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Report

Traceability Handling in Model-based Prediction of System Quality

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ABSTRACT

Abstract heading

Our earlier research indicated the feasibility of the PREDIQT method for model-based prediction of impacts of architectural design changes, on the different quality characteristics of a system. The PREDIQT method develops and makes use of a multi-layer model structure, called prediction models. Usefulness of the prediction models requires a structured documentation of both the relations between the prediction models and the rationale and assumptions made during the model development. This structured documentation is what we refer to as trace-link information. In this paper, we propose a traceability scheme for PREDIQT, and an implementation of it in the form of a prototype tool which can be used to define, document, search for and represent the trace-links needed. The solution is applied on prediction models from an earlier PREDIQT-based analysis of a real-life system. Based on a set of success criteria, we argue that our traceability approach is useful and practically scalable in the PREDIQT context.

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Traceability Handling in Model-based Prediction of System Quality

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Abstract—**Our earlier research indicated the feasibility of the PREDIQT method for model-based prediction of impacts of architectural design changes, on the different quality characteristics of a system. The PREDIQT method develops and makes use of a multi-layer model structure, called prediction models. Usefulness of the prediction models requires a structured documentation of both the relations between the prediction models and the rationale and assumptions made during the model development. This structured documentation is what we refer to as trace-link information. In this paper, we propose a traceability scheme for PREDIQT, and an implementation of it in the form of a prototype tool which can be used to define, document, search for and represent the trace-links needed. The solution is applied on prediction models from an earlier PREDIQT-based analysis of a real-life system. Based on a set of success criteria, we argue that our traceability approach is useful and practically scalable in the PREDIQT context.**

Keywords-**traceability; system quality prediction; modeling; architectural design; change impact analysis; simulation.**

I. Introduction

We have developed and tried out the PREDIQT method [1] [2] aimed for predicting impacts of architectural design changes on system quality characteristics and their trade-offs. Examples of quality characteristics include availability, scalability, security and reliability.

Important preconditions for model-based prediction are correctness and proper usage of the prediction models. The process of the PREDIQT method guides the development and use of the prediction models, but the correctness of the prediction models and the way they are applied are also highly dependent on the creative effort of the analyst and his/her helpers. In order to provide additional help and guidance to the analyst, we propose in this paper a traceability approach for documenting and retrieving the rationale and assumptions made during the model development, as well as the dependencies between the elements of the prediction models.

The approach is defined by a traceability scheme, which is basically a feature diagram specifying capabilities of the solution and a meta-model for the trace-link information. A prototype tool is implemented in the form of a relational database with user interfaces which can be employed to define, document, search for and represent the trace-links needed. The solution is illustrated on prediction models from an earlier PREDIQT-based analysis conducted on a real-life system [3]. We argue that our approach is, given the success criteria for traceability in PREDIQT, practically useful and better than any other traceability approach we are aware of.

The paper is organized as follows: Section II provides background on traceability. The challenge of traceability handling in the context of the PREDIQT method is characterized in Section III. Our traceability handling approach is presented in Section IV. Section V illustrates the approach on an example. Section VI argues for completeness and practicability of the approach, by evaluating it with respect to the success criteria. Section VII substantiates why our approach, given the success criteria outlined in Section III, is preferred among the alternative traceability approaches. The concluding remarks and future work are presented in Section VIII. An overview of the PREDIQT method is provided in Appendix 1. Guidelines for application of both the prediction models and the trace-link information are provided in Appendix 2.

II. Background on traceability

Traceability is the ability to determine which documentation entities of a software system are related to which other documentation entities according to specific relationships [4]. IEEE [5] also provides two definitions of traceability:

1) Traceability is the degree to which a relationship can be established between two or more products of the development process, especially products having a predecessor-successor or master-subordinate relationship to one another; for example, the degree to which the requirements and design of a given software component match.
2) Traceability is the degree to which each element in a software development product establishes its reason for existing.

Traceability research and practice are most established in fields such as requirements engineering and model-driven engineering (MDE). Knethen and Paech [4] argue: "Dependency analysis approaches provide a fine-grained impact analysis but can not be applied to determine the impact of a required change on the overall software system. An imprecise impact analysis results in an imprecise estimate of costs and increases the effort that is necessary to implement a required change because precise relationships have to be identified during changing. This is cost intensive and error prone because analyzing the software documents requires detailed understanding of the software documents and the relationships between them." Aizenbud-Reshef et al. [6] furthermore state: "The extent of traceability practice is viewed as a measure of system quality and process maturity and is mandated by many standards" and "With complete traceability, more accurate costs and schedules of changes can be determined, rather than depending on the programmer to know all the areas that will be affected by these changes".

IEEE [5] defines a trace as "A relationship between two or more products of the development process." According to the OED [7], however, a trace is defined more generally as a "(possibly) non-material indication or evidence showing what has existed or happened". As argued by [8]: "If a developer works on an artifact, he leaves traces. The software configuration management system records who has worked on the artifact, when that person has worked on it, and some systems also record which parts of the artifacts have been changed. But beyond this basic information, the changes themselves also reflect the developer's thoughts and ideas, the thoughts and ideas of other stakeholders he may have talked to, information contained in other artifacts, and the transformation process that produced the artifact out of these inputs. These influences can also be considered as traces, even though they are usually not recorded by software configuration management systems."

A traceability link is a relation that is used to interrelate artifacts (e.g., by causality, content, etc.) [8]. In the context of requirements traceability, [8] argues that "a trace can in part be documented as a set of meta-data of an artifact (such as creation and modification dates, creator, modifier, and version history), and in part as relationships documenting the influence of a set of stakeholders and artifacts on an artifact. Particularly those relationships are a vital concept of traceability, and they are often referred to as traceability links. Traceability links document the various dependencies, influences, causalities, etc. that exist between the artifacts. A traceability link can be unidirectional (such as depends-on) or bidirectional (such as alternative-for). The direction of a link, however, only serves as an indication of order in time or causality. It does not constrain its (technical) navigability, so traceability links can always be followed in both directions".

In addition to the different definitions, there is no commonly agreed basic classification [8]. A taxonomy of the main concepts within traceability is suggested by [4].

An overview of the current state of traceability research and practice in requirements engineering and model-driven development is provided by [8], based on an extensive literature survey. Another survey [9] discusses the state-of-the-art in traceability approaches in MDE and assesses them with respect to five evaluation criteria: representation, mapping, scalability, change impact analysis and tool support. Moreover, Spanoudakis and Zisman [10] present a roadmap of research and practices related to software traceability and identify issues that are open for further research. The roadmap is organized according to the main topics that have been the focus of software traceability research.

Traces can exist between both model- and non-model artifacts. The means and measures applied for obtaining traceability are defined by so-called traceability schemes. A traceability scheme is driven by the planned use of the traces. The traceability scheme determines for which artifacts and up to which level of detail traces can be recorded [8]. A traceability scheme thus defines the constraints needed to guide the recording of traces, and answers the core questions: what, who, where, how, when and why. Additionally, there is tacit knowledge (such as why), which is difficult to capture and to document. A traceability scheme helps in this process of recording traces and making them persistent.

As argued by [6], the first approach used to express and maintain traceability was cross-referencing. This involves embedding phrases like "see section x" throughout the project documentation. Thereafter, different techniques have been used to represent traceability relationships including standard approaches such as matrices, databases, hypertext links, graph-based approaches, formal methods, and dynamic schemes [6]. Representation, recording and maintenance of traceability relations are by Spanoudakis and Zisman [10] classified into five approaches: single centralized database, software repository, hypermedia, mark-up, and event-based.

According to Wieringa [11], representations and visualizations of traces can be categorized into matrices, cross-references, and graph-based representations. As elaborated by Wieringa, the links, the content of the one artifact, and other information associated with a cross reference, is usually displayed at the same time. This is however not the case with traceability matrices. So, compared to traceability matrices, the user is (in the case of cross-references) shown more local information at the cost of being shown fewer (global) links. As models are the central element in MDE, graph-based representations are the norm. A graph can be transformed to a cross-reference. Regarding the notation, there is, however, no common agreement or standard, mostly because the variety and informality of different artifacts is not suitable for a simple, yet precise notation. Requirements traceability graphs are usually just plain box-and-line diagrams [11].

