Bridging the Gap between Multidimensional Business Problem Formulation and the Implementation of Multidimensional Data Models

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Abstract: In data warehouse implementations the comprehensive identification of user requirements is a critical success factor. The translation of business problems into conceptual data models is very challenging and currently there are no information systems that assist in these tasks. In this research, we therefore elaborate on the challenges in that specific area and develop an information system to gather information needs and automatically transform them into conceptual multidimensional data models. We then demonstrate the use of the information system within the domain of Human Resource Management.

1 INTRODUCTION

One of the most critical success factors of data warehouse (DW) implementation is the stringent user involvement and complete definition and consideration of user requirements (e.g., Olbrich, et al., 2012); (Yeoh, 2011); (Yeoh and Koronios, 2010); (Xu and Hwang, 2008). DW store a huge amount of business data from heterogeneous source systems and provide users with relevant business information. The decision whether a piece of information is relevant or not has to be determined by users according to the business problems to be solved. Within the DW context, the business problems addressed show certain characteristics such as multidimensionality or the consideration of hierarchies etc., which are specified in detail in section 2. Nevertheless, the DW system has to be business-driven in order to contribute to the solution of business problems (Olbrich et al., 2012); (Yeoh 2011); (Kimball, 1996). Therefore, the user requirements (in terms of their information needs) regarding certain business problems have to be comprehensively considered within DW projects. They serve as a basis for the business and technical concept of DW. One possibility to develop DW is to use the Model Driven Architecture (MDA) approach, which has been adapted for DW development (Mazón and Trujillo, 2008). Following this approach the user requirements have to be transformed into a conceptual model understandable by IT professionals but still independent from a specific DW platform.

Once the user requirements are known and designed as a conceptual model using for example UML (Mazón and Trujillo, 2008) system support is given in order to transform this model into multidimensional platform specific models and even into multidimensional code to implement DW systems (Mazón and Trujillo, 2008); (Gluchowski et al., 2009).

Concerning the user requirements methodical support is available to ascertain the specific information needs in the DW context (Winter and Strauch, 2003).

System support to transform conceptual multidimensional data models into multidimensional coding and methodical support to analyze information needs in the DW context are available. However, an integrated solution to support the ascertainment of information needs and to automatically transform these user requirements into a conceptual multidimensional model is still lacking.

Additionally there is a gap between the information needs articulated by business professionals using domain specific terms and the conceptual multidimensional model modeled in a language, such as UML for example, understandable

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by IT professionals. Given that the comprehensive consideration of user requirements is still a critical success factor, the support of these two phases, the ascertainment of user requirements and the derivation of a conceptual model, as well as bridging the gap between business professionals and IT professionals within the DW implementation is important.

Therefore, our aim is to develop an integrated solution to ascertain information needs and to automatically transform the user requirements concerning multidimensional business problems into multidimensional conceptual model so as to improve and support this step of DW system implementation.

Following the process model for design science research (Peffers et al., 2007) the paper is structured as follows:

The research problem is elaborated by depicting the state of the art concerning the MDA approach to develop data warehouse systems and by deriving the specific challenges to ascertain information needs concerning multidimensional business problems. In section three we derive the objectives for a solution to solve the research problem. Afterwards, the design and prototypical implementation of a software artifact, that solves the problem, is described. In section five the application of the prototype is demonstrated within the Human Resource Management (HRM) context and finally conclusions are drawn.

2 FROM USER REQUIREMENTS TO DW IMPLEMENTATION

2.1 The Model Driven Architecture Approach for Data Warehouse Development

The MDA serves as a standard framework for software development and allows the development of models by using a standard notation (OMG Group, 2012). The MDA separates the specification of functionality in a computer independent model (CIM) and a platform independent model (PIM) from the specification that is based on a certain technology in a platform specific model (PSM). Mazón and Trujillo (2008) and Mazón et al. (2005) developed an MDA approach especially for the development of data warehouses (see figure 1). In a first step all the user requirements have to be ascertained in a computer independent model (CIM). These user requirements serve as a basis for the modeling of every data warehouse layer by corresponding platform independent models (PIM). These models are specified using several UML profiles. The PIM can be automatically transformed into several platform specific models (PSM) which depend on the required target technology. Finally, from the PSM the necessary SQL code can be derived to create the multidimensional data structures for the Data Warehouse in a relational platform (Mazón and Trujillo 2008); (Gluchowski et al., 2009); (Kurze and Gluchowski 2008).

