM-Referenzmodell für den Entwurf von betrieblichen, transaktionsorientierten Informationssystemen. Physica-Verlag, Heidelberg (1994)
16. Ishikawa, K.: Guide to Quality Control. Tokyo (1980)
17. Hutwelker, R.: Hard und Soft Facts zur Prozessverbesserung – Six Sigma. Report (2005)
18. Kleppe, A.G., Warmer, J.B., Bast, W.: MDA explained: the model driven architecture: practice and promise. Addison-Wesley Professional (2003)
19. Anaby-Tavor, A. et al.: Insights into enterprise conceptual modeling. Data & Knowledge Engineering 69, 1302-1318 (2010)
20. Fill, H.-G. et al.: An Approach to Support the Performance Management of Public Health Authorities using an IT based Modeling Method. 10th Wirtschaftsinformatik, Zürich (2011)
21. Amaravadi, C.S., Lee, I.: The dimensions of process knowledge. Knowledge and Process Management 12, 65-76 (2005)
22. Dodgson, M.: Organizational learning: a review of some literatures. Organization Studies 14, 375-394 (1993)
23. Nonaka, I.: The knowledge-creating company. Harvard Business Rev. 85, 162-171 (2007)
24. Hevner, A.R., March, S.T., Park, J., Ram, S.: Design Science in Information Systems Research. MIS Quarterly 28, 75-105 (2004)
25. Rothchild, I.: Induction, deduction, and the scientific method. Soc. study Reprod. (2006)
26. Johannsen, F.: State of the art concerning the integration of methods and techniques in quality management. In: 19th European Conference on Inf. Sys. (ECIS), Helsinki (2011)
27. Fraser, M.D., Kumar, K., Vaishnavi, V.K.: Strategies for incorporating formal specifications in software development. Communications of the ACM 37, 74-86 (1994)
28. Fill, H.-G., Redmond, T., Karagiannis, D.: FDMM: A Formalism for Describing ADOxx Meta Models and Models. In: Proceedings ICEIS, Poland (2012)
29. Batini, C., Lenzerini, M., Navathe, S.B.: A Comparative Analysis of Methodologies for Database Schema Integration. ACM Computing Surveys 18, 323-364 (1986)
30. Kano, N., Seraku, N., Takahashi, F., Tsuji, S.: Attractive Quality and Must-be Quality. Hinshitsu: The Journal of the Japanese Society for Quality Control 14, 39-48 (1984)
31. George, M.L. et al.: Lean Six Sigma Pocket Toolbox. McGraw-Hill, New York (2005)
32. Shahin, A.: Integration of FMEA and the Kano model: An exploratory examination. International Journal of Quality & Reliability Management 21, 731-746 (2004)
33. Ulrich, D., Kerr, S., Ashkenas, R.: The GE Work-Out. McGraw-Hill, New York et al. (2002)
34. Kirakowski, J.: SUMI user handbook. HFRG, University College Cork, Ireland (1998)
35. Ralyté, J., Rolland, C.: An Approach for Method Reengineering. In: International Conference on Conceptual Modeling, pp 471-484. Springer (2001)
36. Xu, Y., Bernard, A., Perry, N., Lian, L.: Managing knowledge management tools: a systematic classification and comparison. In: Int. MASS Conf., pp 1-4. IEEE Press (2011)