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FROM DATA WAREHOUSES TO TRANSFORMATION HUBS – A CONCEPTUAL ARCHITECTURE

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Abstract

Originally, Data Warehouses (DWH) were conceived to be components for the data support of controlling and management. From early on, this brought along the need to cope with extensive data preparation, integration, and distribution requirements. In the growing infrastructures for managerial support ("Business Intelligence"), the DWH turned into a central data hub for decision support. As the business environment and the underlying technical infrastructures are fostering an ever increasing degree of systems integration, the DWH has been recognized to be a pivotal component for all sorts of data transformation and data integration operations. Nowadays, the DWH is supposed to process both managerial and operational data – it becomes a transformation hub (TH). This article delineates the relevant motives that drive the trend towards THs and the resulting requirements. The logical composition of a TH is developed based on data transformation steps. Two case studies exemplify the application of the resulting architecture.

Keywords: Data Warehousing, Data Transformation, Business Intelligence, Enterprise Systems.

1 INTRODUCTION

Business Intelligence (BI) denotes integrated approaches to decision support (Baars & Kemper 2008). In recent years, BI has been increasingly recognized as a pivotal subject for IT management (Gartner 2009). One of the subjects in the domain of BI that is currently been focused both by BI practitioners and BI researchers is how to extend BI infrastructures to tactical and operational levels and how to achieve a closer coupling of operational and BI systems. There is a puzzling variety of intertwined concepts that can be subsumed under this general theme: *Business Activity Monitoring* (DeFee & Harmon 2004), *Operational Business Performance Management* (Golfarelli & Rizzi & Cella 2004), *Embedded BI* (Hashmi 2004, Klawans 2008), *Real Time Analytics* (Raden 2003), *Active and Real Time Data Warehousing* (Akbay 2006, Brobst 2002, Raden 2003), *and Operational BI* (Chemburkar & Keny 2007, Marjanovic 2007). Each of those terms represents a different facet of the general trend to either utilize BI infrastructures for the support of operational decisions or to further bind operational and managerial systems together (hence the term "*operational BI*" (Eckerson 2007)). There is also one commonality on the architectural side: They are all built upon core components for the integration and exchange of data (White 2005).

The established centre for data integration, storage, and exchange in BI environments is traditionally the Data Warehouse (DWH). Inmon defines a DWH as "*... a subject-oriented, integrated, time-variant and nonvolatile collection of data in support of management's decision-making processes...*" (Inmon 2005). Although this conception still captures the heart of most DWH installations, it becomes somewhat diluted when the DWH is utilized in operational environments. While still fulfilling the tasks known from traditional management support, the DWH additionally needs functionality for storing and exchanging real-time transactional data. To reflect the changed role of such "enhanced DWHs" in the enterprise, this paper introduces the term "Transformation Hub" (TH). Here, a TH is understood to be a logically central component that concentrates functions for data integration, enrichment, and exchange. It is designed to serve for managerial, analytical and operational applications alike.

As the TH differs in content and structure from classical DWHs, the underlying models, structures, and approaches also need to be modified and be rearranged under consideration of state-of-the art components and architectural designs. This paper addresses the respective issues. It specifically focuses on the derivation of a *conceptual architecture* of a TH which captures relevant functional components and their interplay from an application oriented view. About 20 years ago, IT adopted the term "*architecture*" and applied it to almost every structural aspect of hard- and software systems – including DWHs (Hammergren 1996).

As this paper takes a more business oriented perspective, it concentrates on a *conceptual* system structure. The resulting architecture is designed to act as a starting point for the delineation and design of system components and their interplay solely based on application needs. This differentiation is of particular importance in the realm of current TH infrastructures where the essential logical design easily comes out of focus as it is superimposed by more realization-driven design layers, e.g. for the data exchange and middleware architecture, for data-feed-approaches (i.e. data consolidation, federation, or propagation) (Brobst 2002, White 2005), for event handling mechanisms (push vs. pull) (Brobst 2006), etc. Notwithstanding the importance of those aspects, they are secondary in nature in the conceptual design which runs down to selecting functional components for defined business contexts and to specifying how they are supposed to work together.