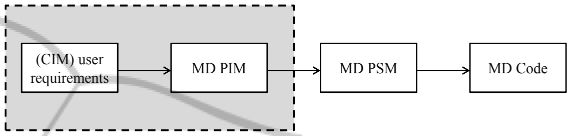

Figure 1: MDA approach for data warehouse modeling (Mazón and Trujillo, 2008).

According to MDA, the ascertainment of the information needs representing the multidimensional business problems is an essential step. As soon as a multidimensional platform independent model (MD PIM) exists an automatic transformation into multidimensional platform specific model (MD PSM) and even the generation of code is possible (Mazón and Trujillo 2008); (Gluchowski et al., 2009). This automatic transformation ensures that the specifications are comprehensively considered and mistakes due to manual transformations are eliminated. The automation therefore leads to time savings concerning the data warehouse implementation. Sophisticated methods to collect information needs in DW projects with clearly defined steps have been developed (Winter and Strauch, 2003), but they lack the support to transform CIM into MD PIM and require the manual modeling of MD PIM.

2.2 Formulating Multidimensional Business Problems

Data warehouses aim at providing OLAP functionalities to users and allow the interactive analysis of measures from multiple perspectives, the so called dimensions. Multidimensional business problems reflect the business need to analyze measures interactively from different and combined views, for example the analysis of the measure "headcount" at a certain time for a specific department detailed by qualification with the possibility to additionally view the age distribution. The main stakeholder in this context is the business professional who is responsible for formulating the multidimensional business problems. Business professionals comprise managers or controllers of certain business domains such as Human Resource Management (HRM), sales or financial management for example. Their information needs, based on their multidimensional business problems, reflect the user requirements to be ascertained in a CIM and which serve as a basis for the MD PIM.

First of all a clear definition and description of the measure has to be found. In order to build a homogeneous information basis with the data warehouse that provides information from heterogeneous source systems, the identification of synonyms and homonyms and a clear and precise definition of the relevant measure are indispensible (Winter and Strauch, 2003). Furthermore, there are not only simple measures, such as “headcount”, but also derived measures which are calculated using simple measures, such as “level of overtime” for instance, which is calculated using the “actual working time” and the “target working time”. A clear definition and in the case of derived measures a valid calculation rule ensures a common understanding of the measures which is essential in the data warehouse context since the data warehouse should serve as a general information base for the company. Multidimensional business problems aim at the analysis of measures from different dimensions. These dimensions (for example “time” or “region”) reflect the analysis facilities of certain measures. Beyond the multidimensional aspect there is also a hierarchical aspect within multidimensional business problems. It is important to perform analyses interactively on different aggregation levels along dimensions. This means for example, that the measure “headcount” should be analyzed within the dimension “time” on the level “day” as well as “week”, “month” and “year” while an interactive change between these different aggregation levels is possible.

The formulation of multidimensional business problems by defining measures or calculating derived measures, specifying dimensions and their hierarchical structure is very time intensive and hence costly. Deep domain knowledge is necessary to achieve a consistent multidimensional business problem formulation. The information needs have to be ascertained manually within a company. Usually, the requirement analysis is done with the business professionals by interviews and by analyzing existing reports and documents (Winter and Strauch, 2003). It is obvious that the formulation of a multidimensional business problem has to be based on business concepts related to a specific business domain such as sales, controlling or HRM. At the same time it needs to be understood by IT professionals in order to derive relevant multidimensional data models. The manual translation of the information needs into a MD PIM understandable by IT professional includes media breaks and hence bears the risk of misunderstandings. To meet these challenges we propose to develop an information system with business content stored in a knowledge base which supports the ascertainment of multidimensional information needs as well as the derivation of technically and conceptually understandable MD PIM. Our solution thus focuses on the creation of the CIM and the MD PIM as well as the respective automatic transformation (see figure 1).

