Integrated Information Supply for Decision Support in Grid Companies

The paper provides a reference model to support the strategic asset management. Based on an identification of requirements posed on network companies by legislation and stakeholders, the need for an integrated information supply to support decision making and reporting becomes validated. Therefore, existing models are examined concerning their potential and shortcomings regarding the identified information needs. The concept for a solution overcomes the drawbacks of existing models by an integration of technical and economic perspective. It is represented in a multidimensional data model and is the basis for an evaluation of the validity by expert interviews. The paper concludes with perspectives of further research.

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1 Introduction

Transmission service operators (TSOs) are faced with an increasing investment demand of approximately 40 billion Euros over the next 10 years (Nguyen 2010; Zdrallek 2005). This demand is due to an increase in the variation of load profiles caused by decentralization (Energiewirtschaftsgesetz 2005), an aging asset structure, and demographic changes. Investments are the result of decisions that are constrained by legal regulations (Anreizregulierungsverordnung 2007). Based on these regulations, TSOs have to deliver their services reliably and cost-effectively (Energiewirtschaftsgesetz 2005). However, the German Federal Network Agency, *Bundesnetzagentur* (*BNetzA*), has calculated grid fees that are up to 14 percent below calculated charges (Microsoft 2008). Therefore, TSOs are faced with the challenge of operating on a cost-covering basis as well as realizing profit reserves. This is only possible if TSOs are able to identify and quantify the economic and technical risks. On these grounds strategic decisions can be taken that consider the current state of the asset base (Fuhrberg-Baumann and Jeltsch 2009, p. 8; Osztermayer 2007). Based on these considerations, it is the goal of this paper to conceptualize a reference model for asset management. This paper builds the role model for an integrated information supply in order to close the current gap between the technical and financial perspectives of asset management. The reference model serves as a recommendation for action (Braun and Esswein 2007). It also standardizes grid asset management and integrates the currently distributed functions. Moreover, the reference model enables the coupling of strategic actions and their operational consequences as cause-effect chains by providing a multidimensional data model.

Industry surveys show a low level of standardized information supply in grid asset management, while reporting and decision support requirements are becoming more complex (Czotscher 2009). The foundation of efficient and effective decisions is appropriate information, which is based on technical monitoring. Information includes both financial and demographic data, which are constrained by the financial, organizational, and reliability specifications of the regulator (*BNetzA*). Furthermore, strategic decisions require the coupling of operational actions, their consolidation within the control center, and their financial and technical valuation with key indicators. Therefore, information supply is the basis for taking decisions in energy and network management. Currently, the process of obtaining information is a time-consuming and error-prone process because of the use of Microsoft Excel (Panko 2009). The disadvantages in the current information supply process lead to a failure to manage assets appropriately because of the gap between strategic and the operational TSO management, incorrect condition monitoring and forecast, and extensive reporting to the *BNetzA*.

Grid asset management frameworks only focus either on technical aspects or on financial aspects. However, strategic decisions influence *operational expenditures* (OPEX) and *capital expenditures* (CAPEX) in the long-term, and thus these measures are becoming the focus of attention in addition to the grid quality key figures. For this reason, the quality of information on the current asset