Knethen and Paech [4] argue that the existing traceability approaches do not give much process support. They specify four steps of traceability process: 1) define entities and relationships, 2) capture traces, 3) extract and represent traces, and 4) maintain traces. Similarly, Winkler and Pilgrim [8] state that traceability and its supporting activities are currently not standardized. They classify the activities when working with traces into: 1) planning for traceability, 2) recording traces, 3) using traces, and 4) maintaining traces. Traceability activities are generally not dependent on any particular software process model.

Trace models are usually stored as separate models, and links to the elements are (technically) unidirectional in order to keep the connected models or artifacts independent. Alternatively, models can contain the trace-links themselves and links can be defined as bidirectional. While embedded trace-links pollute the models, navigation is much easier [8]. Thus, we distinguish between external and internal storage, respectively. Anquetil at al. [12] argue: "Keeping link information separated from the artifacts is clearly better; however it needs to identify uniquely each artifact, even fined-grained artifacts. Much of the recent research has focused on finding means to automate the creation and maintenance of trace information. Text mining, information retrieval and analysis of trace links techniques have been successfully applied. An important challenge is to maintain links consistency while artifacts are evolving. In this case, the main difficulty comes from the manually created links, but scalability of automatic solution is also an issue."

As outlined by [6], automated creation of trace-links may be based on text mining, information retrieval, analysis of existing relationships to obtain implied relations, or analysis of change history to automatically compute links.

Reference models are an abstraction of best practice and comprise the most important kinds of traceability links. There is nothing provably correct about reference models, but they derive their relevance from the slice of practice they cover. Nevertheless, by formalizing a reference model in an appropriate framework, a number of elementary desirable properties can be ensured. A general reference model for requirements traceability is proposed by [13], based on numerous empirical studies.

Various tools are used to set and maintain traces. Surveys of the tools available are provided by [4], [8], [10] and [6]. Bohner and Arnold [14] found that the granularity of documentation entities managed by current traceability tools is typically somewhat coarse for an accurate impact analysis.

III. The Challenge

The PREDIQT process consists of three overall phases: *Target modeling*, *Verification of prediction models*, and *Application of prediction models*. Three interrelated sets of models are developed during the process of the PREDIQT method: Design Model which specifies system architecture, Quality Model which specifies the system quality notions, and Dependency Views (DVs) which represent the interrelationship between the system quality and the architectural design.

Trace-link information can be overly detailed and extensive while the solution needed in a PREDIQT context has to be applicable in a practical real-life setting within the limited resources allocated for a PREDIQT-based analysis. Therefore, the traceability approach should provide sufficient breadth and accuracy for documenting, retrieving and representing of the trace-links, while at the same time being practically applicable in terms of comprehensibility and scalability. The right balance between the completeness and accuracy of the trace information on the one side, and practical usability of the approach on the other side, is what characterizes the main challenge in proposing the appropriate solution for traceability handling in PREDIQT. Therefore, the trace-link creation efforts have to be concentrated on the traces necessary during the application of the prediction models.

A. Structure of the prediction models

Figure 1 provides an overview of the elements of the prediction models, expressed as a UML [15] class diagram. A Quality Model is a set of tree-like structures which clearly specify the system-relevant quality notions, by defining and decomposing the meaning of the system-relevant quality terminology. Each tree is dedicated to a target system-relevant quality characteristic. Each quality characteristic may be decomposed into quality sub-characteristics, which in turn may be decomposed into a set of quality indicators. As indicated by the relationship of type aggregation, specific sub-characteristics and indicators can appear in several Quality Model trees dedicated to the different quality characteristics. Each element of a Quality Model is assigned a quantitative normalized metric and an interpretation (qualitative meaning of the element), both specific for the target system. A Design Model represents the relevant aspects of the system architecture, such as for example process, dataflow, structure and rules.

A DV is a weighted dependency tree dedicated to a specific quality characteristic defined through the Quality Model. As indicated by the attributes of the Class *Node*, the nodes of a DV are assigned a name and a QCF (*Quality Characteristic Fulfillment*). A QCF is value of the degree of fulfillment of the quality characteristic, with respect to what is represented by the node. The degree of fulfillment is defined by the metric (of the quality characteristic) provided in the Quality Model. Thus, a complete prediction model has as many DVs as the quality characteristics defined in the Quality Model. Additionally, as indicated by the *Semantic* dependency relationship, semantics of both the structure and the weights of a DV are given by the definitions of the quality characteristics, as specified in the Quality Model. A DV node may be based on a Design Model element, as indicated by the *Based on* dependency relationship. As indicated by the self-reference on the *Node* class, one node may be decomposed into children nodes. Directed arcs express dependency with respect to quality characteristic by relating each parent node to its immediate children nodes, thus forming a tree structure. Each arc in a DV is assigned an EI (*Estimated Impact*), which is a normalized value of degree of dependence of a parent node, on the immediate child node. Thus, there is a quantified depen-

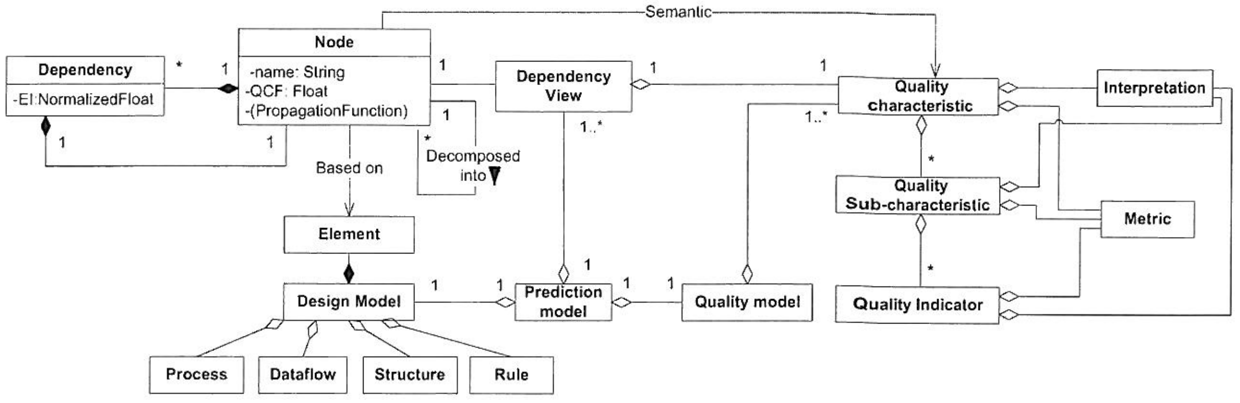


Figure 1. An overview of the elements of the prediction models, expressed as a UML class diagram

dency relationship from each parent node, to its immediate children. The values on the nodes and the arcs are referred to as parameter estimates. We distinguish between prior and inferred parameter estimates. The former ones are, in the form of empirical input, provided on leaf nodes and all arcs, while the latter ones are deduced using the DV propagation model for PREDIQT [3].

The intended application of the prediction models does not assume implementation of change on the target system, but only simulation of effects of the independent architectural design changes quality of the system (in its currently modelled state). Since the simulation is only performed on the target system in its current state and the changes are simulated independently (rather than incrementally), versioning of the prediction models in not necessary. Hence, maintenance of both prediction models and trace information is beyond the scope of PREDIQT. A more detailed overview of the PREDIQT method and the prediction models, is provided in Appendix 1.

B. Success criteria

It is, as argued by [8], an open issue to match trace usage and traceability schemes, and to provide guidance to limit and fit traceability schemes in a such way that they match a projects required usage scenarios for traces. One of the most urgent questions is which requirements a single scenario imposes on the other activities (in particular planning and recording) in the traceability process.

Moreover, it is argued by Aizenbud-Reshef et al. [6] that the lack of guidance as to what link information should be produced and the fact that those who use traceability are commonly not those producing it, also diminishes the motivation of those who create and maintain traceability information. In order to avoid this trap, we used the PREDIQT guidelines (as documented in Appendix 2) for the analyst as a starting point, for deriving the specific needs for traceability support. The guidelines are based on the authors' experiences from industrial trials of PREDIQT [3] [2]. As such, the guidelines are not exhaustive but serve as an aid towards a more structured process of applying the prediction models and accommodating the trace information during the model development, based on the needs of the "Application of prediction models"-phase.

