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Completed Research Paper

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Abstract

Data warehouses increasingly play important roles in the information technology landscape of the financial industry. However, semantic heterogeneity is high in banking – data is defined differently by different banks, business units, and users. Therefore data integration in financial data warehouse development projects relies on the knowledge, know-how, and judgment of human experts. Up to now, methodical support is missing for the communication process among experts that determine and negotiate a shared understanding of requirements. In contrast to ontology-driven or schema-matching approaches proposing the automatic resolution of differences ex-post, we introduce an approach that addresses data integration already in early project phases. Our approach supports developing shared understanding of domain concepts and data fields in financial data warehouse projects, good communication of all participants while the project progresses, and early detection of errors within projects. This way, we prevent problems that result from the ex-post resolution of semantic heterogeneity.

Keywords: Communication theory, Business intelligence (BI), Data warehouse development, Knowledge sharing, Common ground, Language

Introduction

Data warehouses (DWH) increasingly play important roles in the information technology (IT) landscape of the financial industry. IT has become one of the main factors of production in banking because the production process of a bank mainly consists of information processing (Baldwin et al. 2001; Tan and Teo 2000). That is why it is critical for financial institutions to be able to access relevant data when it is needed most. Analytical applications, in practice often described as "business intelligence", allow users to access data and use it to make decisions in order to realize the full value from their DWH costs (Watson and Wixom 2007). Moreover, financial institutions increasingly have to fulfill extensive regulatory requirements such as Sarbanes-Oxley Act, IFRS, or Basel II (McLaughlin 2004). These regulations demand of banks to conduct calculations that include the institutions' whole portfolio and detailed subsidiary data. The importance of such integrated and consolidated risk estimation has been emphasized by the recent financial crisis which has been triggered by the rise in delinquencies in the United States. Therefore many banks have implemented DWH solutions during the last decade to enhance decision-making, controlling, and risk management.

However, the adoption of DWH technology, which requires huge capital spending and also consumes a good deal of development time, has a very high possibility of failure (Hwang et al. 2004). The challenge stems from multiple causes such as poor data quality in the operational source systems, politics around data ownership, and legacy technology (Hwang et al. 2004; Hwang and Xu 2007; Watson et al. 2004; Weir et al. 2003; Wixom and Watson 2001). One of the biggest challenges for DWH designers is *data integration* – the consolidation of data from disparate sources into one consistent body of data (March and Hevner 2007, p. 1036). In general, the meaning of a specific data field in its context varies from company to company, from business unit to business unit, and from department to department. Such differences can be as simple as naming conventions or units of measures (March and Hevner 2007, p. 1038). In the financial industry, the differences frequently are much more complex and involve different meanings ascribed to captured data (Behrmann and Räkers 2008). For example, what is the meaning of terms such as "limit", "bond", "interest payment" and so forth, and which data fields of what source system map to these meanings? Therefore *semantic heterogeneity* (March and Hevner 2007, p. 1038) is high in banking – data is defined differently by different banks, business units, or users. No common standards for data integration exist until today in the financial industry. Such an universal, consistent, and unitary description of all types of financial businesses is not a realistic option because financial institutions constantly update their business models by rapidly developing new products and services in order to gain a competitive advantage (Corcho et al. 2005). Consequently, semantic heterogeneity is likely to stay high in the financial industry. Moreover, banks struggle to integrate all relevant data because data sources are often heterogeneous, disorganized, or even inaccessible. For these reasons financial DWH systems still are tailor-made, cost-intensive applications, even if standardized core banking systems do exist. Therefore effective data integration can only ever be achieved by human experts who have access to knowledge about internal and external business contexts – "What questions are momentarily important?" – and access to knowledge pertaining operational systems that have to be integrated – "Which operational systems provide data for answering those questions?" (March and Hevner 2007, p. 1041).

Although the relevance of data integration in general is assessed to be high (March and Hevner 2007; Rizzi et al. 2006), only few researchers work in this subject area (Skoutas and Simitsis 2006; Vassiliadis et al. 2005). This is remarkable because the high effort of data integration seems to be without controversy – getting data into a DWH is the most difficult aspect of business intelligence, requiring about 80 % of the time and effort and generating more than 50 % of the project costs (Kimball and Caserta 2004; Vassiliadis et al. 2002; Watson and Wixom 2007). The goal of this paper is to introduce an approach that primarily consists of a tool-supported procedure for designing, managing, and tracking requirements for data integration in financial DWH development projects. Our approach aims to support (1) developing shared understanding of domain concepts and data fields, (2) good communication of all participants while the project progresses, and (3) early detection of errors within projects. This way, we prevent data integration problems that result from the ex-post resolution of semantic heterogeneity.

We follow a Design Science approach (Hevner et al. 2004; Hevner and March 2003) that deals with the construction of scientific artifacts for solving a problem. As a theoretical basis for our approach, we make use of linguistic communication theory and Clark (1996)'s central thesis that "language use is really a form of joint action" (p. 3). In projects as a joint activity, the source of project participants' ability to coordinate and create shared understanding is their *"common ground"*, the set of knowledge, beliefs and suppositions that they believe they share (Clark 1992; Clark 1996; Clark and Brennan 1991). Our approach supports development of common ground by jointly introduc-

ing, discussing, and negotiating concepts and terms, including descriptions of their meanings. Although the approach has been developed for financial DWH development projects, which we also use for illustrational purposes, our approach is in principle generic and can be applied to any domain being equally prone to semantic heterogeneity.

The remainder of the paper is structured as follows. First, we analyze related work on DWH development and the research gap that led to the development of our approach. Next, we introduce a conceptual framework for supporting financial DWH development that builds on communication theory. Then we present our approach and the design components. The feasibility of the approach is demonstrated with a detailed application scenario and evaluated using multiple case studies. We finish the paper in a "Conclusions and Outlook" section and motivate further research.

Related Work and Problem Awareness

Several studies have revealed the importance of determining information requirements in DWH development (Watson et al. 2004; Wixom and Watson 2001). To develop DWHs, it is necessary to identify what kind of data has to be provided to whom for what kind of management decision. Consequently, numerous researchers have presented different *approaches for DWH design, DWH development, and DWH engineering* over the recent years. Some of these have been suggested by practitioners (Ballard et al. 1998; Inmon 2005; Kimball and Caserta 2004; Kimball and Ross 1996). In addition, researchers and academics have proposed a variety of approaches (Böhnlein and Ulbrich-vom Ende 1999; Cavero et al. 2001; Chenoweth et al. 2003; Giovinazzo 2000; Golfarelli et al. 1998; Golfarelli and Rizzi 1998; Holten 2003; Mazón and Trujillo 2008; Moody and Kortink 2001; Trujillo et al. 2001; Tryfona et al. 1999). Many of these target a specific conceptual modeling approach (for example, star schemas with ER models) and are often too complex to be used in real-world environments (Malinowski and Zimányi 2008). None of these approaches has been widely accepted and all feature some deficits (Abell et al. 2001; Mazón and Trujillo 2008). The development of a DWH has been traditionally guided by an in-depth analysis of the underlying operational data sources, thus overlooking an explicit development phase in which information requirements of decision-makers are addressed (Mazón et al. 2007). March and Hevner (2007) conclude that current methodologies for DWH engineering are in their infancy.

Even with a fitting DWH engineering approach, semantic heterogeneities and data integration continue to pose enormous challenges for DWH developers, especially in the context of data extraction, transformation, and loading (ETL) (Vassiliadis et al. 2005). *Schema matching* is often proposed as a solution in data integration contexts and relies on discovering correspondences between similar elements in a number of schemas, for example, from different operational source systems. Researchers have proposed several different approaches for schema matching (Bernstein et al. 2004; Do and Rahm 2007; Doan et al. 2003; Ehrig and Staab 2004; Madhavan et al. 2001; Rahm and Bernstein 2001; Shvaiko and Euzenat 2005). However, schema matching in environments with heterogeneous data is time-consuming and error-prone, as existing mapping tools employ semi-automatic techniques for mapping two schemas at a time. Saleem et al. (2008) conclude that even sophisticated state-of-the art semantic matching approaches cannot guarantee that the mappings are 100 % correct, and ultimately still have to rely on human judgment to select the best candidate as the mapping for the source schema elements to the target schema elements.