The objective of this paper is to derive a conceptual architecture for a Transformation Hub. The course of the discussion is as follows: After relevant concepts in the vicinity of the TH are put into context, its actual role is pinpointed by distinguishing and discussing motives for the implementation of THs. This is the foundation for a derivation of the architecture which is mostly based on logical steps of data transformation as known from the data warehousing domain. For each of the different transformation steps, the peculiarities of the TH are discussed and matched with the concepts introduced before. The application and the relevance of the framework are illustrated with two case studies.

2 RELATED CONCEPTS

There is a long tail of research on the architecture design of a Data Warehouse with some influential contributions coming from Inmon (Inmon 2005) and Kimball (Kimball & Ross 2002). The former stands for a strongly centralized, application-independent approach while the latter proposes a more decentralized data management that is bound together semantically by the use of shared dimensions ("dimensional bus"). Empirical research shows that both approaches can be found in similar numbers in current enterprises and that both are to be preferred over less-coordinated approaches (Ariyachandra & Watson 2006). Besides this, a distinction needs to be made between application-specific data excerpts – usually known as *Data Marts* – and a central and logically integrated data storage – the "*Core Data Warehouse*" (Inmon 2005).

Providing near time, transactional data is one of the most significant modifications to classical core Data Warehouses (Inmon 1999). To handle the different access profiles, reliability requirements, and update time-frames, dedicated components have been proposed which have become known as "*Operational Data Stores*" (ODS). Inmon introduced the concept of the "*Information Factory*" for ODS-enhanced DWHs (Inmon & Imhoff & Sousa 1997, Kelley & Moss 2007). Being a more technical and data storage oriented concept, the literature on Information Factories can serve as an outline for the realization options of the data management components of a TH.

There are several contradicting definitions for the term "ODS" (Inmon 1999, Sherman 2005) and not all of them are suited for the TH approach, e.g. an ODS as a mere replication of operational data base tables. In this paper, a ODS is conceptually understood to be a component that provides *integrated* data (Kelley et al. 2007) and for this purpose enables bringing together transactional data from multiple sources. This involves data cleansing and integrity checking. Here, the ODS, the DWH, and the Data Marts are conceived as the main data provision roles that a TH has to incorporate.

ODS-enhanced DWH architectures allow building *Closed-loop* and *Active Data Warehousing* solutions. In *Closed-loop Data Warehousing*, results from analytical processes are directly fed back into DWHs or operational systems (Brobst 2002). Active DWH systems automatically trigger actions based on defined data constellations. As the respective application scenarios frequently go along with the need for current data, "*Active and Real Time Data Warehousing*" is often combined to a fixed phrase (Akbay 2006, Raden 2003). In Closed-loop and Active Data Warehousing the DWH can turn into a data source for the operational systems.

From an application oriented standpoint, a DWH is by its very nature a component for a data driven application integration. Recently, however, some scenarios are proposed that leave this data centric approach: It has been suggested to complement a DWH with components that focus on providing *data processing functionality* rather than actual data. These components are usually conceived to be based on the paradigm of service oriented architectures (SOA). The name that has been coined for this approach is *Embedded BI*. It is "embedded" as the BI functions are conceived to be seamlessly integrated into operational systems, working directly against the local, transactional data, rather than against the integrated repository of a DWH (Hashmi 2004, Klawans 2008).

The above discussed components abstract from the applications they actually support. One of those with immediate relevance for a TH is *Business Activity Monitoring* (BAM). BAM is built upon the idea of providing software for the near-time monitoring of the status and the results of business processes. For this purpose, data from the involved application systems needs to be extracted, integrated and presented in a meaningful way (DeFee et al. 2004, Golfarelli et al. 2004, Melchert & Winter 2004). BAM heavily focuses on the data presentation aspect, especially in the form of "dashboards" and "cockpits" and can be applied both within the confines of an organization or across enterprise borders (Eckerson 2006), e.g. for logistics or production processes.