The specific needs for traceability support in PREDIQT are summarized below:

1) There is need for the following kinds of trace-links:
   - links between the Design Model elements to support identification of dependencies among the elements of the Design Model
   - links from the Design Model elements to DV elements to support identification of DV nodes which are based on specific elements of the Design Model
   - links from DV elements to Quality Model elements to support acquisition of traces from the prior estimates of the DV to the relevant quality indicators
   - links to external information sources (documents, measurement, domain experts) used during the development of DV structure and estimation of the parameters to support documenting the traces from the DV to the more detailed information sources available outside the prediction models.
   - links to rationale and assumptions for: Design Model elements, the semantics of the DV elements, as well as structure and prior parameter estimates of the DVs to support documenting the parts of the process of development of the prediction models, particularly the understanding and interpretations that the models are based on
2) The traceability approach should have facilities for both searching with model types and model elements as input parameters, as well as for reporting linked

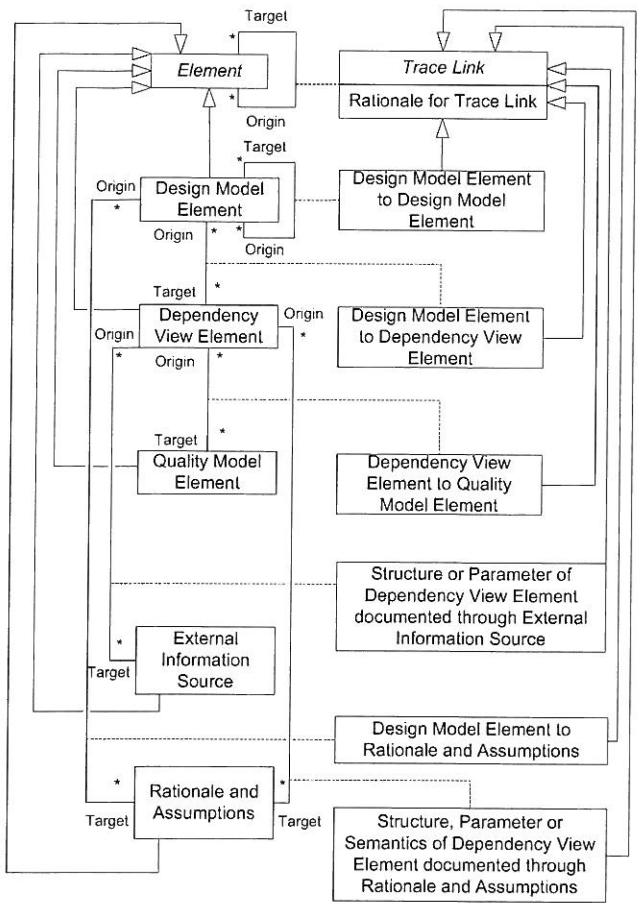

Target
Element
Trace Link
Rationale for Trace Link
Origin
Target
Origin
Design Model Element
Design Model Element to Design Model Element
Origin
Origin
Target
Dependency View Element
Origin
Design Model Element to Dependency View Element
Origin
Origin
Target
Quality Model Element
Dependency View Element to Quality Model Element
Structure or Parameter of Dependency View Element documented through External Information Source
External Information Source
Target
Design Model Element to Rationale and Assumptions
Rationale and Assumptions
Target
Target
Structure, Parameter or Semantics of Dependency View Element documented through Rationale and Assumptions

Figure 2. A meta model for trace-link information, expressed as a UML class diagram

elements and the link properties

3) The traceability approach should be flexible with respect to granularity of trace information
4) The traceability approach should be practically applicable on real-life applications of PREDIQT

These needs are in the sequel referred to as the success criteria for the traceability approach in PREDIQT.

IV. Our solution

This section starts by presenting our traceability scheme for PREDIQT. Then, a prototype tool for trace-link management, implementing the needs specified through the traceability scheme, is presented.

A. Traceability scheme

We propose a traceability scheme in the form of a meta-model for trace-link information and a feature diagram for capabilities of the solution. The types of the trace-links and the types of the traceable elements are directly extracted from Success Criterion 1 and represented through a meta-model shown by Figure 2. The *Element* abstract class represents a generalization of a traceable element. The *Element* abstract class is specialized into the five kinds of traceable elements: *Design Model Element*, *DV Element*, *Quality Model Element*, *External Information Source*, and *Rationale and Assumptions*. Similarly, the *Trace Link* abstract class represents a generalization of a trace-link and may be assigned a rationale for the trace-link. The *Trace Link* abstract class is specialized into the six kinds of trace-links.

Pairs of certain kinds of traceable elements form binary relations in the form of unidirectional trace-links. Such relations are represented by the UML-specific notations called association classes (a class connected by a dotted line to a link which connects two classes). For example, trace-links of type *Design Model Element to Design Model Element* may be formed from a *Design Model Element* to a *Dependency View Element*. The direction of the link is annotated by the origin (the traceable element that the trace-link goes from) and the target (the traceable element that the trace-link goes to). Since only distinct pairs (single instances) of the traceable elements (of the kinds involved in the respective trace-links defined in Figure 2) can be involved in the associated specific kinds of trace-links, uniqueness (property of UML association classes) is present in the defined trace-links. Due to the binary relations (arity of value 2) in the defined trace-links between the traceable elements, only two elements can be involved in any trace-link. Furthermore, multiplicity of all the traceable elements involved in the trace-links defined is of type "many", since an element can participate in multiple associations (given they are defined by the meta-model and unique).

The main capabilities needed are represented through a feature diagram [8] shown by Figure 3. Storage of trace-links may be internal or external, relative to the prediction models. A traceable element may be of type prediction model element (see Figure 1) or non-model element. Reporting and searching functionality has to be supported. Trace-link info has to include link direction, link meta-data (e.g. date, creator, strength) and cardinality (note that all links are binary, but a single element can be origin or target for more than one trace-link). Typing at the origin and the target ends of a trace-link as well as documenting rationale for trace-link, are optional.

B. Prototype traceability tool

We have developed a prototype tool in the form of a database application with user interfaces, on the top of MS Access [16]. The prototype tool includes a structure of tables for organizing the trace information, queries for retrieval of the trace info, a menu for managing work flow, forms for populating trace-link information, and facilities for reporting trace-links. A screen shot of the entity-relationship (ER)

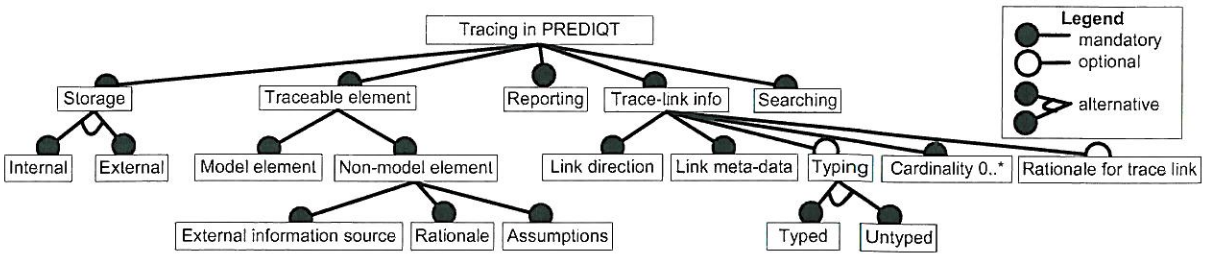


Figure 3. Main capabilities of the traceability approach, expressed as a feature diagram