Ontologies (Campbell and Shapiro 1995; Simperl and Tempich 2006; Uschold et al. 1998) seem like a possible solution for the schema-matching problem. They offer the potential for interoperability because they are semantically rich, computer interpretable, and inherently extensible. Ontologies can be applied for integration of heterogeneous data sources once a robust domain ontology is established. However, several ontologies exist in the financial industry (Mäkelä et al. 2007), and it is unlikely that a common, parsimonious ontology will ever be developed. The financial domain is constantly changing and developing new products, and innovative financial institutions are not willing to share their knowledge, being afraid of losing their competitive advantage (Corcho et al. 2005).

Fundamentally, the problem of data integration in financial DWH development projects is not a pure technological problem. What is really needed in financial DWH development projects is a standardization of the concepts and terms themselves. This results in involved stakeholders from business and IT that communicate and discuss with questions along the lines of "What does this mean?", "Is this the same as one of those?", or "What does this model actually show?" For example, does the term "redemption" for a bond mean the same thing as for a fund? Are the meanings of the term "redemption" in both contexts related or are they completely different? And which data fields of operational source systems capture those meanings? Therefore data integration relies on the knowledge, know-how, and judgment of human experts (Behrmann and Räkers 2008). What financial DWH development projects really need to capture is the semantics of the terms themselves, not only the words or data field names. To sum up,

we identify the following need for the development of DWH in the financial industry: up to now, methodical support is missing for (1) the communication process among experts that determine and negotiate a shared understanding of requirements, concepts, and terms relevant for the financial DWH, and (2) for managing (creating, storing, updating) a consistent terminology based on a shared understanding of the requirements.

Design Rationale and Conceptual Framework

Caused by the broad scope, the large size, and the heterogeneous IT infrastructure and environment, a multitude of different stakeholders is involved in financial DWH development projects, for example, DWH experts, operational source system specialists, business (subject matter) experts, or business managers and decision-makers. Each group of stakeholders owns specific knowledge which has to be reflected in DWH specifications (March and Hevner 2007, p. 1035). During a financial DWH development project, the data integration requirements usually are analyzed starting from the business perspective (business information requirements). After defining the basic scope of the financial DWH, the business content is detailed, specified and merged with the IT perspective (conceptual and logical design). Therefore both business experts and IT experts have to reach a shared understanding and develop an integrated specification of the business information requirements. Financial DWH development can therefore fundamentally be understood as a *communication process* between stakeholders with expertise in different fields of knowledge.

Although the importance of knowledge transfer, negotiation, and communication for IS development (ISD) are recognized (Hansen and Lyytinen 2010; Levina and Vaast 2005; Robillard 1999), linguistics and communication theory have only seldom been applied for studying or supporting ISD (Auramäki et al. 1992; Clarke 2001; Corvera Charaf and Rosenkranz 2010; Flores et al. 1988; Goldkuhl and Lyytinen 1982; Holmqvist 1989; Schoop 2001).

In psycholinguistics, Clark's and collaborators' research on human language (Clark 1992; Clark 1996; Clark and Brennan 1991; Clark and Krych 2004) has provided a communication theory that has been useful in research on human-computer interaction (HCI) and computer-supported collaboration work (CSCW) (Kanda et al. 2004; Maglio et al. 2002; McFarlane and Latorella 2002; Olson and Olson 2000). Although the use of Clark's work as a theoretical framework is not without controversy (Koschmann and LeBaron 2003; Nova et al. 2008), the concept of common ground, for example, has been extensively applied for designing computer-mediated communication (Carroll et al. 2006; Convertino et al. 2009; McCarthy et al. 1991).

In contrast, Clark's theory has sparsely been used in the IS discipline, for example, for studying knowledge integration in virtual teamwork (Alavi and Tiwana 2002), for examining the use of IT systems in organizations (Sjöström and Goldkuhl 2005), or for language-based IS evaluation (Ågerfalk 2004). To the best of our knowledge, however, these concepts have never been applied in the context of examining or supporting ISD. In particular, we are not aware of any study that applies these concepts to deal with DWH development as a communication process.

Some well-established theoretical principles about the communication process follow from research by Clark and collaborators (Clark 1992; Clark 1996; Clark and Brennan 1991; Clark and Krych 2004).

Principle 1: Communication is a joint activity

What makes an action such as DWH development a joint one is the coordination of both *content*, what the participants intend to do, and *processes*, the physical and mental systems they recruit in carrying out those intentions (Clark 1996, p. 59). Joint actions require active involvement and constant verifications by all participants. Joint actions such as DWH development cannot be accounted for without understanding the interplay between content and process, and their place in overall joint activities; conversations cannot work without coordination of both content and process (Clark 1996, pp. 59, 319). Content and process are interdependent: the more complicated the content, the longer the process (Clark 1996, p. 90). Moreover: a minor misunderstanding at the beginning might snowball into major ones in the end (Clark 1996, p. 235). In the context of DWH development, this principle suggest that the whole project team has to establish early transparency regarding the meaning of data fields in order to achieve data integration (content); the available operational source systems have to be jointly analyzed by business experts and IT experts, and subsequently have to be consolidated into an integrated specification of the data supply (process).

Principle 2: Communication depends on a grounding process

The basis for coordination is shared knowledge (common ground) between actors. The grounding process, the process of establishing mutual understanding, is always adaptive to the current context of communication (Clark 1996, p. 99) and totally depends on the assumptions of the common ground made by the sender. In general, two types of

common ground do exist – process and content (Clark and Brennan 1991). *Content common ground* includes "I know that you know that I know *what*", *process common ground* encompasses "I know that you know that I know *how*" (Convertino et al. 2009). Content common ground is the shared understanding on the subject and focus of work, resulting from exchanging content and mutually checking and signaling understanding. Process common ground is the shared understanding of the rules, procedures, timing, and manner in which the interaction will be conducted. The principle of grounding and the concept of common ground are perhaps the most central concepts from Clark's theory for DWH development. Common ground is incrementally built on the history of joint actions between communicators. The creation of a shared understanding and common ground is the prerequisite for a correct data mapping and ETL design. To reach this goal, the business information requirements must be understood by all involved team members. In financial DWH projects, content common ground is related to the need to selectively share information about meanings: for example, team members must know what businesses, operational source systems, and data fields the group is discussing, why they are discussing it, what the meaning of the concepts and terms is, and what information is known by themselves and others. At the same time, process common ground allows team members to be more effective in their information sharing: once they know how the group is working, this process knowledge helps them to know when they should perform specific actions that can help to make progress toward the shared goal (Convertino et al. 2009).

Principle 3: Communication is a multi-modal process

Communication involves more than just words or verbal, written or spoken, conversations. Less conventional forms of language such as vocal gestures, facial expressions, eye gaze, and postures also help people to make signals and exchange messages (Clark 1996, p. 180). It has been proposed that specific communication contexts can be described in terms of specific sets of grounding *constraints* (Clark and Krych 2004): the more constraints a media can provide the better the media is for facilitating common ground. This is mirrored in research regarding the use of media for specific situations (Daft et al. 1987; Kock 2005). In the context of complex DWH development, this principle also implies that mere written specifications of the business information requirements, the conceptual and logical data models, or the ETL concept may not be enough.

Clark's theory and principles have been tested in psycholinguistics by Bromme and collaborators (Bromme 2000; Bromme and Jucks 2001; Bromme et al. 2005a; Bromme et al. 2005b; Bromme et al. 1999; Jucks et al. 2008) in two special situations that are very similar to scenarios of ISD and DWH development projects:

- *Communication in case of high differences in knowledge between sender and receiver* (expert-layperson communication as can also be observed in financial DWH development projects between business users and IT experts). Expert-layperson communication is characterized by low common ground between the actors at the beginning of the communication process in which the common ground will not only be accumulated but also restructured. People usually have an "egocentric bias": if I know something, I am more likely to expect others to know it too (Clark 1996, p. 111). For a successful knowledge transfer a change in perspective is necessary, that is, the expert must assume the knowledge of the layperson. This is difficult because there is a *systematic difference* between the perspectives of both. In this context the term "systematic" means that not only knowledge elements in the layperson's perspective are missing but they are also embedded in a *cognitive reference framework* (CRF). In particular Bromme and Jucks (2001) found that these CRFs are mainly determined by the participants' background and their specific education. Moreover CRFs of laypersons are partly resistant against changes. Utterances of the expert will be embedded in an inaccurate context without stimulating adaptations of the CRF. This may cause an "*illusion of evidence*". In this situation the expert overestimates the understandability of transferred facts (Bromme and Jucks 2001, p. 93).