The idea of BAM is closely interlinked with *Business Process Management*. Business Process Management highlights the integrated management of business processes. In this regard, BAM can be understood as a tool that supports a subset of the tasks for Business Process Management (DeFee et al. 2004, Golfarelli et al. 2004, Melchert et al. 2004, Verner 2004). Further reach full-fledged "*Business Performance Management*" approaches which aim at the integrated, strategy-oriented steering of an entire organization based on consistent indicator systems for all managerial levels (Eckerson 2006, Golfarelli et al. 2004). By interlinking the complete reporting hierarchy, they reach well beyond Business Process Management, although the latter can be smoothly embedded within the former. If realized that way, Business Process Management can be understood as *Operational Business Performance Management* (oBPM).

3 APPLICATION DOMAINS FOR TRANSFORMATION HUBS

A closer look at the literature reveals a variety of interdependent motives that drive the evolution from the classical DWH to the TH:

Integrated management concepts, especially within the realm of Business Performance Management as discussed above. Approaches like the "*Balanced Scorecard*" (Kaplan & Norton 1996) or "*Value Based Management*" (Grant 2003, Rappaport 1998) are built upon the idea that a system of interdependent key performance indicators (KPIs) can facilitate the consistent steering of an entire organization. A consequence of pursuing such approaches is the need for an operational, process-level indicator gathering and communication, especially based on Business Process Management solutions. This entails the need to closely couple operational, tactical, and strategic decision support and to provide a consistent data socket (Eckerson 2006, Golfarelli et al. 2004).

Information logistics. With the diffusion of integrated applications, e.g. for *Customer Relationship Management* (CRM) or *Supply Chain Management* (SCM), and the demand for application-spanning services like security-checks, pro-active fraud-detection, or on-site localization of service issues, the potential of Business Process Management and BAM solutions becomes apparent: respective solutions require infrastructures for data exchange, integration, harmonization, and distribution (Furness 2004, Chemburkar et al. 2006, Nguyen 2005, Raden 2003, Stefanovic & Radenkovic & Stefanovic 2007, Watson 2005, Baars & Kemper & Lasi & Siegel 2007). As THs are innately designed for mass data processing, they are ideal building blocks for large-scale integration solutions. In contrast to the integrated concepts discussed before, these approaches are focusing more on data exchange *along processes* (Bucher & Dinter 2008) than across managerial levels. Closed-loop and Active Data Warehousing are often following information logistics initiatives, as they draw additional value from the achieved data integration.

Analytical access for lower managerial levels. In a turbulent business environment there is value in an analytical access to historical data even for lower managerial levels – which can be provided more conveniently with flexible, BI based reporting and analysis tools (Klawans 2008, Marjanovic 2007).

Centralization and utilization. A powerful rationale for utilizing a TH in an operational context is the centralization of data transformation: The TH is identified as a centre for all kinds of mass data processing activities. A particular concept that can be subsumed under this rationale is Embedded BI. This efficiency based argumentation not only permeates all motives discussed above. It also transcends it, and some of the supported applications can hardly be considered to be "Management Support" or even "Decision Support". The concentration of all administration, monitoring, and resource related tasks for data transformation facilitates unlocking economies of scale and utilizing learning curves that are further fostered by dedicated organizational units. Such BI competence centres have already become widespread in the realm of BI (Unger & Kemper & Russland 2008).

Figure 1 illustrates the role of the TH in this conglomerate of applications: It connects analytical and operational systems, feeds BAM and/or Business Process Management solutions with near time data, extracts and harmonizes data for information logistics purposes, binds together key performance indicators based on Business Performance Management concepts, and provides transformation functionality for further applications.