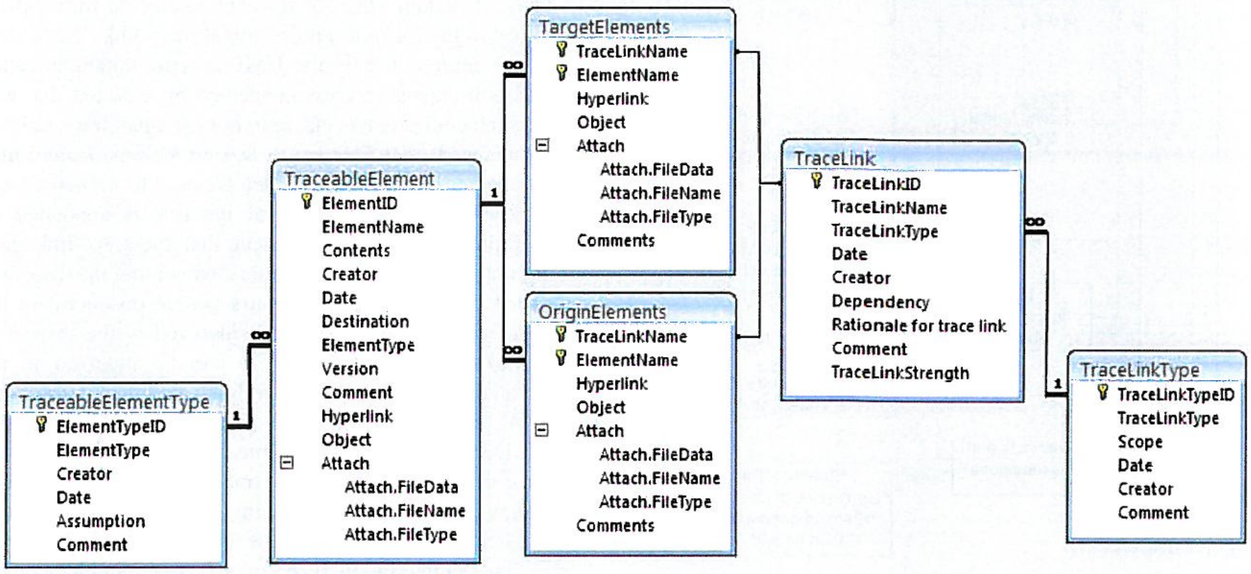


Figure 4. Entity-relationship diagram of the trace-link database of the prototype traceability tool

diagram of the trace-link database is shown by Figure 4. The ER diagram is normalized, which means that the data are organized with minimal needs for repeating the entries in the tables. Consistency checks are performed on the referenced fields. The data structure itself (represented by the ER diagram) does not cover all the constraints imposed by the meta-model (shown by Figure 2). However, constraints on queries and forms as well as macros can be added in order to fully implement the logic, such as for example which element types can be related to which trace-link types.

The five traceable element types defined by Figure 2 and their properties (name of creator, date, assumption and comment), are listed in Table *TraceableElementType*. Similarly, the six trace-link types defined by Figure 2 and their properties (scope, date, creator and comment), are listed in Table *TraceLinkType*. Table *TraceableElement* specifies the concrete instances of the traceable elements, and assigns properties (such as the pre-defined element type, hyperlink, creator, date, etc.) to each one of them. Since primary key attribute in Table *TraceableElementType* is foreign key in Table *TraceableElement*, multiplicity between the two respective tables is one-to-many.

Most of the properties are optional, and deduced based on: 1) the core questions to be answered by traceability scheme [8] and 2) the needs for using guidelines for application of prediction models, specified in Appendix 2. The three Tables *TargetElements*, *OriginElements* and *TraceLink* together specify the concrete instances of trace-links. Each link is binary, and directed from a concrete pre-defined traceable element – the origin element specified in Table *OriginElements*, to a concrete pre-defined traceable element – the target element specified in Table *TargetElements*. The trace-link itself (between the origin and the target element) and its properties (such as pre-defined trace-link type) are specified in Table *TraceLink*. Attribute *TraceLinkName* (associated with a unique *TraceLinkId* value) connects the three tables *TraceLink*, *OriginElements* and *TargetElements* when representing a single trace-link instance, thus forming a

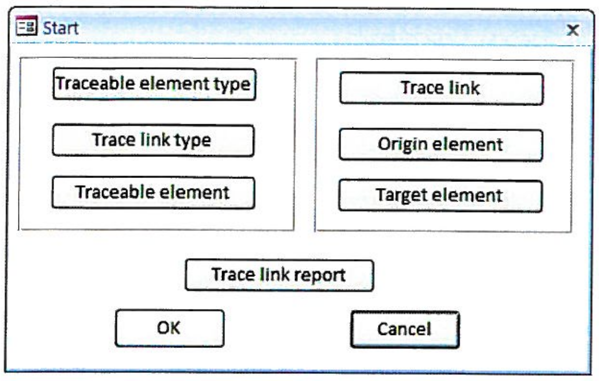
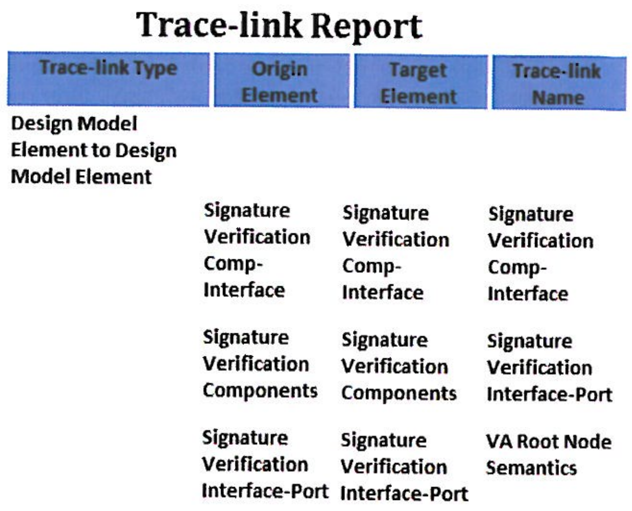


Figure 5. A screen shot of the start menu of the prototype traceability tool



Trace-link Report

Trace-link Type	Origin Element	Target Element	Trace-link Name
Design Model Element to Design Model Element			
	Signature Verification Comp-Interface	Signature Verification Comp-Interface	Signature Verification Comp-Interface
	Signature Verification Components	Signature Verification Components	Signature Verification Interface-Port
	Signature Verification Interface-Port	Signature Verification Interface-Port	VA Root Node Semantics

Figure 6. A screen shot of an extract of a trace-link report from the prototype traceability tool

cross-product when relating the three tables. The MS Access environment performs reference checks on the cross products, as well as on the values of the foreign key attributes. Target elements and origin elements participating in a trace-link, are instances of traceable elements defined in Table *TraceableElement*. They are connected through the Attribute *ElementId* (displayed as *ElementName* in the tables where it has the role of foreign key). Thus, multiplicity between Table *TraceableElement* and Table *TargetElements*, as well as between Table *TraceableElement* and Table *OriginElements*, is one-to-many. Similarly, since primary key attribute in Table *TraceLinkType* is foreign key in Table *TraceLink*, multiplicity between the two respective tables is one-to-many.

A screen shot of the start menu is shown by Figure 5. The sequence of the buttons represents a typical sequence of actions of an end-user (the analyst), in the context of defining, documenting and using the trace-links. The basic definition of the types of the traceable elements and the trace-links are provided first. Then, concrete traceable elements are documented, before defining specific instances of the trace-links and their associated specific origin and target elements, involved in the binary trace-link relations. Finally, reports can be obtained, based on search parameters such as for example model types, model elements, or trace-link types.

V. Applying the Solution on an Example

This section exemplifies the application of our solution for managing traces in the context of prediction models earlier developed and applied during a PREDIQT-based analysis [3] conducted on a real-life system.

The trace-link information was documented in the prototype tool, in relation to the model development. The trace-links were applied during change application, according to the guidelines for application of prediction models, specified in Appendix 2. We present the experiences obtained, while the process of documentation of the trace-links is beyond the scope of this paper.

The prediction models involved are the ones related to "Split signature verification component into two redundant components, with load balancing", corresponding to Change 1 in [3]. Three Design Model diagrams were affected, and one, two and one model element on each, respectively. We have tried out the prototype traceability tool on the Design Model diagrams involved, as well as Availability (which was one of the three quality characteristics analyzed) related Quality Model diagrams and DV. Documentation of the trace-links involved within the Availability quality characteristic (as defined by the Quality Model) scope, took approximately three hours. Most of the time was spent on actually typing the names of the traceable elements and the trace-links.