- *Communication in case of communication without face-to-face contact* (distributed projects as can also be observed in large multi-national financial DWH development projects). In case of written communication without face-to-face contact, direct feedback based on gestures and verbal intervention is not applicable. Caused by the higher effort for feedback in written form the receiver often gives no response. Due to this fact the probability of misunderstanding and illusion of evidence increases rapidly. So missing understanding will often not be signaled in practice (Bromme and Jucks 2001, p. 93; see also Garrod and Anderson 1987).

We argue that these insights from communication theory can be transferred to financial DWH development projects. The financial industry shows a complex problem situation, many involved stakeholders, and lots of misunderstandings, especially regarding the exact meaning of terms and data fields (semantic heterogeneity). If we regard the interaction between the involved stakeholders as an instance of expert-layperson communication then our approach has to address corresponding communication issues. Achieving common ground therefore is the main goal of our

approach. However, there is a high risk of illusion of evidence scenarios. These situations are difficult to detect because none of the involved persons are aware of the lack in common ground. One implication of the findings on expert-layperson communication is the use of feedback-loops to check if the knowledge transfer has been successful. Additionally, supporting application systems, tools, and documents must have a structure which is logical and understandable from both layperson's and expert's perspective. In case of written communication (requirements documents, logical and conceptual models, tools and databases) more effort for the anticipation of the layperson perspective is necessary. We possibly even have to encourage and motivate people to signal a missing understanding. This implicates the importance of strong interaction within groups and face-to-face communication (Bromme et al. 2004, p. 186).

Based on this we propose to follow *three strategies* that support and facilitate the development of both process and content common ground in financial DWH development projects. The three strategies are described in Table 1.

Table 1. Strategies for Supporting Common Ground in Financial DWH Development Projects		
Strategy	**Description**	**Principle addressed**
(1) Improve requirements specification with regard to development of common ground	It may be useful to extend the specification and use formal, standardized descriptions whenever possible as to provide constraints, but to retain and encourage lots of not formalized areas as well as mechanisms and space for discussions and negotiations regarding meaning of requirements, concepts, and terms.	Principle 2 (selectively share information), principle 3 (provide constraints)
(2) Detect and signal remaining communication defects early	Early detection and signaling of remaining communication defects is necessary to avoid high fixing cost. For example, operational systems data analysis at early stages might allow early detection of errors.	Principle 1 (joint activity), principle 2 (share know process)
(3) Reduce scenarios with potential for illusion of evidence	Workshops, personal interaction, and on-site visits are expensive but may be needed, possibly coupled with mechanisms for signaling missing understandings.	Principle 1 (joint activity), principle 3 (multimodality)

Specification of the Approach

We iteratively developed the final configuration of the artifacts that are presented here (Baskerville et al. 2009). Our approach for financial DWH development was continuously refined as the method was put into use and exposed to environmental constraints in field studies (cf. section "Application and Evaluation"). The continuous application of the method led to adaptations and enhancements and resulted in redesigns of the approach, which is a common occurrence in Design Science research (Vaishnavi and Kuechler 2008, p. 25).

To establish common ground in financial DWH development, the strategies (cf. Table 1) are implemented as three artifacts:

1. A *template* for specifying information requirements for the domain of financial DWH completely and understandable wherever possible.

2. A *procedure model* comprising process definitions (i. e., what to do in a project phase) and organizational aspects (i. e., roles and responsibilities) for financial DWH development.

3. A *software tool* implementing template and procedure model. The tool provides views to support different stakeholder groups and communities of practice in financial DWH development projects.

Template for Information Requirements (Specification Format)

Project stakeholders from several (sub-) domains are either experts or laypersons on aspects of the domain in question (here: financial DWH domain). We propose that in such scenarios, a *domain-specific template* helps to define content common ground between stakeholders (design rationale: improve requirements specification, strategy 1, cf. Table 1). In order to discuss the meaning of things or concepts, we need to explicate our knowledge first, for example, by writing it down (Boisot and Canals 2004). Only if we try to formalize and codify the meaning of a thing or concept, we begin to notice that different meanings exist for this concept, and we can engage into discussions of those meanings. In general a template has to instantiate a meta-structure for content common ground in the domain specified by superior categories needed for requirements specification. For financial DWH, the template has to specify the relevant categories for ETL design (Rizzi et al. 2006; Vassiliadis et al. 2005), including basic business information requirements (for example, attribute definitions for data fields) and several additional facets (for example,

meta-data for ETL processing). Appendix A presents the data model of the template and Table 2 gives an overview of the superior categories. A different template is needed for scenarios in other domains.

Field Categories	Description
Table 2. Overview of Template Specification Format	
Supplementing structures and content of attributes	Some information about the content of the attributes cannot be covered easily by a simple description, for example, product catalogues, currency conversion, limit structures, customer structures, and so forth. Requirements pertaining these categories need to be specified and discussed.
Data quality needs	To fulfill both the expectation of the end user and legal requirements, data quality is of uttermost importance in financial DWH. For example, this category includes the specification of mandatory attributes, enhanced data quality rules, and concepts for checking the completeness of DWH data.
Data-processing meta data	The data load strategy and the technical design of issues such as load frequency play important roles for the development of the ETL job framework. Different parts of the information demand are processed on different levels, for example, daily (profit and loss (PNL) data), weekly (internal risk report), monthly (regulatory Basel II reporting), or yearly (balance sheet information). This data-processing meta-data has to be discussed.
Historical data requirements	For a historization concept, the definition of time periods for the storage of the data is needed, for example, for time series analysis or for the fulfillment of archiving requirements.
Granularity of data	Depending on the business information requirements, the granularity for different data may differ. For some analyses, transactional levels must be available (PNL calculations); others can be done on aggregated data.

Procedure Model

Our basic design rationale for the procedure model is that establishing *process* common ground requires stakeholders' knowledge of the intended (formal and informal) communication processes. Recent research on team decision-making and collaborative technology has shifted attention from team mental models to transactive models of sharing – knowledge of who knows what within a team; such models appear more appropriate for group tasks involving interdependency and role specialization (Convertino et al. 2009). We claim that knowing intended communication channels and all other team members' expertise, roles, and responsibilities in the project reduces the need for unintended communication between team members. Therefore we specify the sequence of a set of selected development phases, with explicit forward and feedback communication channels between roles in these phases.

Following transactive models of knowledge sharing, the development of *content* common ground in financial DWH projects can be enhanced by enabling team members to selectively determine what knowledge should be shared in the process. Therefore we specify output objects (for example, files and documents) for every single phase of our procedure model. We propose that the development of content common ground can be enhanced by using these outputs as *boundary objects*. Boundary objects are a form of boundary connection to bridge knowledge boundaries separating stakeholder groups and communities of practice (Bergman et al. 2007, p. 662; Brown and Duguid 2001, p. 105; Pawlowski and Robey 2004, p. 209). In order to actively participate in multi-stakeholder product design, such as the design of a DWH, and to actively support the design, for example, by indicating "successful progress" or "impending issues" in the design, Bergman et al. (2007) argue that boundary objects need to possess four features: (1) promote shared representation, (2) transform the design knowledge, (3) mobilize for design action, and (4) legitimize the design knowledge (Bergman et al. 2007, p. 551). Bergman et al. (2007) define objects embodying these four features as *design boundary objects* (DBO). Therefore our output objects are designed to conform to these four features.