3 OBJECTIVES FOR A SOLUTION

First of all, the system should serve to reduce time and cost for DW development by supporting and automating steps in the process of ascertaining information needs and deriving MD PIM. It is obvious, that the pure mechanism to automate process steps holds the potential to save time and costs, but it is not sufficient. In fact, the costly process of formulating multidimensional business problems (see section 2.2) should be supported by predefined business content reflecting a comprehensive collection of knowledge about potential measures in a knowledge base. The knowledge base stores the knowledge of diverse business domains such as HRM, sales and financial controlling. The measures should be defined clearly and in case of derived measures also concise calculation rules should be provided. Furthermore, all potential dimensions and hierarchy levels to analyze these measures should be stored in the knowledge base. This means that the knowledge base comprises all dimensions and hierarchy levels that are reasonable from a business point of view. This knowledge base then can serve to satisfy future information needs. So beyond necessary technical functionalities the predefined knowledge base is an essential part of the system to be developed. Therefore, the following first requirement for the system can be derived.

(R1) The system must allow the collection and management of knowledge about multidimensional business problems.

Whereas the system should provide a comprehensive and complete knowledge base about multidimensional business problems within a business domain, only a subset of this knowledge base is relevant in specific DW projects. Therefore, the system should support the user to ascertain the information needs with the feature to identify and select a relevant subset of the knowledge base. This specified subset then is used to derive the respective MD PIM. This objective leads to the following system requirement.

(R2) The system must support the user in selecting relevant measures and dimensions from the provided knowledge base according to specific information needs.

As elaborated before, the system should serve to avoid misunderstandings between business and IT professionals. Therefore, the usage of domain specific business vocabulary is mandatory and should be automatically transformed into a model language, such as UML, which IT professionals can easily understand and work with. This ensures a fail-safe communication between business professionals and IT professionals. Furthermore, media breaks are diminished as the formulation of the multidimensional information needs as well as the generation of a MD PIM are integrated in one system. According to the aforementioned objectives, the system must meet the following requirements:

(R3) The system must represent the information in ways understandable by IT professionals as well as business professionals.

(R4) The system must automatically generate a MD PIM based on the information needs of the business professionals in a common multidimensional model language.

The elaborated requirements are realized in a software artifact which is introduced in the following.

4 ARTIFACT DESIGN

4.1 Actors

As information systems are sociotechnical systems, the definition of potential actors is necessary (De Bruijn and Herder, 2009); (Bostrom et al., 2009). According to the objectives of the system, it aims at supporting business professionals and IT professionals who are therefore two potential actors of the system.

Business professionals represent the actual core user of the system. They are employees of organizations who want to execute multidimensional analyses in their business domain. While they have some idea of the information they want to generate they are usually not experts of multidimensional analysis or data warehouses. Their goal is to define and formulate their multidimensional business problem using domain specific concepts stored in the system.

IT professionals are the persons tasked with creating the DW. They usually have no or limited specific domain knowledge and therefore depend on the business professionals to provide them with their information needs. The system provides the IT professionals with understandable information by generating a MD PIM.

Furthermore, the management of the knowledgebase requires the definition of another actor, the domain expert. *Domain experts* represent persons who have a broad understanding of the relevant business domains and hence of relevant measures (their structure as well as their dimensions). This actor type includes business professionals as well as researchers and consultants with wide experience in specific business domains. The knowledge of the domain experts provides the basis for the knowledge base integrated into the system. Domain experts manage the knowledge base.