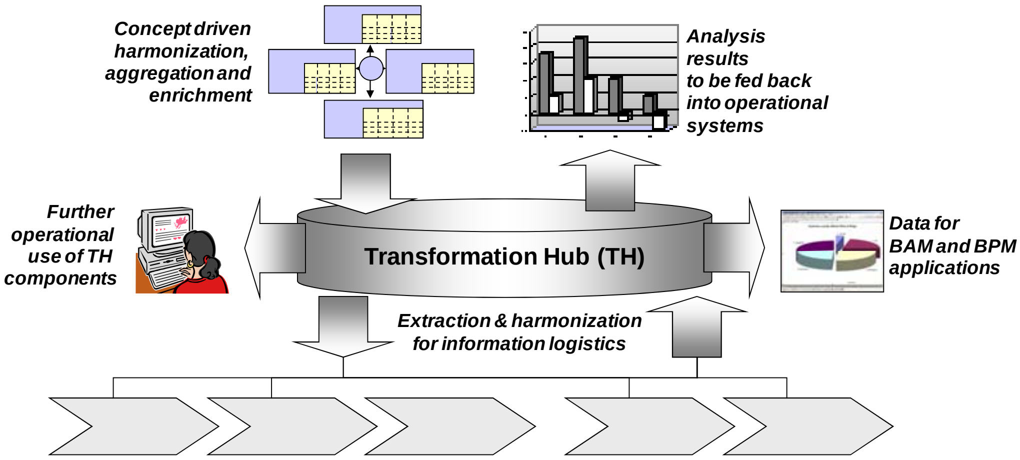

Figure 1: Role of the Transformation Hub

4 THE TRANSFORMATION HUB - ARCHITECTURE

The TH architecture proposed in the following section is designed to support all application settings discussed in the above sections. It is conceived to be vendor-neutral and invariant to physical design choices in order to allow for a sustainable mapping not only of already realized and projected solutions but also of possible development trajectories. It enhances a conceptual ODS enhanced DWH framework that has been iteratively developed over a course of over a decade and that already incorporates a large body of study results (Baars & Kemper 2008, Kemper 2000, Kemper & Finger 2006). Figure 2 depicts the architecture. It consists of the following main components:

- The **transformation components** (Filtering, Harmonizing, Enrichment, and Aggregation) form the heart of the TH. All application domains discussed above are aiming at some kind of data processing – be it a simple integration operations for monitoring tasks or complex enrichment and harmonization procedures for Business Performance Management.
- Associated repositories for **data storage and data access** play the roles of the *ODS, a Data Warehouse and/or Data Marts*. They can be logically differentiated by the respective subsets of transformation steps the data needs to have undergone.
- Interfaces for **service provision**, i.e. for embedded BI solutions. In fact, the whole range of transformation functionality can be made available for third applications.
- **Administration interfaces** which allow for a secure and documented access to relevant data for the user, support the configuration and monitoring of the operational data upload, and provide documentation.
- **Meta data management** that delivers the contextual glue that binds all involved components and contents together and ensures both an efficient technical maintenance as well as a consistent usage of the TH contents. It addresses both *technical meta data* and *semantic meta data*.

The next paragraphs discuss the fundamental transformation steps and the associated data access components and match them with the related concepts from section 2. The following main types of transformational tasks are distinguished (Kemper 2000):

- *Filtering* encompasses the data extraction and the correction of defects in syntax and semantics.
- *Harmonizing* is the process of granularity adaptation and merging data to defined *subject areas*.
- *Aggregation* addresses the summary of data to predetermined levels of detail
- *Enrichment* adds calculated indicators to the data.