18 instances of traceable elements were registered in the database during the trial: seven Quality Model elements, four DV elements, four Design Model elements and three elements of type "Rationale and Assumptions". 12 trace-links were recorded: three trace-links of type "Design Model Element to Design Model Element", three trace-links of type "Design Model Element to DV Element", one trace-link of type "Design Model Element to Rationale and Assumptions", three trace-links of type "DV Element to Quality Model Element", and two trace-links of type "Structure, Parameter or Semantics of DV Element Documented through Rationale and Assumptions", were documented.

An extract of a screen shot of a trace-link report (obtained from the prototype tool) is shown by Figure 6. The report included: three out of three needed (i.e., actually existing, regardless if they are recorded in the trace-link database) "Design Model Element to Design Model Element" links, three out of four needed "Design Model Element to DV Element" links, one out of one needed "Design Model Element to Rationale and Assumptions" link, three out of six needed "DV Element to Quality Model Element" links and one out of one needed "Structure, Parameter or Semantics of DV Element Documented through Rationale and Assumptions" link.

Best effort was made to document the appropriate trace-links without taking into consideration any knowledge of exactly which of them would be used when applying the change. The use of the trace-links along with the application of change on the prediction models took totally 20 minutes and resulted in the same predictions (change propagation paths and values of QCF estimates on the Availability DV), as in the original case study [3]. Without the guidelines and the trace-link report, the change application would have taken approximately double time for the same user.

All documented trace-links were relevant and used during the application of the change, and about 73% of the relevant trace-links could be retrieved from the prototype tool. Considering however the importance and the role of the retrievable trace-links, the percentage should increase considerably.

Although hyperlinks are included as meta-data in the user interface for element registration, an improved solution should include interfaces for automatic import of the element names from the prediction models, as well as user interfaces for easy (graphical) trace-link generations between the existing elements. This would also aid verification of the element names.

VI. Why our solution is a good one

This section argues that the approach presented above fulfills the success criteria specified in Section III.

A. Success Criterion 1

The traceability scheme and the prototype tool capture the kinds of trace-links and traceable elements, specified in the Success Criterion 1. The types of trace-links and traceable elements as well as their properties, are specified in dedicated tables in the database of the prototype tool. This allows constraining the types of the trace-links and the types of the traceable elements to only the ones defined, or extending their number or definitions, if needed. The trace-links in the prototype tool are binary and unidirectional, as required by the traceability scheme. Macros and constraints can be added in the tool, to implement any additional logic regarding trace-links, traceable elements, or their respective type definitions and relations. The data properties (e.g. date, hyperlink or creator) required by the user interface, allow full traceability of the data registered in the database of the prototype tool.

B. Success Criterion 2

Searching based on user input, selectable values from a list of pre-defined parameters, or comparison of one or more database fields, are relatively simple and fully supported based on queries in MS Access. Customized reports can be produced with results of any query and show any information registered in the database. The report, an extract of which is presented in Section V, is based on a query of all documented trace-links and the related elements.

C. Success Criterion 3

The text-based fields for documenting the concrete instances of the traceable elements and the trace-links, allow level of detail selectable by the user. Only a subset of fields is mandatory for providing the necessary trace-link data. The optional fields in the tables can be used for providing additional information such as for example rationale, comments, links to external information sources, attachments, strength or dependency. There are no restrictions as to what can be considered as a traceable element, as long at it belongs to one of the element types defined by Figure 2. Similarly, there are no restrictions as to what can be considered as a trace-link, as long at it belongs to one of the trace-link types defined by Figure 2. The amount of information provided regarding the naming and the meta-data, are selectable by the user.

D. Success Criterion 4

Given the realism of the prediction models involved in the example, the size and complexity of the target system they address, the representativeness of the change applied on them, the simplicity of the prototype tool with respect to both the user interfaces and the notions involved, as well as the time spent on documenting the trace-links and using them, the application of the approach presented in Section V indicates the applicability of our solution on real-life applications of PREDIQT, with limited resources and by an average user (in the role of the analyst).

The predictions (change propagation paths and values of QCF estimates) we obtained during the application of our solution on the example were same as the ones from the original case study [3] (performed in year 2008) which the models stem from. Although the same analyst has been involved in both, the results suggest that other users should, by following PREDIQT guidelines and applying the prototype traceability tool, obtain similar results.

The time spent is to some degree individual and depends on the understanding of the target system, the models and the PREDIQT method. It is unknown if the predictions would have been the same (as in the original case study) for another user. We do however consider the models and the change applied during the application of the solution, to be representative due to their origins from a major real-life system. Still, practical applicability of our solution will be subject to future empirical evaluations.

VII. Why other approaches are not better in this context

This section evaluates the feasibility of other traceability approaches in the PREDIQT context. Based on our review of the approach-specific publications and the results of the evaluation by Galvao and Goknil [9] of a subset of the below mentioned approaches, we argue why the alternative traceability approaches do not perform sufficiently on one or more of the success criteria specified in Section III. The evaluation by Galvao and Goknil is conducted with respect to five criteria: 1) structures used for representing the traceability information; 2) mapping of model elements at different abstraction levels; 3) scalability for large projects in terms of process, visualization of trace information, and application to a large amount of model elements; 4) change impact analysis on the entire system and across the software development lifecycle; and 5) tool support for visualization and management of traces, as well as for reasoning on the trace-link information.

Almeida et al. [17] propose an approach aimed at simplifying the management of relationships between requirements and various design artifacts. A framework which serves as a basis for tracing requirements, assessing the quality of model transformation specifications, meta-models, models and realizations, is proposed. They use traceability cross-tables for representing relationships between application requirements and models. Cross-tables are also applied for considering different model granularities and identification of conforming transformation specifications. The approach does not provide sufficient support for intra-model mapping, thus failing on our Success Criterion 1. Moreover, possibility of representing the various types of trace-links and traceable elements is unclear, although different visualizations on a cross-table are suggested. Tool support is not available, which limits applicability of the approach in a practical setting. Searching and reporting facilities are not available. Thus, it fails on our Success Criteria 1, 2 and 4.

Event-based Traceability (EBT) is another requirements-driven traceability approach aimed at automating trace-link generation and maintenance. Cleland-Huang, Chang and Christensen [18] present a study which uses EBT for managing evolutionary change. They link requirements and other traceable elements, such as design models, through publish-subscribe relationships. As outlined by [9], "Instead of establishing direct and tight coupled links between requirements and dependent entities, links are established through an event service. First, all artefacts are registered to the event server by their subscriber manager. The requirements manager uses its event recognition algorithm to handle the updates in the requirements document and to publish these changes as event to the event server. The event server manages some links between the requirement and its dependent artefacts by using some information retrieval algorithms." The notification of events carries structural and semantic information concerning a change context. Scalability in a practical setting is the main issue, due to performance limitation of the EBT server [9]. Moreover, the approach does not provide sufficient support for intra-model mapping. Thus, it fails on our Success Criteria 1 and 4.

Cleland-Huang et al. [19] propose Goal Centric Traceability (GCT) approach for managing the impact of change upon the non-functional requirements of a software system. Softgoal Interdependency Graph (SIG) is used to model non-functional requirements and their dependencies. Additionally, a traceability matrix is constructed to relate SIG elements to classes. The main weakness of the approach is the limited tool support, which requires manual work. This limits both scalability in a practical setting and searching support (thus failing on our Success Criteria 4 and 2, respectively). It is unclear to what degree granularity of the approach would suffice the needs of PREDIQT.

Cleland-Huang and Schmelzer [20] propose another requirements-driven traceability approach that builds on EBT. The approach involves a different process for dynamically tracing non-functional requirements to design patterns. Although more fine grained than EBT, there is no evidence that the method can be applied with success in a practical real-life setting (required through our Success Criterion 4). Searching and reporting facilities (as required through our Success Criterion 2) are not provided.