4.2 Components of the System

The underlying idea for the general design of the system is to gather the knowledge of the domain experts in a knowledge base which then can be accessed and used by other business professionals in order to generate a model the IT professional can work with (Earl, 2001). For this the System must provide three core functionalities: the management of the knowledge base, the selection of measures and dimensions (creating a MD requirements model) and the model generation (creating a PIM). The overall architecture of the system resulting from this design choice is shown in figure 2. Each component is further described in the following sections.

The repository comprises the knowledge base and a collection of MD requirements models. The knowledge base bases its models on the MD domain meta model describing the structure of the concepts in the domain and each MD requirements model is based on the MD requirements meta model.

As such, a first step in the creation of a system offering the required functionalities is the representation of the problem domain in the system: the MD domain meta model and the MD

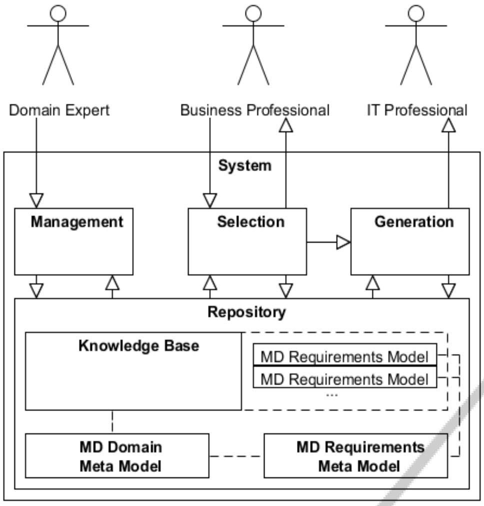

Figure 2: Components of the system.

requirements meta model. There are three types of primitives that make up the structure of these models: concepts, properties and relations between concepts. Concepts are central objects in the domain (e.g. a dimension or a measure). Each concept can have (one or more) properties. Each property has a name and a value. Concepts can be related to each other by relations. Relations are used for hierarchical ordering of concepts as well as other semantic meanings. For example the dimension “time” can be viewed at the dimension level “day” and “month” (hierarchical ordering), and the derived measure can be derived from other measures.

The concepts of these meta models are shown in figure 3. The main concept around which all other concepts are centred is the measure. Measures represent a numerical value uniquely determined by the value of the dimensions that provide its context (Chaudhuri and Dayal, 1997). Measures can be differentiated into simple measures and derived measures which are calculated using other measures. Dimensions allow the representation of measures on different aggregation levels.

The concept function can be used to categorize measures into specific business functions. Each function represents one business function and can be associated to as many measures as are relevant for that business function. Measures are not limited to one specific function, but can be relevant to multiple functions. The measures “actual working time” and “target working time” are relevant in the business function personnel retention as well as the business function personnel planning for example. This information is especially relevant for business professionals as they search relevant measures for the specific business problem they try to formulate.

The knowledge base stores the knowledge about multidimensional business problems in entities that are created based on the concepts defined in the MD domain meta model. Known and useful measures, calculation rules, dimensions and dimension levels as well as the functional association relevant for a business domain and relevant for multidimensional business problems are specified and stored in the system. For example, when the measure “actual working time” is described in the knowledge base, all potential dimensions such as time, region, organization etc. with respective dimension levels such as minute, hour, day, etc. are specified and personnel functions are determined and associated.