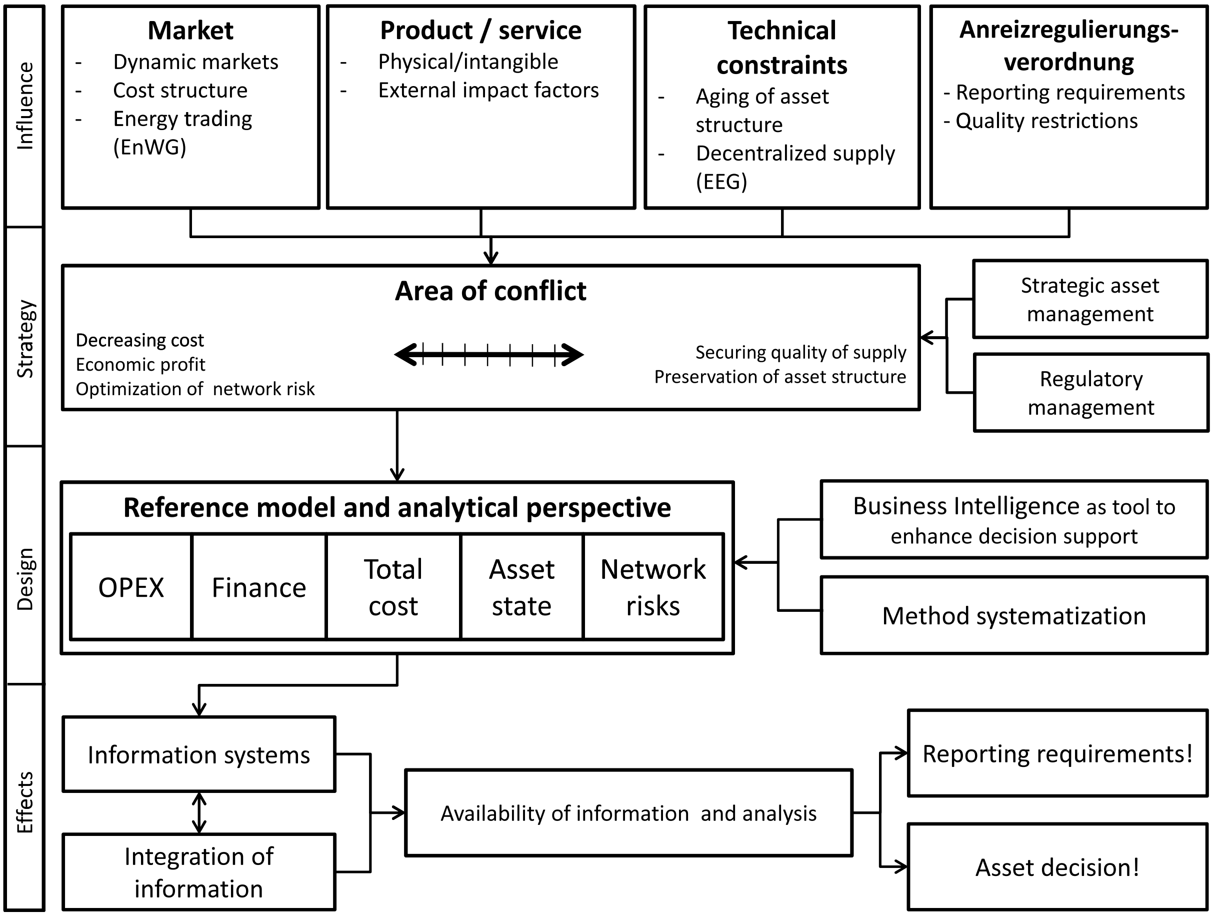

Fig. 1 Research design (modified according to Lehr 2006, p. 137)

state influences the quality of the asset state forecast. This point is recognized in practice (Fette 2008). However, the gap between these different perspectives still exists within the information systems. In fact, there are integration approaches that emphasize the need for IT integration (Osztermayer 2004; Safirov and Kamphans 2010, pp. 94 f; Wellßow 2006). However, a tool-based coupling of these strategic and operative perspectives has not yet been achieved. Existing asset management tools are based on the data from regulatory management. Obviously, extraction, transformation, and loading (ETL) are carried out manually, which is an error-prone process. Hence, the contribution of our reference model is to integrate the various functional frameworks into a multidimensional framework in order to give recommendations to improve the information supply within grid asset management.

The research is carried out using a multi-perspective approach, which includes four different levels. These are presented in **Fig. 1**.

The *level of influence* contains factors that affect TSOs but that cannot be influenced by them. The result is a conflict between the financial aspects of cost and risk reduction and regulatory requirements. The second level addresses the strategic decision. Decisions have to be taken at the *strategic level* and these influence the operational level in terms of key figures and management perspectives. The reference model addresses these different management perspectives and integrates them in order to give a consistent view in one management cockpit. The *design level* addresses the implementation of a *Business Intelligence* (BI) architecture. Finally, the level of effects addresses potential users to validate the functional aspects of the reference model through audits and expert interviews.

2 Grid Asset Management

Asset management is defined as the process of maximizing investment return on equipment by maximizing performance, minimizing cost, and ensuring a defined service and security standard over the whole technical life cycle (Schneider et al. 2005). Its task is to balance customer needs, regulators’ requirements, and adequate returns on investment for shareholders. This section first explains strategic asset management and then discusses current challenges in order to link operational and strategic asset management with information systems.

2.1 Asset Management

Taking strategic asset management decisions requires a balance between the different stakeholders because assets have long lifetimes. Therefore, decisions about maintenance strategy and construction are irreversible in the medium- and long-term (Bahadoorsingh and Rowland 2007). In order to realize additional earnings, the coupling of strategic decisions and their operational implementation is one of the major challenges of TSOs.[1] Nevertheless, TSOs have to consider regulatory requirements, such as grid reliability and price cap regulations (Wenzler 2005, p. 75 ff). Due to these challenges, strategic asset management is the starting point of the planning process. This includes grid dimensioning, risk assessment, the identification of asset state and maintenance strategy, the simulation of asset state using defect analysis and aging models, and the financial valuation of OPEX and CAPEX (Fette 2009; Schneider et al. 2005). The methodological definitions of technical tasks, such as asset state, risk identification, and the choice of aging models, are important to gain reliable results (Osztermayer 2007; Theil and Demiri 2007, pp. 209 ff; Thurner et al. 1998, pp. 318 ff). However, they have to be linked with the financial impact. Besides the risk, financial key figures such as *OPEX* and *CAPEX* are the key drivers of asset management (Balzer et al. 2007; Fette 2008; Goes 2003; Stender 2008).

2.2 Challenges and Problems in Grid Asset Management

Regulatory requirements such as price and revenue caps as well as the German *Anreizregulierung* make it necessary to consider not only the technical perspective, but also the financial and risk perspectives of asset management (Anreizregulierungsverordnung 2007).

The results of the technical planning process have to be assessed regarding OPEX and CAPEX over the entire asset life cycle. This analysis is not limited to the aggregated equipment level only. Furthermore, a more accurate level of the operative control of every single asset is required. Accuracy is necessary because it ensures a higher level of voltage quality and avoids asymmetries caused by voltage rises as well as islanding caused by short circuits. Consequently, detailed asset management avoids costs and improves the regulation of quality.