Many traceability approaches address trace maintenance. Cleland-Huang, Chang and Ge [21] identify the various change events that occur during requirements evolution and describe an algorithm to support their automated recognition through the monitoring of more primitive actions made by a user upon a requirements set. Mäder and Gotel [22] propose an approach to recognize changes to structural UML models that impact existing traceability relations and, based on that knowledge, provide a mix of automated and semi-automated strategies to update the relations. Both approaches focus on trace maintenance, which is as argued in Section III, not among the traceability needs in PREDIQT.

Ramesh and Jarke [13] propose another requirements-driven traceability approach where reference models are used to represent different levels of traceability information and links. The granularity of the representation of traces depends on the expectations of the stakeholders [9]. The reference models can be implemented in distinct ways when managing the traceability information. As reported by [9], "The reference models may be scalable due to their possible use for traceability activities in different complexity levels. Therefore, it is unclear whether this approach lacks scalability with respect to tool support for large-scale projects or not. The efficiency of the tools which have implemented these meta-models was not evaluated and the tools are not the focus of the approach." In PREDIQT context, the reference models are too broad, their focus is on requirements traceability, and tool support is not sufficient with respect to searching and reporting (our Success Criterion 2).

We could however have tried to use parts of the reference models by Ramesh and Jarke [13] and provide tool support based on them. This is done by [23] in the context of product and service families. The authors discuss a knowledge management system, which is based on the traceability framework by Ramesh and Jarke [13]. The system captures the various design decisions associated with service family development. The system also traces commonality and variability in customer requirements to their corresponding design artifacts. The tool support has graphical interfaces for documenting decisions. The trace and design decision capture is illustrated using sample scenarios from a case study. We have however not been able to obtain the tool, in order to try it out in our context.

A modeling approach by Egyed [24] represents traceability information in a graph structure called a footprint graph. Generated traces can relate model elements with other models, test scenarios or classes [9]. Galvao and Goknil [9] report on promising scalability of the approach. It is however unclear to what degree the tool support fulfills our success criterion regarding searching and reporting, since semantic information on trace-links and traceable elements is limited.

Aizenbud-Reshef et al. [25] outline an operational semantics of traceability relationships that capture and represent traceability information by using a set of semantic properties, composed of events, conditions and actions [9]. Galvao and Goknil [9] state: the approach does not provide sufficient support for intra-model mapping; a practical application of the approach is not presented; tool support is not provided; however, it may be scalable since it is associated with the UML. Hence, it fails on our Success Criteria 1 and 2.

Limon and Garbajosa [26] analyze several traceability schemes and propose an initial approach to Traceability Scheme (TS) specification. The TS is composed of a traceability link dataset, a traceability link type set, a minimal set of traceability links, and a metrics set for the minimal set of traceability links [9]. Galvao and Goknil [9] argue that "The TS is not scalable in its current form. Therefore, the authors outline a strategy that may contribute to its scalability: to include in the traceability schema a set of metrics that can be applied for monitoring and verifying the correctness of traces and their management." Hence, it fails with respect to scalability in a practical setting, that is, our criterion 4. Moreover, there is no tool support for the employment of the approach, which fails on our success criterion regarding searching and reporting.

Some approaches [27] [28] [29] that use model transformations can be considered as a mechanism to generate trace-links. Tool support with transformation functionalities is in focus, while empirical evidence of applicability and particularly comprehensibility of the approaches in a practical setting, is missing. The publications we have retrieved do not report sufficiently on whether these approaches would offer the searching facilities, the granularity of trace information, and the scalability needed for use in PREDIQT context (that is, in a practical setting by an end-user (analyst) who is not an expert in the tools provided).

VIII. Conclusion and future work

Our earlier research indicates the feasibility of the PREDIQT method for model-based prediction of impacts of architectural design changes on system quality. The PREDIQT method produces and applies a multi-layer model structure, called prediction models, which represent system design, system quality and the interrelationship between the two.

Based on the success criteria for a traceability approach in the PREDIQT context, we put forward a traceability scheme. Based on this, a prototype tool which can be used to define, document, search for and represent the trace-links needed, is developed. We have argued that our solution offers a useful and practically applicable support for traceability in the PREDIQT context. The model application guidelines provided in Appendix 2 complement the prototype traceability tool and aim to jointly provide the facilities needed for a schematic application of prediction models.

Performing an analysis of factors such as cost, risk, and benefit and following the paradigm of value-based software-engineering, would be relevant in order to stress the effort on the important trace-links. As argued by [8], if the value-based paradigm is applied to traceability, cost, benefit, and risk will have to be determined separately for each trace according to if, when, and to what level of detail it will be needed later. This leads to more important artifacts having higher-quality traceability. There is a trade-off between the semantically accurate techniques on the one hand and cost-efficient but less detailed approaches on the other hand. Finding an optimal compromise is still a research challenge. Our solution proposes a feasible approach, while finding the optimal one is subject to further research.

Further empirical evaluation of our solution is also necessary to test its feasibility on different analysts as well as its practical applicability in the various domains which PREDIQT is applied on. Future work should also include standard interfaces and procedures for updating the traceable elements from the prediction models into our prototype traceability tool. As model application phase of PREDIQT dictates which trace-link information is needed and how it should be used, the current PREDIQT guidelines focus on the application of the prediction models. However, since the group of recorders and the group of users of traces may be distinct, structured guidelines for recording the traces during the model development should also be developed as a part of the future work.

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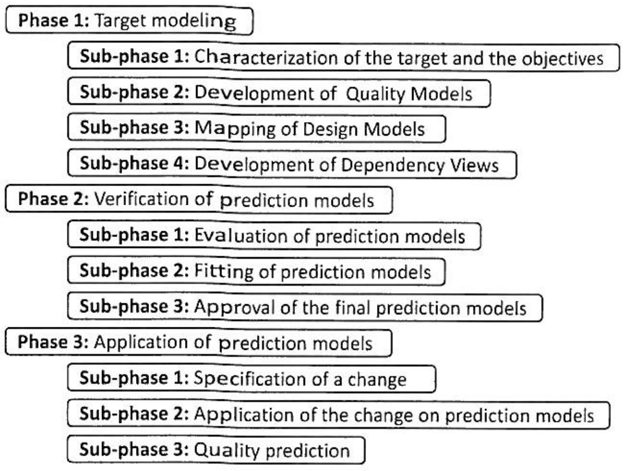
Phase 1: Target modeling
Sub-phase 1: Characterization of the target and the objectives
Sub-phase 2: Development of Quality Models
Sub-phase 3: Mapping of Design Models
Sub-phase 4: Development of Dependency Views
Phase 2: Verification of prediction models
Sub-phase 1: Evaluation of prediction models
Sub-phase 2: Fitting of prediction models
Sub-phase 3: Approval of the final prediction models
Phase 3: Application of prediction models
Sub-phase 1: Specification of a change
Sub-phase 2: Application of the change on prediction models
Sub-phase 3: Quality prediction

Figure 7. A simplified overview of the process of the PREDIQT method

APPENDIX 1: AN OVERVIEW OF THE PREDIQT METHOD

The PREDIQT method produces and applies a multi-layer model structure, called prediction models, which represent system relevant quality concepts (through "Quality Model"), architectural design (through "Design Model"), and the dependencies between architectural design and quality (through "Dependency Views"). The Design Model diagrams are used to specify the architectural design of the target system and the changes whose effects on quality are to be predicted. The Quality Model diagrams are used to formalize the quality notions and define their interpretations. The values and the dependencies modeled through the Dependency Views (DVs) are based on the definitions provided by the Quality Model. The DVs express the interplay between the system architectural design and the quality characteristics. Once a change is specified on the Design Model diagrams, the affected parts of the DVs are identified, and the effects of the change on the quality values are automatically propagated at the appropriate parts of the DV. This section briefly outlines the PREDIQT method in terms of the process and the artifacts. For further details on PREDIQT, see [1] [30] [2].