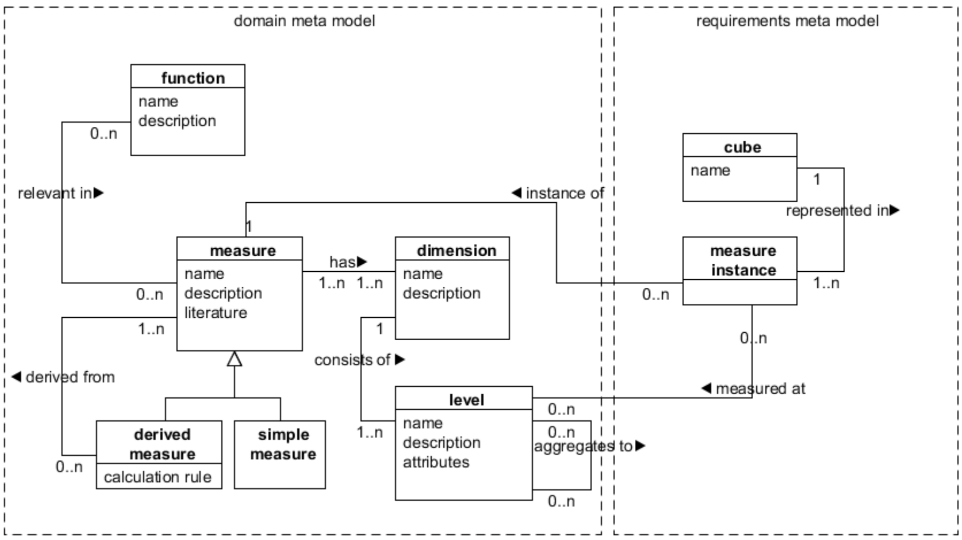

Figure 3: Meta models used by the system.

These entities of the knowledge base also have their properties assigned. While the properties used can differ from concept to concept, generally they all include a name and description property. Following the previous example, the property "description" of the measure contains a general description of this measure allowing other actors to better understand its meaning. Furthermore, the property "literature" of a measure can contain bibliographic content pointing to literature with comprising and detailed definition of the measure. If a measure is derived from other measures, the property calculation rule contains the rule by which this measure is derived from others. Beyond that, the source property of a measure provides information about the source systems from which a specific measure can be obtained.

The concepts cube and measure instance depicted in the MD requirements meta model (figure 3) are relevant for representing specific information needs contained in the MD requirements models. The MD requirements models each link to a specific part of the knowledge base according to the specific information needs they represent. While the knowledge base comprises the general knowledge about multidimensional business problems within different business domains, the specific information needs of business professionals constitute a partition of the whole knowledge base. By determining the information needs, measures are instantiated with specific dimensions and levels. As for example the measure "actual working time" has the potential dimension levels "minute", "hour", "day" up to "year" stored in the knowledge base, a specific information need comprises relevant dimension levels on a more aggregated level from "day" up to "year" neglecting the more granular levels. To allow this the measure instance concept links between the general measure and a specific dimension level at which it is measured.

4.3 Core Functions

The system offers three core functions providing the interaction of the actors with the system: the *management* of the knowledge base, the *selection* of requirement specific measures and the *generation* of a platform independent model from the knowledge base and the specific requirements.

The management component allows domain experts to access the knowledge base and to create, edit and delete respective entities. The domain experts are able to define functions, measures, dimensions and dimension levels and to specify the respective properties such as name, description, calculation rule, literature source etc.

Based on the knowledge stored in the knowledge base, business professionals can select measures, dimensions and dimension levels to define and formulate their multidimensional business problem, resulting the specific MD requirements models The process of formulating multidimensional business problems is facilitated by selecting relevant measures and determining the needed level and hence the business professional creates the MD requirements model, which can be seen as a CIM according to the MDA introduced in chapter 2.1.

Based on the MD requirements model and further information available in the knowledge base, a multidimensional platform independent model (MD PIM) based on ADAPTed UML (Priebe and Pernul, 2001) is generated. This model can then be used by IT professionals for further development of the DW.

4.4 Implementation Detail

The system architecture described is realized as a web application created using Java technologies. In the prototype the raw data managed in the repository is saved in a graph database Neo4j (Neo Technology inc., www. neo4j.org/) since the interconnected concepts in the domain and requirements model suggest that form of storage. Furthermore Neo4j offers a simple and clearly defined API, allowing the wrapping of nodes directly to java objects. The different components of the system can then work on those objects without having any knowledge of the underlying persistence layer. The inference mechanisms needed by the selection and generation components are achieved by extending the java objects, i.e. adding new methods that will support the inference based on the underlying graph nodes and relations. For example the measure instance "actual working time" gathered at the level "day" is also available at all aggregated levels such as "week", "month" and "year" which are inferred by the method. In the database the node representing the measure instance "actual working time" specified at the level "day" is only connected to the node of the dimension level "day". By traversing the graph the system can then infer the other dimension levels available for the measure.