Asset management frameworks show that besides asset state prognosis and simulation, the choice of an effective maintenance strategy is a critical factor. However, academic research has focused on single aspects of asset management, such as reliability simulation (Konnov 2007; Obergünner et al. 2002, p. 32 ff), the effectiveness of aging models (Osztermayer 2007; Bahadoorsingh and Rowland 2007), and the effects of maintenance (Theil and Demiri 2007, pp. 209 ff). Other frameworks deal with the whole asset life cycle (Balzer et al. 2007; Schneider et al. 2005; Schreiner et al. 2002, pp. 776 ff) and describe asset management as a process over the entire asset life cycle concentrating on technical aspects and risk mitigation. The frameworks of Goes (2003), Accenture (2005), and Stender (2008) develop a performance measurement system for asset management. Although this system is based on technical aspects, these are neither discussed nor explained in detail. Balzer et al. (2007) develop a framework to describe asset management as a process. The process starts at the strategic level, describes the maintenance strategy, and explains efficiency measurement. However, the focus lies on the measurement and prognosis of asset states, as also discussed in the frameworks of Bahadoorsingh and Rowland (2007) and Spitzer and Engels (2009). Osztermayer (2007) examines asset states and their effects on the quality of supply. Nevertheless, he ignores the financial effects concerning the key drivers, i.e. OPEX and CAPEX. Therefore, a coupling of strategic decisions and operational actions, and vice versa, is not enabled. Even though Accenture (2005) and Stender (2008) propagate the integration of different perspectives, implementation in information systems remain unmentioned.

It becomes obvious that a lot of methodological work has neglected the information supply in TSOs. However, information is essential to implement the frameworks and to enable effective asset management. While operational information is available in single parts of grid management, the high-level information supply is a bottleneck. This affects the synchronization of technical and financial data, reporting, and regulatory management. Currently, the lack of high-level information supply leads to inaccuracies within the planning process, which influence the estimation results concerning asset lifetimes and maintenance costs. In fact, single solutions and tools address this bottleneck of information supply, as described in the following section.

2.3 Market Overview

Various discussions with TSO representatives have revealed that the integration of different operational information systems is an important task. However, only a small number of TSOs use an integrated system for decision support. Instead, the majority is confronted with the construction of an appropriate architecture to enable automated decision support and reporting. Furthermore, overcoming the bottleneck of information supply is classified as a subordinated task in TSOs and smaller network service companies. Currently, asset state simulation and reporting based on MS Excel requires a manual transformation and consolidation process. According to Panko (2009), the use of Excel as a consolidation tool leads to a significant number of errors as the amount of data increases. In fact, the interviews reveal that quarterly reports need thorough reworking, which is a time- and labor-consuming process. Furthermore, the required information is not available to all employees at all times. Therefore, there is a risk of reduced comparability of identical analyses at different times. The missing single point of truth can lead to a loss of knowledge. Finally, no tool manages to overcome the information bottleneck, which is discussed in more detail in **Table 1**.

In conclusion, solutions exist which have their origins in their vendors' history. Currently, the vendors consider themselves as service providers. They have broad portfolios, but they do not cover every single aspect of asset management. In the context of solutions that provide long-term planning and vendor independency, the current ones are inappropriate.

The solution proposed by ABB supports data integration between ABB-specific solutions that focus on energy generation and engineering. However, ABB and other vendors ignore existing BI tools. GE and Siemens provide sophisticated solutions that have a strong focus on the data model. The GE tool, though, refers more to the US market than it does to the German one. By contrast, Siemens provides a best practice approach with a German focus. Both vendors consider a broad range of operational and strategic applications. However, choosing those vendors involves the risk of a lock-in

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[1] Long-term orientation and strategies are in conflict if a grid decision endures because of the long-term use of the assets (60 years). An operative decision (i.e. the choice of chain assemblies) always influences maintenance in the next 5 to 10 years and possibly determines replacements.

Table 1 Software Solutions of selected vendors

ABB	The *TEC Monitor* addresses the maintenance and operational monitoring of standardized components and assets. It refers only to ABB-specific and -certified products, such as the solutions of GE, Westinghouse, and ASEA. *ABB Maintenance* includes a process control system and provides local maintenance services. *ABB Maintenance* is an operational system based on Supervisory Control and Data Acquisition (SCADA) (ABB Power Management ABB Ventyx) (n.a. 2011a). *ABB 800xA Asset Optimization* is not an industry-specific solution, and is rather used as a factory control system. It is also a standardized product, but it renounces applications for strategic asset management. ABB has developed it to support energy generation and electrical engineering (n.a. 2011b).
Siemens	The modular *Grid Asset Management Suite* represents a reference model and contains its own data model. This model considers control, analysis, and regulatory management. It is a Siemens best practice approach that provides customization. Furthermore, it includes a service-oriented connection to Supervisory Control and *SCADA*. Therefore, it emphasizes the technical aspects of asset management and renounces the integration of technical, financial, and geographic data.
Signion	Integrated Asset Management is based on the current data of technical and geographical information systems. In order to calculate aging rates, external information such as economic loss curves can be integrated into the simulation. All necessary data are loaded into an integrated Data Warehouse (*LCC asset base*), which uses the MS Excel toolset as a graphical user interface for data analysis and presentation (n.a. 2011c).
IBM	The *Maximo Energy Management for Optimization* and its integrated *Intelligent Utility Network* focus on information, management, and the analysis of energy data. They create a sensor- and actuator-based information system that orientates on the Common Information Model. The data exchange is service-oriented. However, it concentrates on data supply and ignores the functional aspects of asset management or regulatory management. Instead, these aspects are mentioned in short (n.a. 2011d).
GE	The *Concorda Software Suite* contains various modules such as the *Positive Sequence Load Level*, *Multi-Area Production Simulation*, and *Multi Area Reliability Simulation*, which were developed for the US market. The simulation component is based on a Monte-Carlo simulation in order to simulate load profiles and maintenance actions. The components contain many extensions, such as the integration of US energy market data (*MAPS Public Domain Database*). The *Multi-Area Production Simulation* consists of a broad range of data, such as weather, machinery, and default rates. Furthermore, the toolset enables operational control, data consolidation for performance measurement and strategic asset management with simulation functions (e.g., market data, default rates, and aging mechanisms). Furthermore, GE provides a full data and tool maintenance service (n.a. 2011e).
SAG	*MABI2.0* with its xRCM is an add-on for the SAP-PM and addresses SAP customers. The focus of MABI is the financial aspect of asset management. The budgeting function refers to asset management, construction management, and asset valuation. This function defines a balanced budget for every single asset in order to build a ranking and to enable a financial simulation. However, SAG references other vendors and tools to provide a more technical analysis (n.a. 2011g).
Samco	The TWA asset base integrates technical and financial asset data. It is a management toolset to support investment decisions and regulatory requirements. All relevant data are integrated into one database. Moreover, TWA can be extended with other Samco solutions to enable the different operational and strategic tasks of asset management. The database has defined interfaces with the ERP system. However, additional interfaces with technical and geographic data are not exactly defined. The database extracts reports for MS Excel or for additional exchange or presentation formats, e.g., csv, html/xml, or jpeg. Furthermore, it can be extended to the use of additional Samco modules, e.g., prognosis (TWA) (n.a. 2011f).