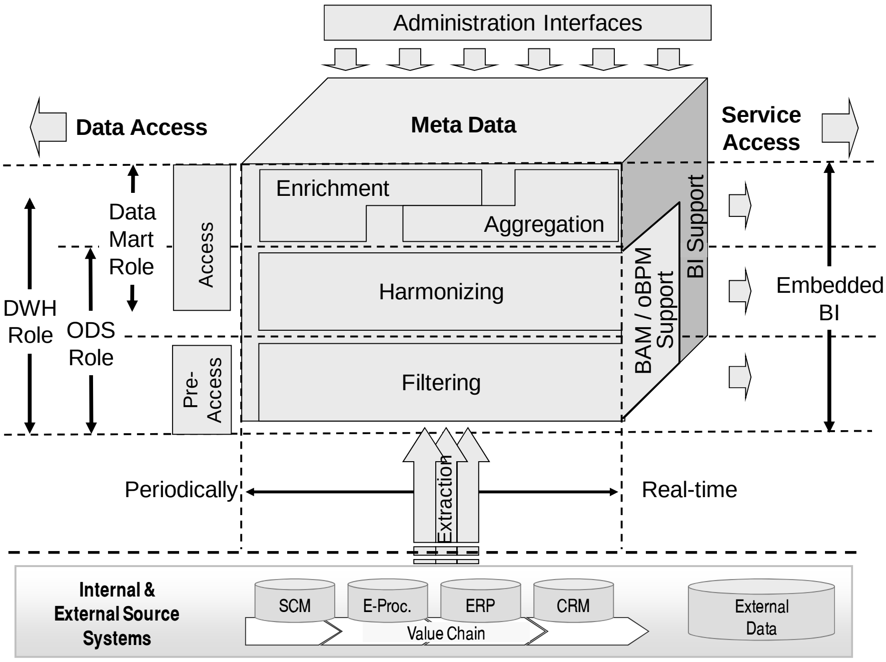

Figure 2: The Transformation Hub – Basic Architecture

4.1 Filtering and pre-access components

The filtering process starts with the extraction of data from operational data repositories. From a conceptual viewpoint it is imperative to check the quality of the operational data sources (systems, fields) that are considered as inputs for the TH (English 1999).

Regarding the actual extraction process, there are basically two basic options (Akbay 2006):

- Periodical updates that adhere to a classical Extract-Transform-Load (ETL) logic or
- Continuous, real-time streams ("trickle feed") that directly mirror changes in the operational systems.

The two approaches need to be distinguished conceptually because of the consequences regarding timeliness, costs, performance impact on the operational systems (Brobst & Morrey 2002), and data quality (handling incomplete/wrong transaction data, time buffer for quality checks). As the TH is supposed to feed both real time applications like BAM and data analysis applications based on historic data, components for both might be necessary (Brobst & Rarey 2002).

When actually conducting the extraction, a variety of syntactic and semantic incompatibilities or defects needs to be taken care off. In a near-time setting, the options to tackle semantic errors that cannot be automatically corrected or not even be detected are naturally limited. A way to narrow down the respective error handling times is to implement tightly defined work flows which ensure a minimal timeliness of the respective activities and that might be tracked and controlled by a workflow management system (Bartel & Schwartz & Strasser 2000).

For applications that rely on near-time, local data, the results of the extraction and the automated error corrections might already be relevant. In this paper, components to read out the respective intermediate data are labelled "Pre-Access" as the data is still not consistent across different sources.

4.2 Harmonizing, the ODS, and BAM support

Systems supporting operational processes rely on data that normally differs in granularities, definitions, time periods, etc. (Kemper 2000). Clearly, harmonization is not a mere technical issue but rather a conceptually challenging task which needs business support (Berg & Heagele 1997). Bringing heterogeneous data together is one of most fundamental tasks of a TH.