The representation on the client side is achieved by different dynamic pages. They allow users to access the management functionality of the knowledge base as well as the selection and generation component.

The generation component furthermore allows a visual representation of PIMs in the ADAPTed UML notation on the dynamic page, as well as the export of these models as an XML document, so that they can be further edited with independent modeling tools.

5 APPLICATION IN HRM

The prototype implemented so far contains a comprehensive knowledge base for the business domain Human Resource Management (HRM). A comprehensive literature review in the domain of HRM was performed. To identify relevant literature a keyword search using a scholarly Internet search engine (scholar.google.com), several scholarly online databases (ABI/Inform, Business Source Premier, Scopus, and Science Direct) and online-libraries was employed. Search terms such as " HRM" and "controlling" in combination with "metrics" or "measures" as well as "recruiting" or "performance" were applied. The literature review revealed 208 domain specific HR measures such as "headcount", "level of overtime" or "absence quote" with nine dimensions such as "organization", "time" or "communication channel". Within every dimension detailed hierarchies are stored which reflect the most granular and widest possible spread of the respective dimension. Also heterarchies, parallel hierarchies and different path lengths are possible. The dimension "time" for example contains "minutes" as the most granular level and can be aggregated into "weeks", "month" and "years" also considering the specific aggregation of "days" in "weeks" and in "months". To give an example considering the knowledge base: The measure "actual working time" can be analyzed via the dimensions "time", "organization", "employee" and "region" where all of these dimensions contain comprehensive hierarchies such as depicted for the dimension "time". Furthermore a clear definition of the measure "actual working time" is provided. The "actual working time" is a simple measure and has no calculation rule. But the "level of overtime" for example uses the "actual working time" and rates this against the "target working time" which is defined in the respective calculation rule. Beyond that, it is also possible to enter the source system in which the measure or part of the measures are stored. If for example the "actual working time" is so far stored in Excel files, this information can be entered into the system so as to provide the IT professionals with information for the ETL-process in the DW project.

The screenshots provided in figure 4 represent the functionality to select certain measure instances (a) and to specify the needed dimension levels (b)

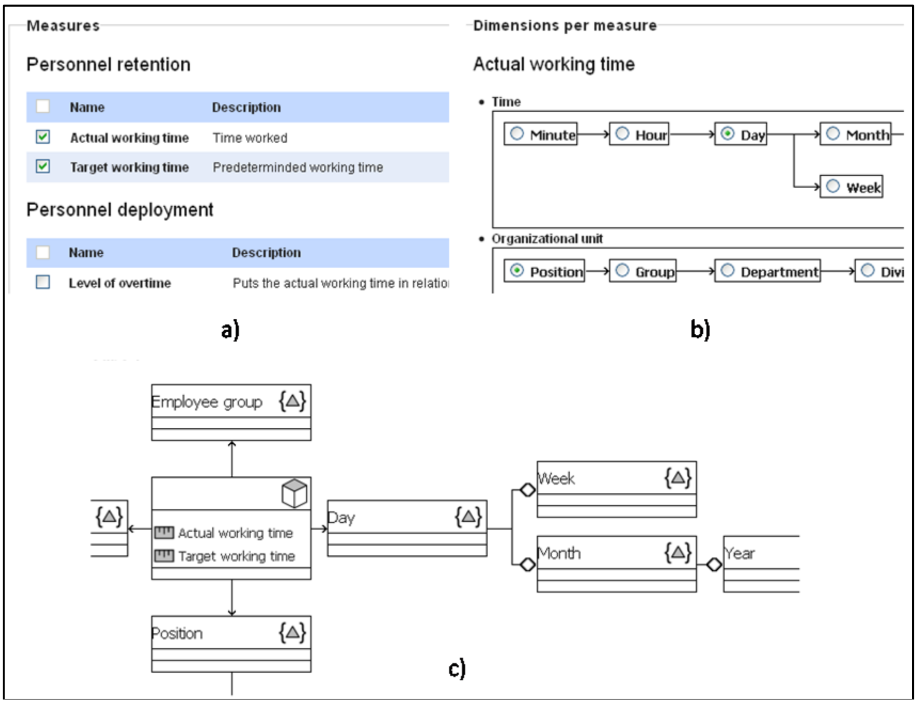

Figure 4: Screenshots of the prototype.

and the generated MD PIM using ADAPTed UML (c).