effect. A necessary separation between visualization, data, and the integration layer is not yet available. Therefore, it is not possible to create a long-term-oriented and flexible architecture. There is also no possibility to exchange prognosis data or simulation methods, to adapt the data model, or to alter the extent of the integration level. Regarding changes within the energy market, flexibility is necessary because TSOs have to gain experience in the technical and regulatory aspects. The solutions of Signion and Samco are closely related to BI solutions. However, they are very vendor-specific and MS Excel/Access-oriented. Furthermore, they were not developed for large-scale applications with volatile and complex datasets. Moreover, neither solution is a ready-to-use software that is appropriate for regulatory and asset management. The discussion with TSOs also reveals that a BI architecture already exists. Nevertheless, BI is used neither as an integration tool nor as an analytical support tool.

For these reasons, a standardized BI tool addresses the necessary integration of these various asset management perspectives and the coupling of operational asset state information with the results of strategic grid dimensioning and development. A BI reference model represents all the necessary requirements of regulatory and strategic asset management. The goal of this BI reference model is to overcome the current problems of contemporary, appropriate, and reliable reporting and decision support. The data model builds a conceptual structure to represent all required technical and financial key figures. A key figure system is a finite, directed graph that builds a multidimensional data room with elements, dimensions, and cubes. On the one hand, the conceptual data model is the initial point to discuss its relevance and validity in order to implement it into real-world applications. On the other hand, it also addresses research. In the long-term, it will enable a comparison of different aging model methods, i.e. life tables, stochastic Markov chains, fuzzy methods, and System Dynamic models.

3 Research Framework

The requirements of information supply have changed. In order to meet the requirements of accuracy in the context of an increasing amount of data and real-time reporting, three main aspects have to be considered. First, relevant data have to be consolidated automatically. Second, key figures have to represent the relevant information for grid decisions and dimensioning. Finally, they have to be set into a key figure system. BI addresses and meets these requirements (Chamoni and Gluchowski 2006, pp. 143 ff). In a narrower sense, BI core applications subsume all applications that deal with data collection, storage, processing, and presentation. The analytical BI view builds an extension of core applications with more complex tasks such as data mining (Kemper et al. 2006). With regard to the missing data integration, consolidation, and evaluation, a data warehouse is important (Inmon 2005). The initial point to implement a BI asset management solution is the multidimensional data model, which describes the objects, their relations, and their integrity conditions. Furthermore, a data warehouse provides different viewpoints of the physically stored data. Taking a multidimensional approach, the linkage of financial and technical data is enabled in one key figure system.

In order to standardize asset management and to consider both the technical and the financial aspects, the reference model uses a methodological technique. It builds a foundation to generate both application-oriented instance models and models of information systems (Braun and Esswein 2007). Based on functional asset management frameworks, all relevant phenomena are captured, defined, and explained to create the reference model (Fettke and Loos 2004, pp. 331 ff). All relevant tasks are captured by interviewing the representatives of TSOs and reviewing the relevant frameworks. The designed reference model has the goal to improve the information supply in order to generate real-time, cost-effective, and risk-optimized reporting. Therefore, the reference model is not only seen as a recommendation, but also as a technique (Fettke and Loos 2004, pp. 331 ff).

Designing the reference model first requires an appropriate methodology and a process model that contains all the necessary artifacts of the universe of discourse. In a second step, the collected artifacts are modeled. Based on these considerations, we apply the *Online Analytical Processing (OLAP)* system of Totok and Jaworski (1998). This process model follows both the reference modeling requirements that are formulated in Fettke and Loos and the engineering requirements of Frank (2007, p. 404). It is divided into three parts, namely requirements analysis, conceptual modeling, and physical implementation.