Our procedure model (cf. Figure 2) follows an iterative, agile development approach (Cao et al. 2009) and differs from traditional "waterfall-based" methodologies often used in DWH development (Giorgini et al. 2008; Inmon 2005; Kimball and Caserta 2004; Mazón and Trujillo 2008; Moody and Kortink 2001). Sprints-like stages are used for procedure phases and are coupled with constant forward and feedback loops, data quality checks, and a focus on communication for detecting errors near the beginning through early deployment and quality testing of data integration and ETL models. Therefore *explicit* and extensive communication phases for presenting and negotiating the meaning of data requirements by all stakeholders are designed for the procedure model:

- *Business Information Requirements Analysis*. Design rationale: improve requirements specification (strategy 1, cf. Table 1). By interviewing business managers, other decision-makers, and business experts, DWH experts determine the project goal from an end user perspective and iteratively collect needed information. Output: end

users' information requirements are documented as formally as possible as *target data models* using the domain-specific template.

- *Data Requirements Presentation and Negotiation*. Design rationale: detect communication defects early, reduce illusion of evidence, and improve requirements specification (strategies 1 to 3, cf. Table 1). DWH experts discuss all target data models with business experts, business owners of operational source systems, and corresponding IT experts during Joint Application Design (JAD)-like workshops (Dennis et al. 1999). Joint discussions with these "data suppliers" and operational experts are crucial because they allow early detection of misunderstandings, different meanings, and other communication problems such as illusion of evidence. If necessary, team members have to step back to the "business information requirements analysis" phase to clarify end user needs. Output: *mapping specification* between target data models and data sources.

- *ETL Design and Implementation*. Design rationale: detect communication defects early; reduce illusion of evidence (strategies 2 and 3, cf. Table 1). Technical as well as business problems concerning data sources and transformation are clarified during implementation between DWH experts and operational IT experts on a very detailed level (for example, issues such as load frequency for a specific data field). Open questions concerning these technical and operational details force team members to step back to the "data requirements presentation and negotiation" phase and improve and correct the specifications. The specification is gradually improved until all open issues are deemed to be addressed. Finally, an interim version of the DWH is deployed. Output: *reports* based on the data that is loaded into the DWH.

- *Sample Data Analysis*. Design rationale: detect communication defects early; reduce illusion of evidence (strategies 2 and 3, cf. Table 1). The reports as results of the previous phase are jointly analyzed in detail by DWH experts, operational IT experts, and business experts as regards completeness, correctness, and accuracy. Sample data analyses are conducted automatically and manually (for example, it is checked if reported measures account for the same numbers as a manual calculation of business experts). This is done to prevent illusion of evidence and to detect communication defects that still remain after the previous sprint cycle early on. This check of data quality is especially important if regulatory and legal requirements need to be fulfilled or if the data are used for risk management. Output: *data quality issues list* that compiles remaining data integration conflicts.

- *Clarification and Negotiation*. Design rationale: detect communication defects early; reduce illusion of evidence (strategies 2 and 3, cf. Table 1). The remaining data quality issues have to be resolved with all stakeholders. The resulting discussions feed directly back into the "business information requirements analysis" phase of the next cycle. Output: *edited data quality issue list* that is annotated with comments from all stakeholders.

The phases are repeated in cycles until all data quality issues are sufficiently resolved and the final DWH is constructed.

Software Tool

Bergman (2009, p. 405) suggests that specifications in a development process need to conform to the four features of a DBO. This can be supported by a software tool that manages the output DBOs and that affords selective sharing, specifying, and negotiating of information meanings. We argue that such a software tool (IT artifact) supports faster discovery of misunderstandings between all team members and thereby accelerates the creation of content common ground. This enables the transfer of knowledge across boundaries between stakeholder groups. Moreover, a software tool can act as a bracket connecting the different steps of the procedure model, thereby effectively supporting process common ground through guiding team members along the stages of the procedure model (design rationale: implement template and support procedure model, thus addressing all three strategies). In this, it is a DBO in its own right. The so-called *Data Requirements Tool (DaRT)* was iteratively developed to support the procedure model (cf. Figure 1Figure 1Figure 1 for a screen shot of the user interface, showing an exemplary form). DaRT implements the template (specification format) described above (cf. Appendix A for the underlying data model). Its navigation tree supports navigation of data requirements (left side of Figure 1); completeness of the requirements specification is enforced by the structured user interface for discussing and editing content (right side of Figure 1).

Database tables are defined in the technical configuration overview. The tool encourages the user to create a business view which contains a selection of fields coming from data tables. A combination of those views is grouped to business areas. Figure 1 shows client table 'Deals - External rating deal' and business area 'Standardized Approach'. The focused attribute 'RATING_AGENCY_ID' is shown in detail on the right side. Views can be set as mandatory

or not in every business area on its own. General comments on table attributes can be enhanced by view-related comments. This supports discussions and negotiations of meanings directly in DaRT. A field status indicates the reached status of negotiation. Multiple status values can be used and defined individually to support each user organization best. Further information is provided to document the identified data source for the data requirements in this specific business area (source system, table, and field name). Additionally, a free text field allows further documentation (for example, meeting minutes, involved persons, time references, and so forth). These features make the tool a reliable information pool containing details of the financial DWH development process.

Every suggestion in DaRT reduces misunderstandings, enhances content common ground, and improves specification quality. When working together with the tool and documenting every single step, all involved people commit to the results of their work immediately and also control whether other involved team members document their work correctly. This helps detecting illusion of evidence scenarios. By applying the procedure model and using DaRT, people are literally "forced to talk to each other" about the problems and get into deep interaction. DaRT also allows versioning of these negotiation steps. The formalized structure of the tool also leads to a better documentation and eases tracking and control for project managers. The current status and status changes can promptly be reported. DaRT thus provides a central repository for the DWH design status. As a financial DWH is a central system with lots of stakeholders, lots of people can access this documentation. Project managers have a good overview regarding deficient data requirement negotiations by tracking the field status over time. Therefore problems can be detected early and directed to specialists. In addition DaRT is used to configure data quality rules. Those rules are directly derived into the database management system to provide technical checks in the ETL process. During the application in real-life field situations (cf. section "Application and Evaluation") lots of standard rules were implemented in DaRT. This knowledge about data sources can now be reused throughout future financial DWH development projects dealing with similar business areas. Furthermore, existing data requirement descriptions can be reused as well.
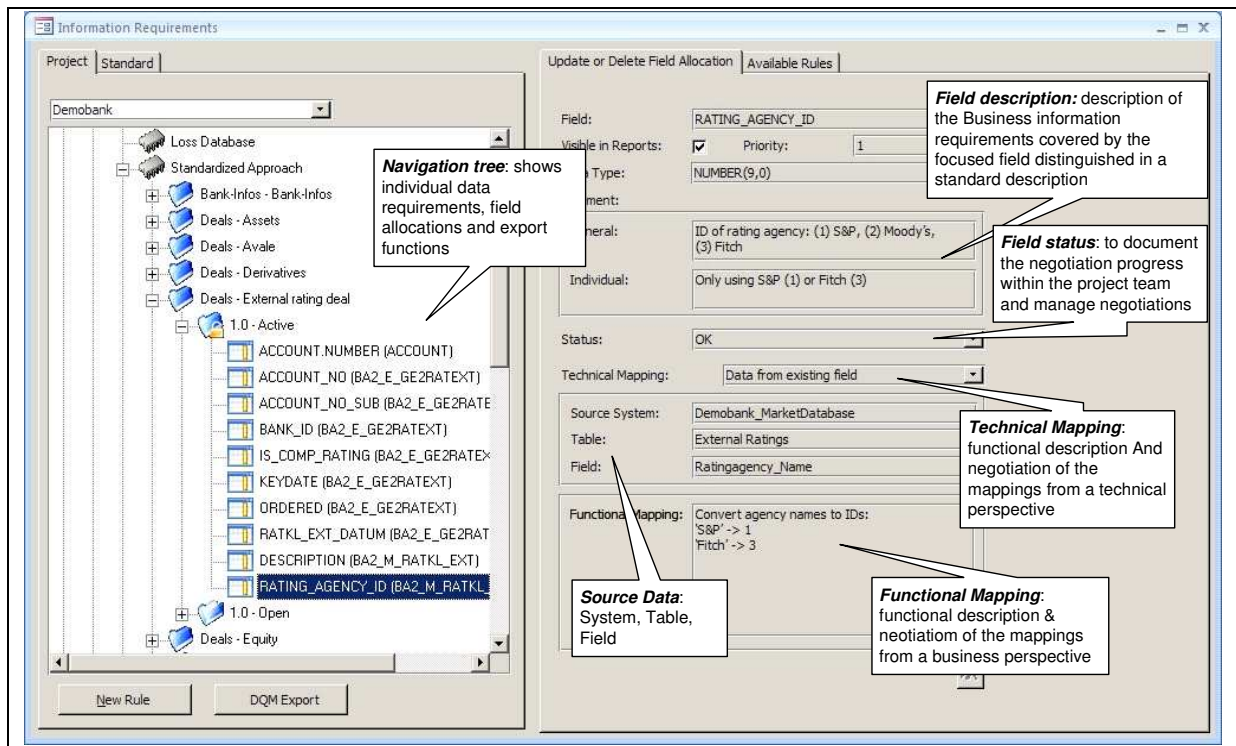

Figure 1. Exemplary Screenshot of DaRT Interface

Recap of the Approach

Figure 2 summarizes our approach and illustrates the iterative interplay of artifacts and roles in each cycle. At the beginning of a financial DWH development project, the business information requirements and the resulting data requirements are collected and codified as best as possible in a structured way, using mostly interview-based techniques (phase "business information requirements analysis").