The process of the PREDIQT method consists of three overall phases. Each phase is decomposed into sub-phases, as illustrated by Figure 7. Based on the initial input, the stakeholders involved deduce a high level characterization of the target system, its scope and the objectives of the prediction analysis, by formulating the system boundaries, system context (including the usage profile), system lifetime and the extent (nature and rate) of design changes expected. Quality Model diagrams are created in the form of trees, by defining the quality notions with respect to the target system. The Quality Model diagrams represent a taxonomy with interpretations and formal definitions of system quality

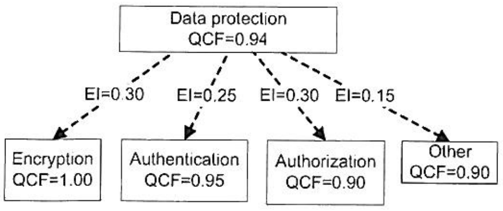

Figure 8. Excerpt of an example DV with fictitious values

notions. The total quality of the system is decomposed into characteristics, sub-characteristics and quality indicators. The Design Model diagrams represent the architectural design of the system.

For each quality characteristic defined in the Quality Model, a quality characteristic specific DV is deduced from the Design Model diagrams and the Quality Model diagrams of the system under analysis. This is done by modeling the dependencies of the architectural design with respect to the quality characteristic that the DV is dedicated to, in the form of multiple weighted and directed trees. A DV comprises two notions of parameters:

1) EI: Estimated degree of Impact between two nodes, and
2) QCF: estimated degree of Quality Characteristic Fulfillment.

Each arc pointing from the node being influenced is annotated by a quantitative value of EI, and each node is annotated by a quantitative value of QCF.

Figure 8 shows an excerpt of an example DV with fictitious values. In the case of the *Encryption* node of Figure 8, the QCF value expresses the goodness of encryption with respect to the quality characteristic in question, e.g., security. A quality characteristic is defined by the underlying system specific Quality Model, which may for example be based on the ISO 9126 product quality standard [31]. A QCF value in a DV expresses to what degree the node (representing system part, concern or similar) is realized so that it, within its own domain, fulfills the quality characteristic. The QCF value is based on the formal definition of the quality characteristic (for the system under analysis), provided by the Quality Model. The EI value on an arc expresses the degree of impact of a child node (which the arc is directed to) on the parent node, or to what degree the parent node depends on the child node, with respect to the quality characteristic under consideration.

"Initial" or "prior" estimation of a DV involves providing QCF values to all leaf nodes, and EI values to all arcs. Input to the DV parameters may come in different forms (e.g., from domain expert judgments, experience factories, measurements, monitoring, logs, etc.), during the different phases of the PREDIQT method. The DV parameters are assigned by providing the estimates on the arcs and the leaf nodes, and propagating them according to the general DV propagation algorithm. Consider for example the *Data protection* node in Figure 8 (denoting: DP: Data protection, E: Encryption, AT: Authentication, AAT: Authorization, and O:Other):

$$QCF_{(DP)} = QCF_{(E)} \cdot EI_{(DP \to E)} + QCF_{(AT)} \cdot EI_{(DP \to AT)} + QCF_{(AAT)} \cdot EI_{(DP \to AAT)} + QCF_{(O)} \cdot EI_{(DP \to O)} \quad \text{Eq. 1}$$

The DV-based approach constrains the QCF of each node to range between 0 and 1, representing minimal and maximal characteristic fulfillment (within the domain of what is represented by the node), respectively. This constraint is ensured through the formal definition of the quality characteristic rating (provided in the Quality Model). The sum of EIs, each between 0 (no impact) and 1 (maximum impact), assigned to the arcs pointing to the immediate children must be 1 (for model completeness purpose). Moreover, all nodes having a common parent have to be orthogonal (independent). The dependent nodes are placed at different levels when structuring the tree, thus ensuring that the needed relations are shown at the same time as the tree structure is preserved.

The general DV propagation algorithm, exemplified by Eq. 1, is legitimate since each quality characteristic DV is complete, the EIs are normalized and the nodes having a common parent are orthogonal due to the structure. A DV is complete if each node which is decomposed, has children nodes which are independent and which together fully represent the relevant impacts on the parent node, with respect to the quality characteristic that the DV is dedicated to.

The rationale for the orthogonality is that the resulting DV structure is tree-formed and easy for the domain experts to relate to. This significantly simplifies the parametrization and limits the number of estimates required, since the number of interactions between the nodes is minimized. Although the orthogonality requirement puts additional demands on the DV structuring, it has shown to represent a significant advantage during the estimation.

The "Verification of prediction models" is an iterative phase that aims to validate the prediction models, with respect to the structure and the individual parameters, before they are applied. A measurement plan with the necessary statistical power is developed, describing what should be evaluated, when and how. Both system-as-is and change effects should be covered by the measurement plan. Model fitting is conducted in order to adjust the DV structure and the parameters to the evaluation results. The objective of the "Approval of the final prediction models" sub-phase is to evaluate the prediction models as a whole and validate that they are complete, correct and mutually consistent after the fitting. If the deviation between the model and the new measurements is above the acceptable threshold after the fitting, the target modeling phase is re-initiated.

The "Application of the change on prediction models" phase involves applying the specified architectural design change on the prediction models. During this phase, a specified change is applied to the Design Model diagrams and the DVs, and its effects on the quality characteristics at the various abstraction levels are simulated on the respective DVs. When an architectural design change is applied on the Design Model diagrams, it is according to the definitions in the Quality Model, reflected to the relevant parts of the DV. Thereafter, the DV provides propagation paths and quantitative predictions of the new quality characteristic values, by propagating the change throughout the rest of each one of the modified DVs, based on the general DV propagation algorithm. We have earlier developed tool support [3] (below referred to as the "DV tool") based on MS Excel for simulation and sensitivity analysis of DVs.

APPENDIX 2: GUIDELINES FOR APPLICATION OF PREDICTION MODELS

In order to facilitate quality and correct use of prediction models, this section provides guidelines for application of the prediction models and the trace-link information, with the analyst as the starting point. Thus, unless otherwise specified, all the guidelines are directed towards the analyst. Overall guidelines for the "Application of prediction models" – phase (see Figure 7) are presented first, followed by detailed guidelines for each one of its sub-phases: 'Specification of a change", "Application of the change on prediction models" and "Quality prediction", respectively.

Guidelines for the "Application of prediction models" – phase

Objective During this phase, a specified change is applied to the prediction models, and its effects on the quality characteristics at the various abstraction levels are simulated on the respective Dependency Views (DVs). The simulation reveals which design parts and aspects are affected by the change and the degree of impact (in terms of the quality notions defined by the Quality Model).

Prerequisites The fitted prediction models are approved. The changes applied are assumed to be independent relative to each other. The "Quality prediction" sub-phase presupposes that the change specified during the "Specification of a change" sub-phase can be fully applied on the prediction models, during the "Application of the change on prediction models" sub-phase.

How conducted This phase consists of the three sub-phases:

1) Specification of a change
2) Application of the change on prediction models
3) Quality prediction

Input documentation Prediction models: Design Model diagrams, Quality Model diagrams and Dependency Views; Trace-links.

Output documentation Change specification; Pre- and post-change Design Model diagrams; DVs.

People that should participate

- Analysis leader (Required). Analysis leader is also referred to as analyst.
- Analysis secretary (Optional)
- Representatives of the customer:
  - Decision makers (Optional)
  - Domain experts (Required)
  - System architects or other potential users of PREDIQT (Required)

Modeling guideline

1) Textually specify the architectural design change of the system.
2) Modify the Design Model diagrams with respect to the change proposed. Modify the structure and the values of the prior parameters, on the affected parts of the DVs.
3) Run the simulation and display the changes on the Design Model diagrams and the DVs, relative to their original (pre-change) structure and values.

Guidelines for the "Specification of a change" sub-phase

Objective The change specification should clearly state all deployment relevant facts necessary for applying the change on the prediction models. The specification should include the current and the new state and characteristics of the design elements/properties being changed, the rationale and the assumptions made.

Prerequisites The fitted prediction models are approved.

How conducted Specify the change by describing type of change, the rationale, who should perform it, when, how and in which sequence of events. In case change specification addresses modification of specific elements of the Design Model diagrams or the DVs, the quality characteristics of the elements before and after the change have to be specified, based on the definitions provided by the Quality Model. The change specification has to be at the abstraction level corresponding to the abstraction level of a sufficient subset of the Design Model diagrams or DVs.