The first part deals with the assessment of the universe of discourse. This assessment is based on a literature review of functional asset management frameworks. Furthermore, all relevant data sources and flows are considered and examined. The functional aspects of the reference model are based on the General Asset Management Process of Power Systems (Balzer et al. 2007). In particular, the examination of data sources and flows is essential to analyze the flow of information. Therefore, the cause-effect chains of asset parameters can be analyzed and an abstract reference base designed. Because the framework of Balzer et al. (2007) focused only on technical aspects, the reference model is extended to financial aspects as well as to the integration in a key figure system for a BI implementation. The core of the reference model comprises a multidimensional data model as a conceptual model. The most important aspects are *asset state* and the *importance* of assets. They require the prioritization of assets and the definition of relevant asset parameters that describe the state of an asset. Moreover, the dependencies of relevant parameters have to be examined and analyzed. Based on these tasks, the dimensions and elements of the multidimensional model can be described precisely. The parameters are used to describe the asset condition. Collecting asset parameters requires the definition of functional dependencies within the functional elements. The collection of condition data at a specific point in time is essential to define the behavior of assets, which are defined as condition rates. According to Balzer et al. (2007), functional dependencies and the behavior of assets are the bases on which to identify risks.

Concerning the multidimensional data model, the elements of the asset parameters have to be extended to information on the likelihood and consequences of a failure or breakdown. The value proposition of an extended description of condition parameters and their integrated data storage is an increased level of accuracy (Schreiner et al. 2002, pp. 776 ff). The integration of various parameters and the hierarchical structure of assets enable drill-down operation from an aggregated asset view to a component-related one. Moreover, assets are classified into condition classes. Based on this classification, OPEX and CAPEX are determined (Bahadoorsingh and Rowland 2007). Furthermore, the examination of cause-effect chains is only possible if parameters and their dependencies are described in detail. The parameter description, examination of dependencies, and collection of condition data are the foundations for simulating different aging models. In this context, the reference model defines the conceptual model within the scope of the ANSI/SPARC architecture (Elmasri and Navathe 2007). Therefore, the functional requirements are defined and presented independently from the technical implementation.

4 Reference Model for Grid Asset Management

This multidimensional data model represents the main components of the asset management reference model. The model is a blueprint to store data within the represented architecture (**Fig. 2**).

Module 1 characterizes the ETL level in which the heterogeneous data are transformed and coupled. ETL requires the identification of relevant data within the data sources in order to copy them into the staging area. The staging area is part of the ETL level. After harmonization and aggregation, the data are loaded into the data warehouse (*Module 2*). By taking the multidimensional data model (which is implemented as an info object), the data are linked logically in order to represent reporting and forecasting functions (*Modules 3* and *4*).

The key figures are derived from the underlying hierarchies and dimensions. The multidimensional data model is represented by the Application Design for Analytical Processing Technologies (ADAPT) (Bulos 1996, pp. 33 ff) because it is explicitly designed for conceptual multidimensional modeling. Furthermore, it is able to consider complex algorithms and it can be combined with other object-oriented approaches.

A multidimensional conceptualization offers flexibility concerning input data, their processing (e.g., for a continuous extension), their integration with diverse data sources, and their presentation in a graphical user interface. Multidimensional structuring also addresses the scalability of large datasets. The main value proposition lies within the ETL processing guidelines, which process data from diverse data sources, transfer them into the data warehouse, and make them useable for complex analysis.