These requirements are described in the specification format according to the domain-specific template and stored in a structured database within DaRT. An initial draft version of the data requirements specification is used to align all data requirements in the bigger picture and to derive the draft target data model. For each requirement the relevant data sources need to be identified in JAD-like workshops and face-to-face discussions (phase "data requirements presentation and negotiation"). The target data model is amended stepwise by detailing the data requirements and designing data flows from different source systems. During the workshops the project team discusses the data requirements, adds details to the descriptions to document their understanding of the requirements, and defines a status for each data requirement. People are forced to write-up more documentation for data requirements that lead to defects in communication, thereby allowing others to gain a better understanding of the defects. The data requirement status is also used by project managers to validate effort estimations and forecast the progress of the project.

Next, DWH experts and source system specialists use DaRT to document first rough ideas of how the source system data needs to be transformed to fit in the DWH (phase "ETL design and implementation"). The team uses these initial designs to add details, negotiate open issues, and improve the specification. The highly dynamic ETL implementation process requires a timely documentation to avoid misunderstandings. Therefore DaRT is used to document decisions taken by DWH experts and source system specialists.

As soon as possible, the team loads sample data in the DWH using the implemented data flows from one source system each (phase "sample data analysis"). This allows finding problems regarding design, implementation, or data quality as early as the first cycle.

Figure 2. Summary of Approach for Financial DWH Development Projects and IT Artifact Support
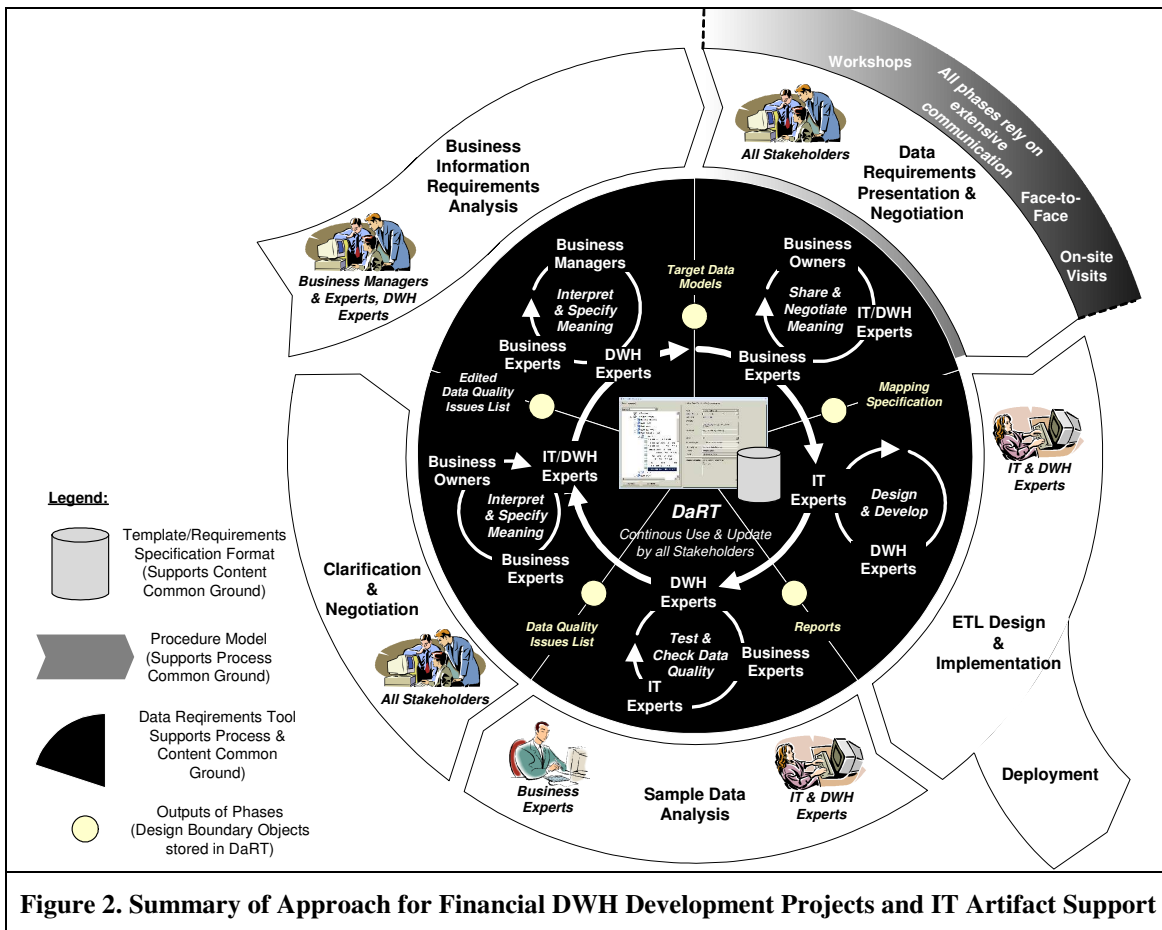
Application and Evaluation

During design science research the intended (and unintended) impact of the artifacts needs to be scientifically evaluated to show their usefulness in solving the intended problems (Hevner et al. 2004; Winter 2008). This can involve comparing objectives and observed results in real-world settings. We therefore translate our theoretically motivated

design into expectations about observable behavior in financial DWH development projects to enable its empirical evaluation. This results in the following propositions for evaluating effectiveness and utility of the artifacts:

The use of the artifacts supports the development of process and content common ground in financial DWH development projects. Therefore (1) it leads to earlier detection of errors, (2) it significantly enhances project performance (the development process), and (3) it significantly enhances the quality of the final product (the DWH).

Research Strategy and Design

For the evaluation of our artifacts in organizational settings, adequate research methods are required (Gregg et al. 2001). As a first step, we employed an *embedded multiple case study design* (Yin 2003, p. 49) in order to examine the usefulness of the artifacts during their iterative development. The six financial DWH projects of various banks in Europe that were selected as cases are typical for recent projects in the European financial services sector. The trigger for all selected projects was the supervisory requirements known as Basel II (BCBS 2006). These regulations demand specified risk calculation and risk treatment processes that have an impact on the whole structure of financial institutions and became law in most member states of the European Union in 2007. Table 3 gives an overview of the cases. All projects were conducted with the help of zeb/information.technology, a German consultancy which focuses on IT in the financial services industry.

The first set of cases (projects at Bank A-C) did not employ any of the developed artifacts whereas the second set of cases (projects at Bank D-F) did use some or all of the artifacts in different states of their development (cf. row "Treatment (artifact)" in Table 3). Following Lee (1989), natural controls that were already in place were also utilized. For example, focusing on persons who were participants in more than one of the cases held constant the people factors while comparing projects. Therefore control in the research design was already in place. Other examples of natural controls are the scope of the project and the parallel implementation of a new core banking system. Two of the authors are practitioners that have worked for more than seven years for zeb/information.technology. They participated in all three of the selected projects that were conducted without the approach (Bank A to C). Afterwards both participated in the design of the artifacts but not in the subsequent projects (Bank D to F). The other two authors were not involved in any project. They acted as unbiased observers and neutral interviewers in the case studies and during the evaluation of the artifacts. The analyses of the case studies in Bank D to F evaluated the artifacts and led to refinements of the design (for example, DaRT was a response to a need for managing the template).