Input documentation Prediction models: Design Model, Quality Model, Dependency Views.

Output documentation Textual specification of a change.

Modeling guideline

1) Textually specify an architectural design change of the system represented by the approved prediction models.
2) Specify the rationale and the process related to the change deployment.

Guidelines for the "Application of the change on prediction models" sub-phase

Objective This sub-phase involves applying the specified change on the prediction models.

Prerequisites The change is specified. The specified change is, by the analyst and the domain experts, agreed upon and a common understanding is reached.

How conducted Detailed instructions for performing the six steps specified in "Modeling guideline", are provided here.

1) This first step of relating the change to the Design Model diagram(s) and their elements is a manual effort. The analyst and the domain experts confirm that a common understanding of the specification has been reached. Then, they retrieve the diagrams and the respective elements of the Design Model and identify which elements are potentially affected by the change, with respect to the system quality in general. The identified elements are marked, and their post-change status specified. The status may be of three types: update, delete or add. The update may involve change of a property related to design or a quality characteristic. In the case of delete, the diagram element is marked and its new status is visible. In case of add, a new diagram element is introduced.
2) The trace-links between diagrams and diagram elements are (during the "Target modeling" phase) documented in the form of a database, which they can be retrieved from. Each one of the above identified Design Model diagrams and diagram elements (except the added ones) is searched in the existing trace-link database (created during the model development). The result displays the searched items being in the role of the origin or the target element, and all the elements that depend on them or that they are dependent on, respectively. The result also displays overall meta-data, e.g. the kinds of the trace-links and their rationale. The retrieved (linked) elements are, by the domain experts and the analyst, considered whether they are affected by the specified change. Depending on the contents of the change and the trace-link type and rationale, each diagram or element which, according to the search results is linked to the elements identified in the previous step, may be irrelevant, deleted or updated. The updated and the deleted elements are, on the diagrams, assigned the new (post-change) status and meta-data.
3) Search in the trace-link database for all the above identified elements which have been updated or deleted, and retrieve their trace-links to the DV model elements. Manually identify the overall DV model elements that may be affected by the change. For all the retrieved and manually identified DV model elements, retrieve from the trace-link database, their rationale for the DV structure and the node semantics. Consider whether the added design element models require new DV nodes. Manually modify the DV structure, based on the retrieved trace-link information.
4) The domain experts and the analyst manually verify the updated structure (completeness, orthogonality and correctness) of each DVs, with respect to the 1) quality characteristic definitions provided by the Quality Model, and 2) the modified Design Model.
5) The estimates of the prior parameters have to be updated due to the modifications of the Design Model and the DV structure. Due do the structural DV modification in the previous step, previously internal nodes may have become prior nodes, and the EIs on the arcs may now be invalid. New nodes and arcs may have been introduced. All the earlier leaf nodes which have become internal nodes, and all new internal nodes are assumed to automatically be assigned the function for the propagation model, by the DV tool. All the new or modified arcs and leaf nodes have to be marked so that the values of their parameters can be evaluated. Manually identify the overall unmodified arcs and leaf nodes whose values have may have been affected by the change. In the case of the modified arcs and leaf nodes, trace-links are used to retrieve the previously documented rationale for the estimation of the prior parameter values and node semantics. The parameter values on the new and the modified arcs and leaf nodes are estimated manually based on the Quality Model.
Estimate the leaf node QCFs of a sub-tree prior to estimating the related EIs. The rationale is to fully understand the semantics of the nodes, through reasoning about their QCFs first. In estimating a QCF, two steps have to be undergone:
   a) interpretation of the node in question – its contents, scope, rationale and relationship with the Design Model, and
   b) identification of the relevant metrics from the Quality Model of the quality characteristic that the DV is addressing, as well as evaluation of the metrics identified.

   When estimating a QCF the following question is posed (to the domain experts): *"To what degree is the quality characteristic fulfilled, given the contents and the scope of the node?"* The definition of the rating should be recalled, along with the fact that zero estimate value denotes no fulfillment, while one denotes maximum fulfillment.
   In estimating an EI, two steps have to be undergone:
   a) interpretation of the two nodes in question, and
   b) determination of the degree of impact of the child node, on the parent node. The value is assigned relative to the overall EIs related to the same parent node, and with a consistent unit of measure, prior to being normalized. The normalized EIs on the arcs from the same parent node have to

sum up to one, due to the requirement of model completeness.

When estimating an EI the following question is posed (to the domain experts): "*To what degree does the child node impact the parent node, or how dependent is the parent node on child node, with respect to the quality characteristic that the DV is dedicated to?*" The definition of the quality characteristic provided by its Quality Model, should be recalled and the estimate is provided relative to the impact of the overall children nodes of the parent node in question. Alternatively, an impact value is assigned using the same unit of measure on all arcs of the sub-tree, and normalized thereafter.
Once one of the above specified questions is posed, depending on the kind of the DV parameter, the domain expert panel is asked to provide the estimate with an interval so that the correct value is within the interval with a probability given by the confidence level [30].

6) Manually verify the updated prior parameter values, so that the relative QCF values are consistent to each other and the rest of the estimates, and so that EIs on the arcs from a common parent sum up to one.

If the specified change can be fully applied, it is within the scope of the prediction models, which is a prerequisite for proceeding to the next sub-phase. Otherwise, the modifications are canceled and the change deemed not predictable by the models as such.

Input documentation Prediction models: Design Model, Quality Model, Dependency Views, change specification, trace-links.

Output documentation Design Model and DVs modified with respect to the change.

Modeling guideline

1) Relate the specified change to manually identifiable Design Model diagram(s) and their elements.
2) Use the trace-links to identify the affected parts (diagrams and diagram elements) of the Design Model. Apply the change by modifying (updating, deleting or adding) the identified affected parts of the Design Model.
3) Use the trace-links to identify the affected parts (nodes and dependency links) of each DV, by retrieving the traces from the modified and the deleted parts of the Design Model to the DVs, as well as the rationale for the DV structure and the node semantics. Modify the structure of the affected parts of the DVs.
4) Manually verify the updated structure (completeness, orthogonality and correctness) of the DVs, with respect to the Quality Model and the modified Design Model.
5) Use trace-links to identify the documented rationale for the estimation of the prior parameter values. Manually identify the overall prior parameters which have been affected by the change. Use Quality Model to modify the values of the affected prior parameters (i.e., Estimated Impact (EI) and leaf node Quality Characteristic Fulfillment (QCFs)).
6) Manually verify the updated prior parameter values (that QCFs are consistent relative to each other and that EIs on the arcs from a common parent sum up to one).

Guidelines for the "Quality prediction" sub-phase

Objective The propagation of the change throughout the rest of each one of the modified DVs, is performed. The propagation paths and the modified parameter values are obtained.

Prerequisites The specified change is within the scope of and fully applied on the prediction models.

How conducted Use the DV tool support to propagate the change. The tool explicitly displays the propagation paths and the modified parameter values, as well as the degrees of parameter value change. Obtain the predictions, in terms of the propagation paths and the parameter value modification. The result must explicitly express the changes with respect to the pre-change values. The propagation of the change throughout each one of the modified DVs, is performed based on the general DV propagation model, according to which the QCF value of each parent node is recursively calculated by first multiplying the QCF and EI value for each closest child and then summing up these products. Such a model is legitimate since each quality characteristic DV is complete, the EIs are normalized and the nodes having a common parent are orthogonal (with respect to the quality characteristic that the DV is dedicated to) due to the structure. The root node QCF values on the quality characteristic specific DVs represent the system-level rating value of the quality characteristic that the DV is dedicated to. If the predicted parameter values are beyond a pre-defined uncertainty threshold, the modifications are canceled and the change deemed not predictable by the input data and the models as such.

Input documentation DVs.

Output documentation The change is propagated throughout the DVs, based on the DV propagation model. Propagation paths and parameter value changes (relative to the original ones) are displayed.

Modeling guideline

1) Run the simulation on the DV tool, in order to obtain the change propagation paths and the modified QCF values of the affected non-leaf nodes of the DVs.
2) Display the changes performed on the Design Model and the DVs (structure and the prior parameter values).