In order to support the business professional with the selection of relevant measures, the measures within the domain model are structured based on HR functions derived from the Michigan Approach (Tichy et al., 1982). This is a well known and wide spread approach to categorize HR functions and is relevant for practice as well as for research. Hence, this categorization supports the business professional to select the relevant measures and diminishes the costs of structuring specific multidimensional business problems. The possibility to select relevant measures and relevant dimensions supports the ascertainment of user requirements. Furthermore, domain experts can also expand the knowledge base in case new requirements appear.

In the screenshot (figure 4, a), the two measures “actual working time” and “target working time” associated to the HR function personnel retention are selected. As these measures are relevant for multiple HR functions such as personnel retention, personnel planning and cost planning for example, these measures can be found within all of these HR functions. The business professional selects these two measures from one of the mentioned HR functions and further determines the relevant hierarchy levels by selecting the appropriate dimension level (figure 4, b). The functionality of the system is demonstrated for the case that the “actual working time” and the “target working time” should be analyzed from multiple perspectives such as time and organizational unit (among others). Depending on the information needs the aggregation levels can be flexibly selected such as for example the dimension level “day” (and higher levels) within the dimension “time” and the dimension level “position” (and higher levels) within the dimension “organizational unit” (figure 4, b). In a last step the IT professional can trigger the model generation and receives a conceptual multidimensional data model in ADAPTed UML (figure 4, c), the MD PIM. IT professionals can use this model to further implement the DW. The XML-export function also allows the export of the specific requirements model into a modeling tool.

6 CONCLUSIONS

It could be demonstrated that the developed prototype supports the specification of user requirements concerning the formulation of multidimensional business problems. The business professionals can work with the predefined knowledge base and specify a requirements model using their familiar business terms. This requirements model then serves as a basis for the generation of the MD PIM. Due to the knowledge base, time intensive and hence costly processes of ascertaining information needs and of formulating the multidimensional business problems can be avoided. Furthermore the communication with the IT professional can be improved since the business professional still works in his business domain using domain specific vocabulary and the conceptual model for the IT professional can be generated automatically. The HR business professional works only with concepts known in the HR domain and does not have to think about e.g. parallel hierarchies or the number of cubes to model. All the concepts are provided within a predefined knowledge base familiar to the HR business professional. Given the generated MD PIM, the DW development process can further take advantage of the transformation steps demonstrated by Mazón and Trujillo (2008) and Gluchowski, Kurze and Schieder (2009).

Nevertheless, there are some limitations and further work to be done. First of all, the developed system has to be evaluated by professionals within DW projects. The evaluation could for example be based on the Technology Acceptance Model (Davis, 1989) or the Information System Success Model (DeLone and McLean, 2003) to research acceptance and success of the system.

Furthermore, it is obvious that the knowledge base, especially its completeness, is essential for the applicability and success of the prototype. So far, the prototype only contains HR measures, dimensions and dimension levels found in literature. It is planned to integrate the knowledge of domain experts that are business professionals as well as researchers or consultants in the specific business domain into the knowledge base. For this purpose the prototype will be provided via web so the domain experts can access the system and incorporate their knowledge and enter measures, definitions, calculation rules, dimensions and dimension levels. To ensure the consistency and validity of the system, an authorization and releasing concept for the changes made by the domain experts has to be worked out and implemented. So far only the HRM domain is implemented but other business domains such as sales or financial controlling can be integrated as well.

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