Table 3. Cases Overview and Comparison						
	Bank A	*Bank B*	*Bank C*	*Bank D*	*Bank E*	*Bank F*
Balance value	100 bn. EUR	70 bn. EUR	7 bn. EUR	4 bn. EUR	2 bn. EUR	230 bn. EUR
No. of countries	> 13	> 5	1	2	2	> 5
No. of subsidiaries	18	6	-	-	-	15
Person days (CONS)	~13,500	~5,000	~5,000	~4,000	~7,000	~3,000
Project scope	Europe	Europe	Germany	Germany	Germany	Europe
Project duration	> 5 years	> 2.5 years	> 2 years	> 1.5 years	> 2 years	> 1.5 years
No. of team members	> 100	> 150	> 20	> 25	> 15	> 25
Core system change	no	yes	yes	no	no	no
Perceived complexity[1]	very high	high	medium	very high	medium	high
Treatment (artifact)	-	-	-	procedure & template	procedure & DaRT prototype	procedure & DaRT
[1] collectively determined on a scale from 1 (very low) to 5 (very high) during a focus group meeting of all involved project managers						

Direct observations by the first two authors, unstructured and semi-structured interviews, structured self-estimation surveys of project members, project documentation, and e-mail exchanges were used to generate data and collected in a case study database. We interviewed both project managers and project workers. Since at the time of the interviews most of the selected projects or related successor projects were still ongoing, this minimized the risk that participants displayed retrospective bias or that they had already forgotten something in their interactions with other project members. The collection of the data was started in March 2007 and ended in December 2008. During data collection, we conducted 17 interviews with 11 project members, spread over all six projects. The interviews were controlled by a semi-structured interview guideline and were either conducted by phone if the informants worked at

the time in geographically remote locations or in face-to-face sessions at the organizations' site. The interview guideline was not shared with interviewees and was only used as a general outline. Coding techniques and checklists were used to connect data with the propositions (Miles and Huberman 1994, pp. 170-244; Yin 2003, pp. 109-138).[1]

Case Studies' Narratives and Analyses

All projects deal with the following typical setup. All banks consist of a head office and subsidiaries in Germany or different European countries. The projects aim to develop an application system which meets the regulatory requirements of Basel II and delivers reports to the financial supervisory authorities. One main task of the projects is to implement a central financial DWH. The focus of the projects lies in determining the relevant amount of capital required for credit risk for the total international bank portfolio of the banks. Primarily, data of transactions, collaterals, customers, and rating information of both head office and subsidiaries have to be delivered and consolidated into the central financial DWH. To achieve this, each subsidiary has to develop extraction jobs for their local databases and operational source systems (for example, for managing collaterals); the extracted data are then sent to head office and imported into the financial DWH.

As expected, semantic heterogeneity was high in all six cases. Different meanings of important IT-related and business-related concepts and terms existed in all banks. Several concepts were not immediately interpreted in the same way by all involved stakeholders (low initial content common ground in all six cases).

> *"[…] we had problems concerning demarcations of conceptions, what really is meant by turnovers and settlements of accounts in the context of … in connection with credit cards. There, they always understood it differently in parts because you can definitely argue 'Is the disposal on the credit card a turnover or is it not a turnover until I have the credit card debit booked to the account?'"* (Interview with project member DF, translated by the authors)

> "*A typical example is the 'Buchwert'* [German: book value]*, which is really interpreted differently by each department. Whether these are people from risk management or the controlling people, or also the different units, everybody understands something a little bit different, so whether some interests are included or not or whether these are outlined separately ….*" (Interview with project member BK, translated by the authors)

Cross-Case Analysis for Bank A, Bank B, and Bank C (Cases with no Treatments)

Several problems resulting from a different understanding of the meaning of concepts surfaced in the projects that did not employ the approach but instead followed a more traditional, specification-driven methodology for DWH development. For most of the projects' runtime, it seemed as if project members from head office, different departments, and subsidiaries each "spoke different languages" because the interpretations of the published specification varied to a considerable degree (slow creation of content common ground in the cases of Bank A, B, and C).

> "*In fact, there are really thirteen data warehouses that have to be loaded identically, but which weren't loaded identically because how should one load them identically if nobody takes care that this happens? This was the case in the first implementation phase, that one just gave the documents to everybody and everybody did interpret them. And the results were thirteen interpretations. […] This only surfaced in the discussions later […]. There it made kind of 'Click! Ah, that is why so very much is not working here!'* " (Interview with project member JS, translated by the authors)

Moreover, throughout Bank A to C, the waterfall-based, specification-driven approach caused similar problems and made communication and knowledge exchange processes very difficult by being too constrained and too formalized (low process common ground in the cases of Bank A, B, and C).

> "*… one simply used examples to reach an agreement, if possible, and then one came out of the workshop. And then, naturally, every time there were callbacks and further inquiries, one met on the floor. Thus it was not concluded with the workshop; but then, it always was this special business case, and then they called us by phone or we met somewhere and they say 'By the way, I have another question' and 'How do we do this exactly?', and we discussed this together.*" (Interview with project manager WB, translated by the authors)

However, the mode-of-procedure within all three projects was changed from being specification-driven to being more communication-driven as the projects progressed. Self-estimated efforts for on-site meetings were up to three times higher after this than before. For example, so-called task forces were established for subsidiaries that had not been able to deliver data on time because their interfaces did not work properly. The project managers at head office

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[1] Due to space constraints, details on the interviewees and interview guideline are available from the authors on request. Max-QDA (http://www.maxqda.com/) was used for coding interview transcripts and for linking other data from the database.

voiced concern that just sending out the interface specification had not been enough to clarify the meaning of all important concepts. Personal face-to-face contact and even on-site visits were necessary for solving these misunderstandings. The creation of content common ground by intensive face-to-face communication and physical inspection was one of the central factors for project success according to the key informants within the projects (low initial process common ground, slow creation of process common ground by change to communication-driven procedure that helped to establish better content common ground in the cases of Bank A, B, and C).

> "*This then changed from the initial procedure of 'We send you a concept; look what you got and send us back the results' to a much more workshop-oriented procedure. So one did say 'We have to support you much more, we come over to you and look everything through in workshops together with you' and in a second step one conscripted the colleagues respectively and said 'We let our project member sit with you and he will support you for the next days and weeks'.*" (Interview with project manager TA, translated by the authors)

> "*… but the real turning point, where this issue had full management attention, came actually in April 2007, where one said the data delivery does not work at all … and only then one saw what a shit this was … and then did decide that we need so-called task forces, and only then I came back to the project, very different persons now became involved, who really were on-site [at the subsidiaries] and went through the data with them weekly, looked at the data fields and discussed every single thing.*" (Interview with project member BK, translated by the authors)

Consequently, the specification and the few initial workshops were not enough to generate a shared understanding. The technical face-to-face coaching and on-site visits were very important so that the stakeholders discussed the requirements and could analyze and negotiate if the specified requirements really were reasonable and meaningful for everybody (creation of content common ground). To recap, we observed slow creation of content and process common ground at Bank A, B, and C. This resulted in errors, quality issues with delivered data, and project performances were ranked lower by project managers compared to the other three projects (cf. row "Ranking" in Table 4).

Cross-Case Analysis for Bank D, Bank E, and Bank F (Cases with Treatments)

As shown above, high semantic heterogeneity and low initial content common ground also characterized the projects in Banks D, E, and F. The major difference is that these projects were using some or all of the approach's artifacts in some version (early design, prototype, or final configuration; cf. row "Treatment (artifact)" in Table 3). During the course of the projects, shared understanding emerged due to the daily interactions of all project members and stakeholders (early development of content common ground). The employed procedure model relied on the initial workshops of all involved stakeholders, and a lot of direct face-to-face communication ensured that ambiguity gradually was reduced. Most of the time was spent for specifying the data requests in face-to-face communication.