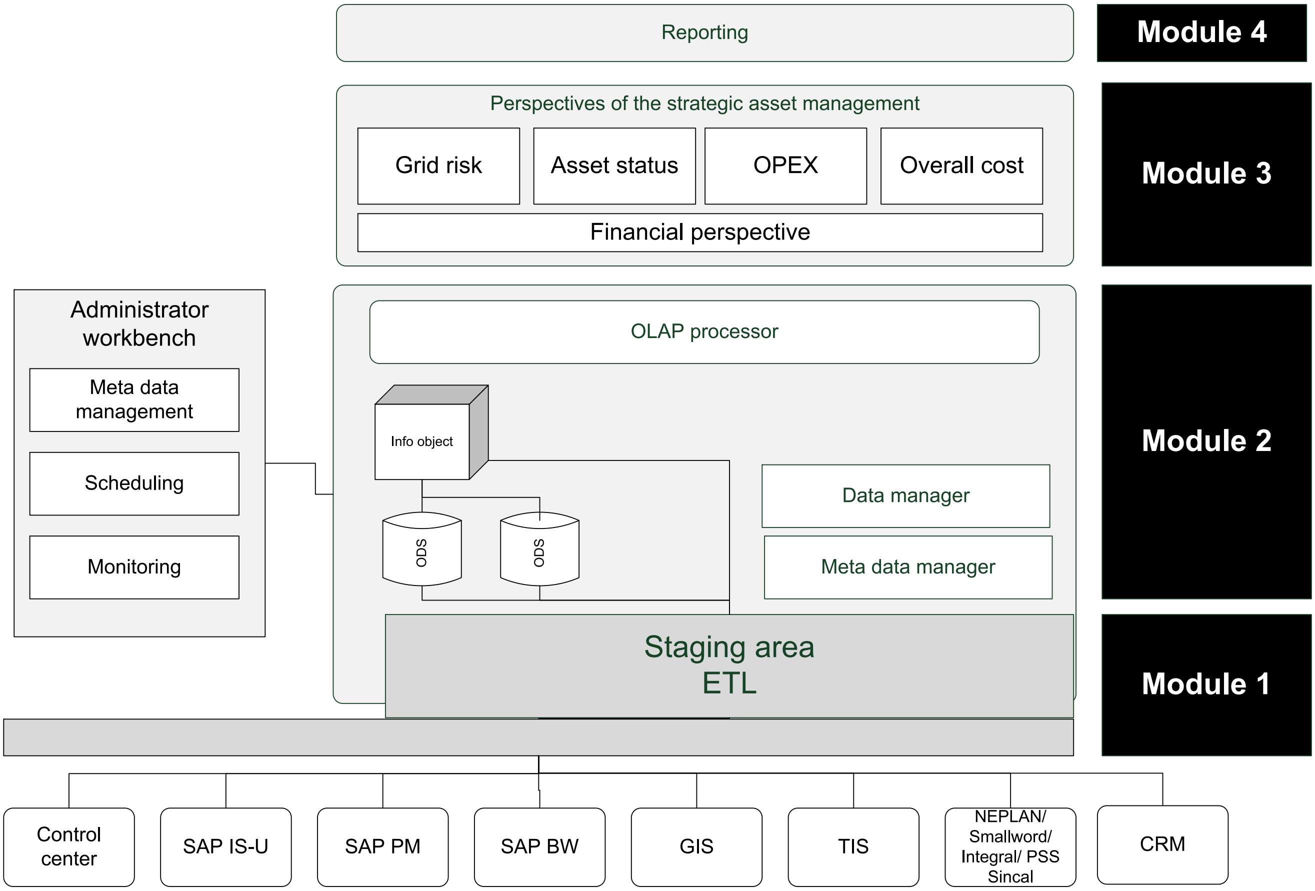


Fig. 2 Business Intelligence Architecture

4.1 Conceptual data model

The model represents the multidimensional semantic data with a selection of elements at an aggregated level (**Fig.** 3). The model only contains those elements of the asset base that are relevant for determining the *Importance* and the *Condition*. Determining the current and future conditions is of major interest. By contrast, the Importance is an indicator that is used to prioritize different assets in their asset hierarchy. Measurability is the most important factor to describe the current *Condition data* in order to evaluate the transition rates of aging statuses (Fette 2009; Bahadoorsingh and Rowland 2007). By using a transformer as an example, every single net transformer is considered. The parts of a transformer are, for example, its coils and on-load tap changer. The components of a coil are the coil core, ferrite rod, and insulating oil. The current condition of a transformer is determined by current data. These are loaded from a technical information system (TIS) (e.g., SCADA) into the elements of the defined condition dimensions. Considering the insulating oil, condition-relevant factors are temperature, color index, breakdown voltage, acid content, loss factor, surface tension, and dissolved and detected fault gases of the insulating oil. The determination of the current condition status and the dependencies between the different factors occurs within an engineering process that offers a technical perspective on asset management. Nevertheless, not every single asset is part of a regular control and therefore provides data. Moreover, the evaluation of condition databases using the multifactor framework of Bahadoorsingh and Rowland (2007) means considering which set of data is available and which dependencies exist.

The dimension key figure is built as a key figure system or pyramid. This dimension distinguishes between the technical and financial key figures that are crucial for asset management. The Asset management framework of Stender (2008) strongly relates to financial aspects and financial key figures. Additional requirements are adapted from regulatory requirements and reporting to the *BNetzA* (Anreizregulierungsverordnung 2007; Energiewirtschaftsgesetz 2005; Fette 2008). Overall, the financial key figure scheme contains approx. 160 individual key figures that consider different equipment and voltage level dimensions for regulatory management. Condition-related key figures for a transformer are the maximum load, electrical energy not supplied, and probability of failure. In fact, relevant key figures are controlled using integrated tools such as those provided by ABB or Siemens. However, they do not provide a centralized storage that enables the coupling of strategic decisions and operational actions. The required data for methods such as *Failure mode and effects analysis* or *System dynamics* are available in a data warehouse. In addition to the condition data, different default prediction models for specific regions can be simulated that consider the changes in load or breakdown profiles caused by demographic (energy demand), geographic (decentralized generation), or weather changes. As grid dimensioning and condition control are currently sep-