The respective merging operations pertain to both syntactical and semantic inconsistencies:

- *Syntactic harmonization* means the coding of keys and attributes on the one hand and the handling of homonyms (attributes which carry identical names but have different meanings) and synonyms (attributes which are referred to by different names but have the same meaning) on the other. Usually this type of issues can be managed on a basis of defined routines and is of low criticality.
- More serious are cases of *semantic harmonization*. A common cause for the occurrence of such predicaments is of historical nature: In many enterprises a plethora of homonymous business terms is used, each with varying local definitions and connotations. Seemingly clear time-periods differ, and so do the definitions for performance indicators like sales, revenue, profit etc. Merging data together in a TH demands the harmonization of these terms across unit borders (English 1999). This type of harmonization activities can easily result in severe political and cultural problems (Kemper 2000) and needs to be backed by a tight meta-data management.

Providing filtered and harmonized data is a core feature of a TH. Following the definition in this paper, a data access system that ensures these two layers in near-time and on transactional level is an ODS. This kind of data provision also forms the heart of BAM- and oBPM applications.

4.3 Aggregation, enrichment, Data Marts, Data Warehouses, and BI support

On the third layer of transformation, the filtered and harmonized data is further refined by implementing hierarchy structures and calculating business indicators.

The hierarchy structures of the *aggregation* extend the idea to centralize the definition of semantics to the specification of pathways along which granular data should be analyzed (e.g. from store to country to world region). This can include parallel dimensions: The dimension “product group” can for instance be alternatively summarized over product categories (customer based) or profit centres (organization based) – both hierarchies stand for valid analysis corridors.

A centralized calculation of indicators (*enrichment*) guarantees the consistence of the business terms on the basis of homogenous definitions for entire fields of applications. A DHWs can and Data Marts do include aggregated and enriched data. This type of enrichment violates the paradigm of a separation between logic and data: There is a deliberate built-up of redundancy for purposes of performance and usability. As Data Marts are understood to be application driven, a simple and immediate provision of aggregated data is in fact often one of the main strengths of the Data Mart.

By incorporating the roles of the DWH and the Data Marts, the TH also takes over the function of the focal component for the support of a BI approach.

The powerful features for mass-data enrichment make the TH also interesting for a variety of operational systems: This functionality can be just as well utilized for operational data that does not require any form of harmonization, e.g. in a shop floor environment. Some of those applications lie well beyond the confines of even the widest conceptualization of BI.

4.4 Mapping transformation steps and application domains

Coming back to the application domains from section 3, their concrete relationship with the TH and with the transformation steps can be laid out (cf. Table 1).

Integrated management concepts aim at a vertical integration with a consistent set of indicators. This requires rigid data harmonization as well as a logically centralized indicator definition, calculation, and aggregation. It can thereby be concluded that special attention needs to be devoted to a meticulous definition and maintenance of meta data.

Information logistics driven applications are built on data exchange and harmonization. By the vary nature of those approaches, they need to weave together multiple heterogeneous systems and therefore require strong extraction interfaces and respective filtering components.

When it comes to **analytical access on operational levels**, a Data Mart based access to historical data is needed that is seamlessly interlinked with current (near-time) data.

The **centralization/utilization** motive captures a whole range of applications. In essence, this demands for a flexible usability of the different components and their functions. The resulting requirement is that the architecture is defined in a modular fashion with building blocks that at best can be immediately used as self-contained, service-oriented units.

	Integrated management concepts	**Information logistics**	**Operational analytics**	**Centralization / utilization**
Focus	Coupled systems for all managerial levels	Data exchange and harmonization	Data aggregation and analysis for lower mgmt. levels	Consolidating data processing and analysis tasks
Examples	Value-Driver Trees, Balanced Scorecard	Supply Chain Management, BAM in the realm of manufacturing	Support of decisions regarding replenishment	Mass indicator calculation for manufacturing execution
Relevant components	Harmonization, aggregation, and enrichment, Meta data and meta data administration	Extraction, Filtering, Harmonizing	Aggregation (over time), Data mart based access to historical data	All transformation components, made accessible via self-contained services
Particular requirements	Functionality for shared meta data management	Multiple interfaces and flexible extraction routines	Options to interlink low-aggregated transactional and historical, aggregated data	Component based architecture with building blocks that allow for a flexible integration

Table 1: Applications and Transformation Hub requirements

5 CASE STUDIES

Two cases are presented to illustrate the ongoing trend towards Transformation Hubs and to highlight relevant discussion areas. In both cases research projects have been conducted jointly with the respective organization. This allowed for deep insights into the solutions and approaches. Data gathering methods have primarily been workshops and qualitative document analysis.