> "*[The procedure model] makes it easier in the implementation phase, but is more complicated during the coordination of data requests. […] Because you have to discuss this longer so that they understand it correctly, that you make the point. […] And that's why the coordination just took months, especially those events concerning loss control, this is so complicated, till you understand that yourself and because they had to implement that in the source system themselves, this took ages.*" (Interview with project manager SK, translated by the authors)

The specification format was first used in the project at Bank D. At Bank E, the complete course of the project was accompanied by a prototype of DaRT for the first time, implemented by zeb/information.technology's internal software department.[2]

> "*At Bank D the tool was not existing […] we had Excel sheets containing the data requests, and there not two persons could work simultaneously, you have version conflicts. Then in customizing a lot of people work with views, and data quality management is in the views and nobody knows why, if an error occurs […] And that's why I figured it could be useful to have such a tool […] where you have standard data requests and can describe the mappings.*" (Interview with project manager SK, translated by the authors)

Due to the employed procedure supported by DaRT and the communication-intensive "data presentation and negotiation" phase, content common ground quickly emerged. After the first cycle, additional meetings and discussions of DWH experts, IT experts and business experts became necessary, for example, if data field descriptions had to be supplemented in order to make the meaning of terms clear and to reduce ambiguity. The prototype was used intensively for specifying data requests in these phases and for quality checks in the "sample data analysis" phase.

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[2]   DaRT is commercially available as a module of "zeb/data.quality-manager", see http://www.zebcontrol.com/.

As described above (cf. "Software Tool" section) DaRT allows for detailed consistency checks in both testing phases and operational loading phases, and generates reports showing errors and open issues. All project members including employees of Bank E and Bank F used DaRT for specifying the business view mappings according to source systems. Moreover, all project members used the tool for checking the consistency of the data fields and to mark open issues and problems. The use of the tool, coupled with the intensively communication-oriented procedure model, provided process common ground and facilitated the creation of content common ground within the project.

> *"So, DaRT, we basically enter all data requests that we have into it. […]And in the next step, for each source system, a specialist […] looked where he could get those data fields in his source system. And then you naturally always had inquiries […] by setting a status marker accordingly and by sending the questions regarding those fields back to the business department, who could really use DaRT for directly giving the answers. And the next step was that those who should get the data out of the source systems, into the data warehouse of the bank, again looked into DaRT and there they found their … yes, they quasi found the mappings already described there and could implement them relatively quickly."* (Interview with project member MK, translated by the authors)

During the coordination phase and the accompanying discussions DaRT proved to be extremely useful in order to really understand the situation and relationships at Bank E and Bank F. The tool documented the history of common ground creation and all project team members could refer back to it and use it as a guideline for open issues, problems and misunderstandings. Basically, the tool allowed for semantically mapping the meaning of concepts at Bank E and Bank F to data fields in the DWH and the operational source systems, and to engage into clarifying discussions about understanding issues. Together with the procedure model this provided process common ground and simplified the creation of content common ground, speeding up the process of sense-making. Open issues could be tracked and questions regarding meanings of terms could be sent to the business department. Employees in the business department tried to answer those questions directly in the tool and afterwards, the IT developers could continue directly with those fields. This was perceived as an enormous support for the procedure model.

Comparing the cases of Bank D, Bank E, and Bank F, which all used the new procedure model, DaRT – which was only used as a first prototype at Bank D – especially helped to follow through with the distinctive phases:

> *"Eventually, if you make such alignments, then this leads to the uncovering of any errors or that we ask any questions, and then they [the employees of the bank] give thought to those issues and then new solutions appear, so 'you don't really need this, this possibly is still wrong in our system', so you get more clarity in this, clearly. [At Bank E] we put a lot of emphasis on the standardization of the data requests, that wasn't that standardized before […] and at Bank E the customer worked with the tool, continuously, and then a process came into life. […] it isn't an agony to consolidate the data requests but a part of the job. [At Bank F it took] two and a half months, then we had the first connection, the complete system. At the others this took seven, eight months in parts […]."* (Interview with project manager SK, translated by the authors)

Cross-Case Summary

For ranking the projects' performance we have taken the following approach. After conducting the case studies we contacted seven project managers involved in all six projects to invite them to participate in a focus group discussion with us. The purpose was to (a) discuss the projects and (b) to establish a ranking scheme on the basis of their expert opinions. These professionals had an average experience of five years with financial DWH development and created two to four financial DWH each during this period, indicating a considerable level of expertise.

During the workshop, a presentation was given by the researchers, explaining each project. Next, all participants were asked to rank the six projects with respect to the project's performance, understood as the quality of the process, the quality of the final product, and the project's efficiency using a scale of 1 to 6. For this scale, a rank of 1 indicates that a project is perceived as having the highest relative performance; a rank of 6 indicates the other end of the scale, representing the lowest relative performance. The participants were asked to give a full ordering, that is, assigning an equal rank to two or more project was not allowed. Afterwards the single rankings were presented, discussed among all workshop participants, and consolidated into one final ranking (presented in Table 4).

Summing up, all six projects are comparable in scope and complexity. The latter projects that used some or all of the components of the presented approach are ranked higher in performance than the first three projects that did not; the quality of product and process of the latter three projects were stated to be superior. The projects managers also ascribed this difference in performance, at least partially, to the artifacts. Based on our findings we cannot completely rule out that, as all projects have been conducted with the help of zeb/information.technology, the DWH consultancy's many aspects of abilities on DWH application will be increased with the experiences of the previous pro-

jects. Although we tried to employ natural controls such as interviewing project team members for both single and across projects, we cannot completely eliminate factors like the improvement on project abilities. These abilities, however, are also clearly supported by the artifacts.

> *"[…] and only at this point in time [the start of the project at Bank F] we finally had finished all the tools. So, DQM [data quality management], DaRT, and we had people and so on, which extremely look to it that if something doesn't work you still continue […] instead of botching. […] DaRT assists us, personally, very strongly because we do the DQM process with it, that is, [we] maintain all data quality management rules with it, keep hold of all data requirements with it. Because we thus have had four or five controller loops so far, we always could extract the data requirements quite fast. Everybody knows exactly where they have to check and have the same approach."* (Project manager SK during workshop, translated by the authors)

The experience and knowledge about data sources, for example, is at least partially stored within DaRT, existing data requirement descriptions are reused in lather phases of the financial DWH development project, and DaRT and the procedure let all team members know about their tasks, roles, and responsibilities. The cumulated expert knowledge about and experience with the procedure is taken to other financial DWH development projects by the involved team members of the consultancy. This important issue has to be addressed in further performance and utility evaluations of the artifacts.

Table 4. Summary of Cases Evaluation and Design Cycles						
	Bank A	**Bank B**	**Bank C**	**Bank D**	**Bank E**	**Bank F**
Ranking	6th	5th	4th	3rd	2nd	1st
Treatment A (Template)	-	-	-	+ (in spreadsheets)	++ (in prototype)	++ (in DaRT)
Treatment B (Procedure)	-	-	-	+ (without tool)	++	++
Treatment C (DaRT)	-	-	-	-	+ (prototype)	++ DaRT
Observed Effects	Illusions of evidence & late detection of errors were observed (low content common ground). Once the procedure shifted from a specification-driven approach to a more communication-driven approach common ground was created.	Communication problems & late detection of errors were observed (low content common ground). The procedure shifted to a more communication-driven approach. Problems were realized earlier than in Bank A.	Communication problems, illusions of evidence & late detection of errors were observed. The procedure was shifted to a more communication-driven approach at an earlier stage than in Bank A or Bank B.	Early existence of content & process common ground. Early detection of errors, better communication and better project performance compared to Bank A-C.	Template & procedure helped create content and process common ground DaRT prototype helped create process common ground. Better communication and better project performance compared to Bank A-D.	Template & procedure helped create content and process common ground. DaRT helped create process common ground. Early detection of errors, better communication and better project performance compared to Bank A-F.