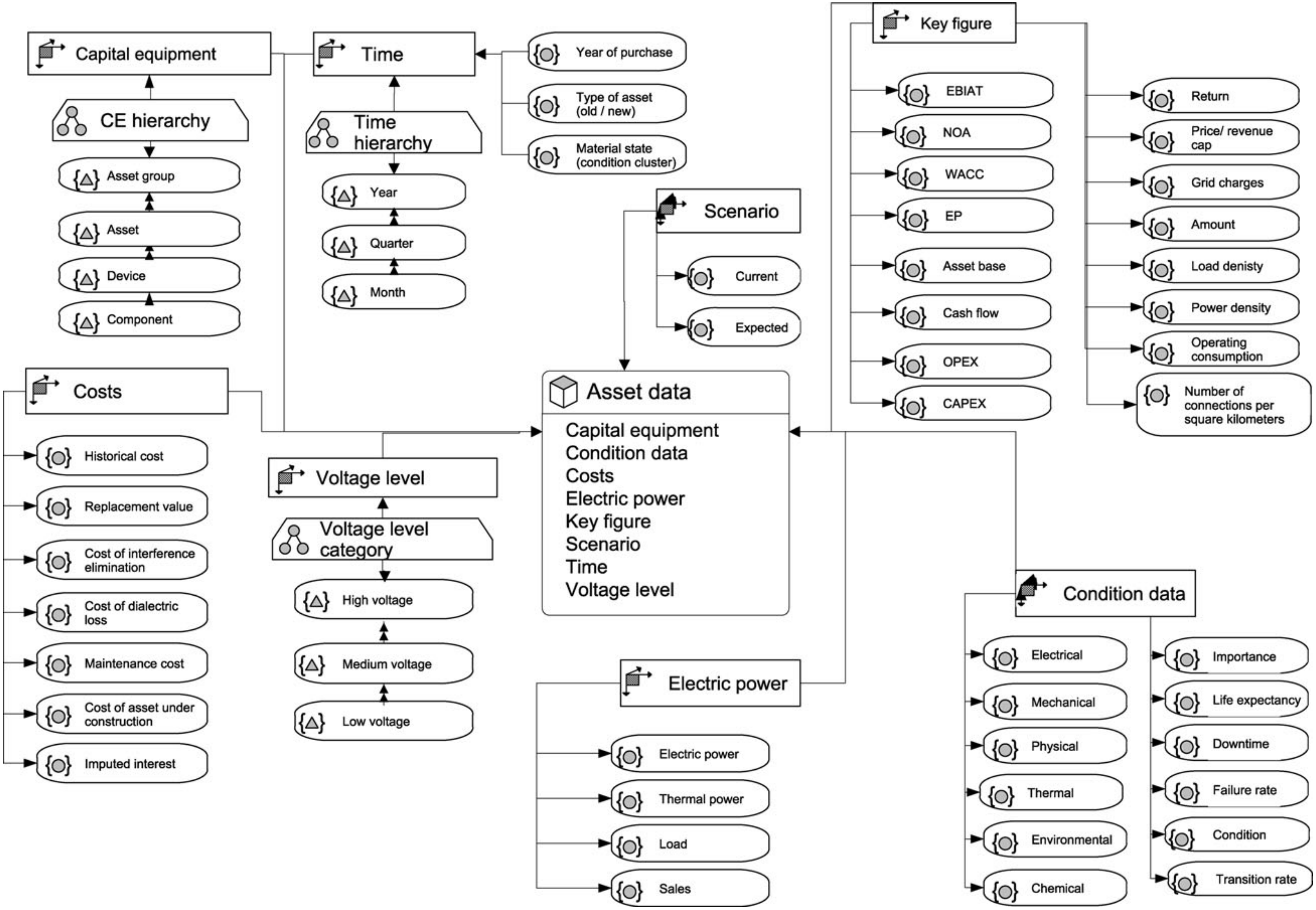
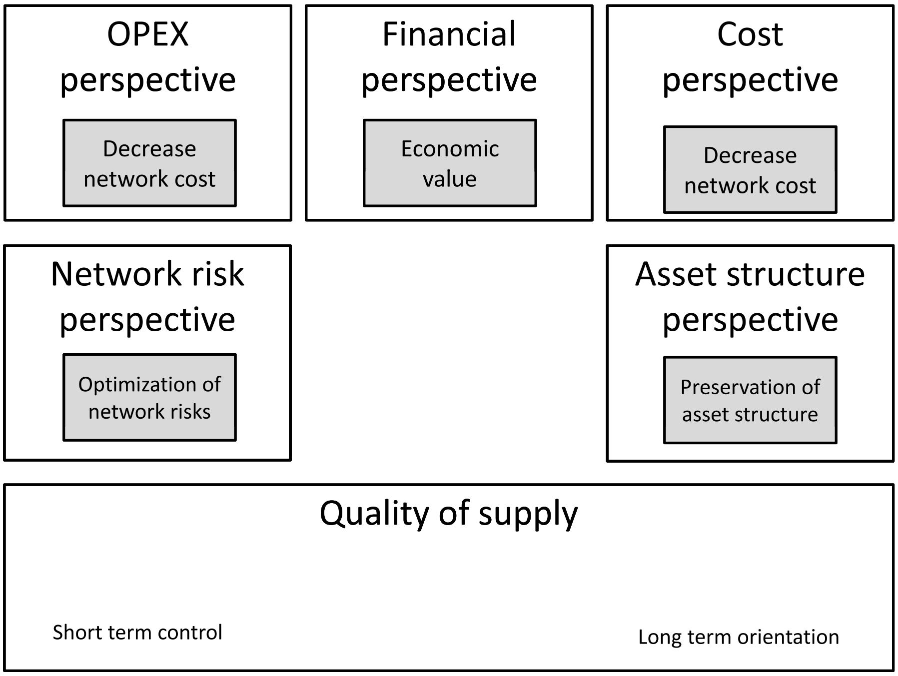


Fig. 3 ADAPT model of asset management

Fig. 4 Functional scope of asset management (adapted from Stender 2008)



arate, a data warehouse integrates these functions. The result is a more effective and efficient representation of the complex analysis and a better forecast of natural or failure-related breakdown scenarios. Key figures are represented in fact tables, which build the core components within the extended star schema. The composition of different dimensions enables the coupling of operative tasks and their effects at a strategic level and vice versa. This is realized using operations such as *slicing* and *dicing* (Hahne 2005).

These different elements, dimensions, and hierarchies are consolidated in the multidimensional data model of asset management. The use of hierarchies is essential for using drill-down and roll-up operations on key figures from the asset group level to single components. Moreover, key figures are separated by voltage level. The dimension scenario enables users to compare historical data with current calculations. The scenario *Expected* is the result of the simulation of the condition data, which is based on aging modeling methods. Then, OPEX and CAPEX can be determined within the future scenarios.[2] The dimension *Costs* consolidates data from the ERP system. The representation of asset data refers to the dimensions *Costs* and *Capital equipment*. These form the core of management considerations. However, these considerations depend on the level of detail of the asset base. Therefore, it is necessary to map and consolidate data from the ERP, GIS, and control centre. Mapping (identification and integration) as well as consolidation is required in order support the management at an accurate level.