5.1 Stock Exchange

The first case highlights the approach of a former national stock exchange that has over time turned into one of the largest stock exchange organizations in the world. By the end of the last century, the company not only faced new environmental conditions like increased dynamics in the verge of internet-based trading but also increasing requests of internal and external stakeholders for precise, trustworthy and real time decision support content. The developed BI solution is a real time TH. It acts as a hub for information distribution to a worldwide financial community and permits internal and external users a prompt analysis of market related mass data.

The solution of the stock exchange delivers both classical DWH services (aggregated, historical data for management analysis) as well as direct feeds into operational systems which are relying on harmonized financial data. The latter part is heavily information logistics driven.

Depending on the structure of the source systems and the time variance of the data, internal and external source systems are connected either in real-time or via periodical updates. The data transformation is completely meta data driven. Automatic filtering and harmonization are realized in a separate “validation layer” while unstructured data and semantic defects are dealt with based on a workflow approach. The (approved) results are gathered in a container with the label “single point of truth”. Eventually, there is a dedicated “analytical business layer” which is in fact a manifestation of the aggregation and enrichment layers discussed here. The results – denoted as “information products” – are delivered in a multitude of forms, including data streams to operational downstream systems, cubes prepared for data analysis, website content, reports, spreadsheet files, or even text messages.

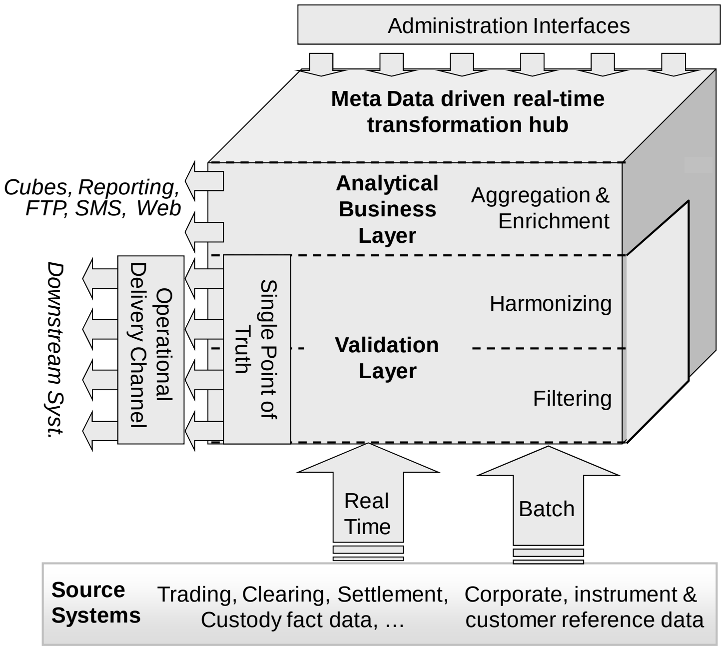

Figure 3: The TH of Case 1 (under consideration of Detemple & Feidieker & Münch 2006)

The mapping of the solution with the developed framework is visualized in Figure 3. Noteworthy are the systematic integration of manual activities and the consequently layered approach.

5.2 Manufacturing

In the second case, the move from classical BI to a full-fledged TH infrastructure is still in its conceptual phase, although it clearly shows the centralization forces at work.