Conclusion and Outlook

The four overarching objectives for DWH support of management decision-making processes identified by March and Hevner (2007) – integration, implementation, intelligence, and innovation – assume a high affiliation between the stakeholders participating in a DWH development project. Until today effective techniques (a) for collecting information needs and requirements and (b) for translating those requirements into conceptual models based on a common vocabulary between IT experts and decision-makers are missing (Jarke et al. 2009; Rizzi et al. 2006). As demonstrated through our evaluation, our approach successfully addresses these problems for the case of financial DWH development projects. Integrating principles grounded in communication theory is promising for increasing the performance of financial DWH development projects and avoiding ambiguities in knowledge representation due to semantic heterogeneity. Two characteristics are significant to avoid common problems:

- Defining and providing mechanisms for supporting content common ground prior to financial DWH development project start is the basis for avoiding errors early on rather than resolving them later. Therefore time-consuming ex-post data quality checks and correction become dispensable.

- Guiding project team members during financial DWH development and creating process common ground is of substantial importance, since we can assure the compliance with the procedure model and thus the creation of content common ground only in this way.

Thus, the main contribution to practitioners concern projects' time and costs. However, analyzing costs-benefits, several issues have to be taken into account, which seem to decrease the benefit of the approach at a first glance. The procedure model relies on intensive communication of all stakeholders, not just on specifying information requirements in written form, and this can be very time-consuming. We found that defining, presenting, discussing and negotiating the requirements is indeed quite time-consuming. Taking into account that in most financial DWH development projects requirements are defined anyway (although in absence of methodical support), and that early detection of errors due to early creation of content common ground trade-offs early communication costs against late coordination and fixing costs of errors, this cost issue is moderated. Moreover, once the requirements specification format is defined, it is reusable for further projects in the organization or domain.

Looking at the financial DWH development process itself, the suspected slow-down turned out not to be significant in the case studies. The execution of the procedure model including defining, discussing, and negotiating is fast enough not to be recognized by project team members as a burden and leads to less overall communication because of significantly reduced errors and illusions of evidence. After our first field studies, project team members expressed that they were not slowed down by the approach overall, but even sped up, because they did not need to think about later errors and issues of data quality any more. However, the most promising aspect of the approach is that semantic heterogeneity is overcome by intensive communication and development of common ground between all stakeholders. With regard to the use of DBOs as presented by Bergman et al. (2007), we can confirm that DBOs help to resolve the ambiguity and uncertainty associated with semantic heterogeneity and complex requirements. However, Bergman et al. (2007) mainly concentrate on the features that boundary objects need to reflect in order to become DBOs; this gives no concrete guidance for practitioners on how to implement these features into DBOs. Our research shows an example of how DBOs can be designed and used within ISD.

The case studies we have conducted provide a first understanding of the benefit of the approach, but they have to be extended to a significant population of projects to be able to score it precisely. Since the cases took place in real-life environments, we cannot rule out that better performance was achieved because of other causes than due to our approach. Likewise, we focused on communication processes. Other factors (users' capabilities, characteristics and goals, institutional contexts, power, or culture) may be important and might need to be supported by other means as well. Another obvious limitation of the evaluation relates to the ranking scheme used for performance measurement. Clearly, the derived ranking has a small empirical basis as it relies on the involvement of seven project managers only. This raises the importance of further studies to arrive at a more rigorous evaluation, for example, through experimentation and surveys. However, as the qualitative content analysis reveals, project members attribute the better performance to the artifacts and are quite positive about it. Further evaluations concerning applicability and acceptance as well as efficiency will be subject of empirical studies to be performed in the short term.

Our main contribution to research is the combination of the two so far separated research areas of ISD and communication theory. Linguistic alignment in interactions between humans plays a critical role in achieving successful communication; there is now growing evidence that the same processes are operative in interactions between humans and computers, and indeed that they occur to a greater extent (Branigan et al. 2010). Linguistics and communication theory, however, have until now only seldom been applied for studying or supporting ISD. Applications of communication theory in ISD open new research opportunities, for example, in the area of ISD stakeholder communication (expert-layperson). The explication of expert knowledge and support of expert-layperson communication in ISD, which are nearly impossible without mechanisms and constraints for creating common ground, are further very promising areas of research. Finally, applying concepts from communication theory and linguistics in IS research permits a new field of application and the evaluation of these concepts.

Our future research will focus on further evaluating the proposed approach. In the short-term, the approach will be instantiated for different DWH development projects and for other application scenarios that are characterized by high semantic heterogeneity as well. In particular, the capability of our approach to increase the efficiency of distributed ISD and its acceptance will be evaluated. Long-term research will evaluate on a larger scale to what extent the development of common ground can improve the knowledge representation and communication processes in ISD projects.

Acknowledgements

Appendix A: Data Model

Figure 3 shows a simplified Entity Relationship Diagram (ERD) for an excerpt of the DaRT relational database that implements the specification format (domain-specific template). Martin's notation (crow's foot notation) for cardinality and optionality is used to show the relationships between the tables (Finkelstein 1989). Open circles indicate an optional relationship, while vertical slashes indicate a required relationship. The 'crow's feet' indicate that many tuples (i. e., many rows) can take part in the relationship, while a single slash indicates that only one tuple (i.e., one row) may take part. Dotted lines are used to indicate relationships that are not completed.
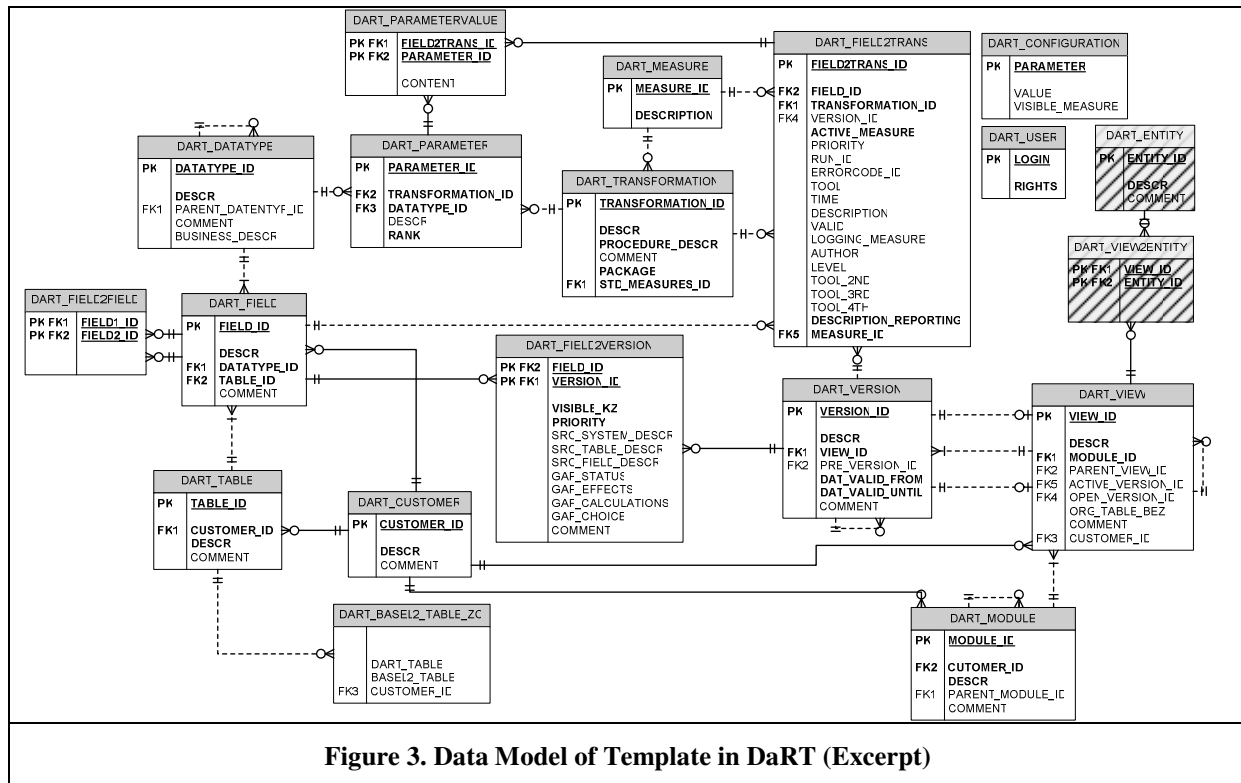

Figure 3. Data Model of Template in DaRT (Excerpt)

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