The respective (large) manufacturing enterprise has already enforced a physically centralized BI approach, based on one obligatory data warehousing product that is used for all sorts of data refinement tasks. The results are used by a multitude of systems, among them diverse reporting solutions. Due to the historical development, a variety of independent Data Mart based solutions has grown that is not yet *logically* integrated: The solutions run on separated instances of the software and are individually customized. Over time, the solutions grew in number, data volume, and business relevance. Furthermore, multiple interdependencies between the different systems became apparent that were sources for blatant redundancies. To address this situation, the company has set up a large-scale consolidation initiative that addresses both inconsistencies between the diverse data repositories as well as the respective redundancies in the data transformation activities.

Among the various solutions in place quite a few are *not* directed at classical managerial support. Those applications often utilize just a subset of the functionality of the DWH solution, e.g. only the data extraction from the ERP system or the (efficient) data enrichment features.

Especially from the side manufacturing and logistics, first near time data transformations have been implemented – predominantly aiming at enrichment. This type of application is actually prone for an Embedded BI approach: Only local, unprocessed data is enriched and the data storage on the system is just temporary – the main strengths of the classical DWH environment are underused.

The logical structure of the TH is depicted in Figure 4.

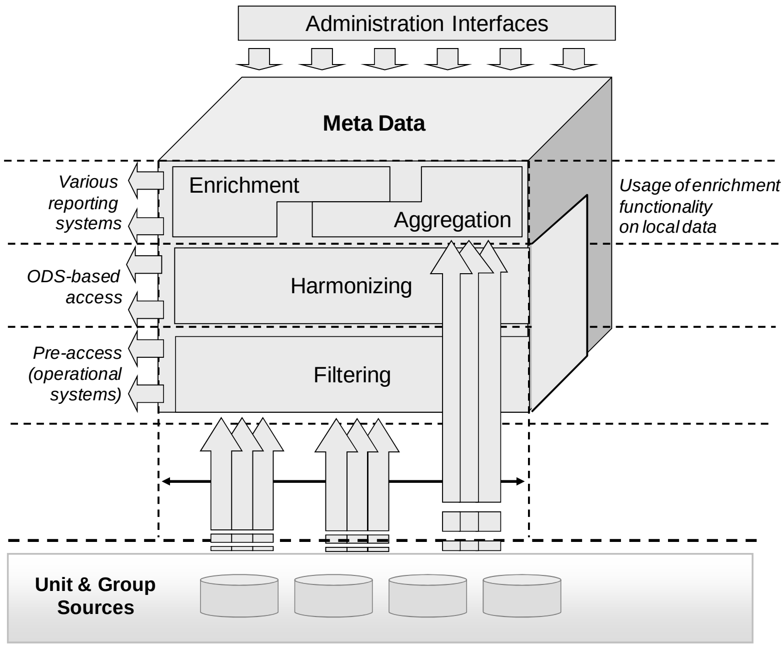

Figure 4: The TH of Case 2

Currently it is investigated which types of solutions can indeed be embedded coherently in the conceived TH, which ones need to be handled with different (but logically integrated) components and which ones should be utterly separated into distinct systems for either technical or economical reasons. This development goes along with the implementation of an overall governance approach that safeguards the efficient and strategy-conform usage of the systems.

6 DISCUSSION AND OUTLOOK

The cases illustrate the development to extend classical Data Warehouses towards an integrated Transformation Hub. They also highlight the need to couple technical and organizational design – by thoroughly defining, embedding, and supporting processes for manual data transformations on the one hand and by purposefully implement overarching governance concepts to ensure the efficiency and adequacy of the solution on the other. A relevant best practice of the first case is the strict layer based approach that follows the transformation logic.

Clearly, additional research is necessary to unravel the interplay of the discussed conceptual architecture and lower level structures. Of particular interest should be research on the role of SOA in TH environments. Besides, further empirical research is needed that sheds light on the relative significance of the discussed developments and how they evolve in concert.

Conceptually, the discussed trends entail the necessity to redefine the future role of Business Intelligence – and subsequently for the organizational units that support them as well: the metamorphosis towards mission critical Transformation Hubs reaches well beyond issues of technology design.

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