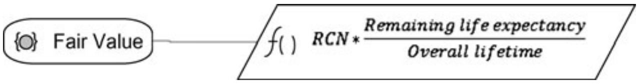


Fig. 5 Fair value

4.2 Functional Aspects of the Reference Model

While the definition of hierarchies within the Capital Equipment dimension is the foundation to couple the operative with the strategic key figures, the functional orientation refers to the coupling of technical and financial key figures. **Figure 4** represents the content of such a functional scope, which outlines the technical and financial tasks and considers the time perspective.

The functional scope depends on the defined dimensions, hierarchies, and elements. The technical planning process includes the *Network risk*, *Asset structure, and OPEX* perspectives. Their results are the inputs for the financial valuation within the *Financial* and *Cost* perspectives.

4.2.1 Asset Structure perspective

This perspective represents the development of the asset structure based on current replacement cost (Replacement Cost New, RCN) (Schneider et al. 2005). Stender (2008) used a fair value approach to evaluate the asset structure. Fair value depends on the quality of the analysis of the remaining life expectancy of single or all assets within the different voltage levels (**Fig. 5**).

Remaining life expectancy is determined using the maintenance strategy. Therefore, it depends on the OPEX within the asset groups. The remaining life expectancy is not a fixed parameter, but is rather influenced by the asset conditions and depends on the behavior over the lifetime of the asset. The base is the prognosis of condition statutes (**Fig. 6**).

Regarding the condition, we must differentiate between *current data* and *expected scenarios*. These different views are shown in the dimension *Scenario*. In order to determine the behavior of assets, it is necessary to model their cause-effect

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[2] This means that the technical interdependencies between different parameters are the foundation for financial evaluation. Maintenance and replacement are primarily technical necessities, not financial ones, even though they affect OPEX and CAPEX.

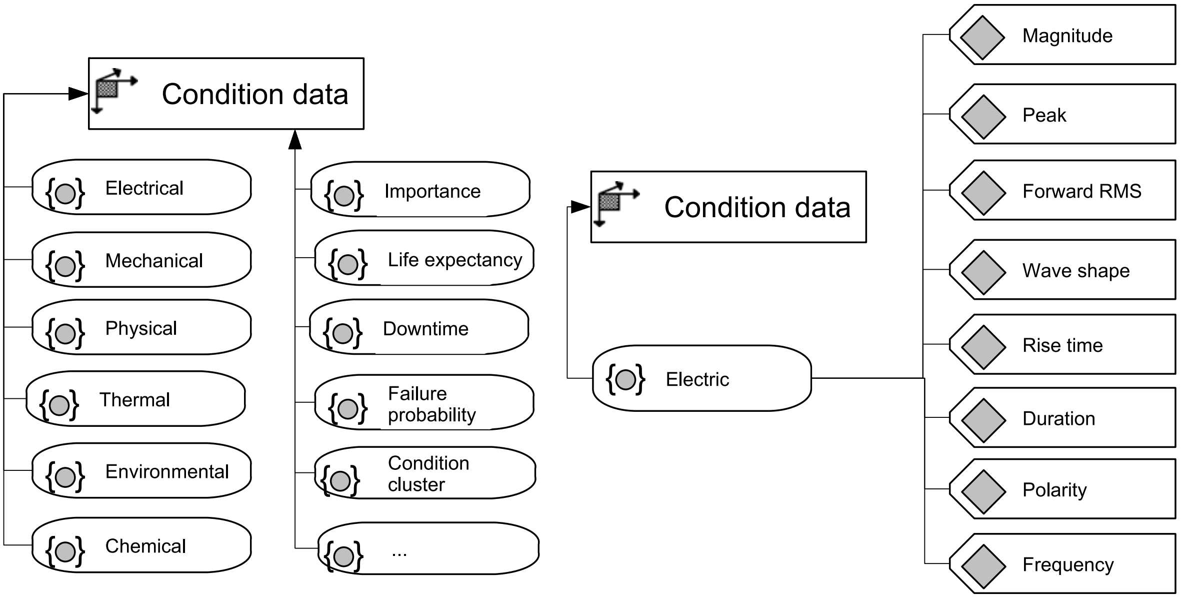

Fig. 6 Condition data

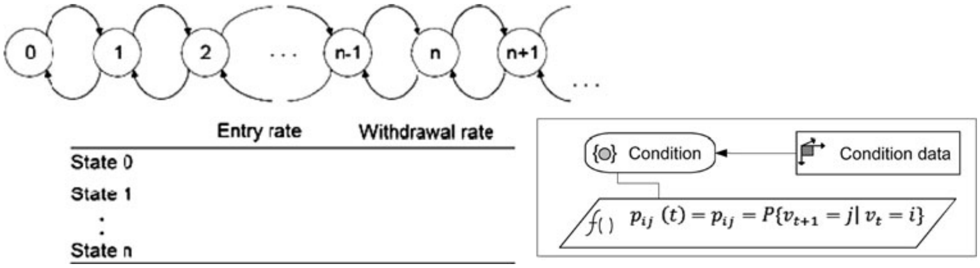

Fig. 7 Representation of a Markov chain

chains. Modeling requires the calculation of the condition function $v_j(t)$, which is based on all possible states i. The transition from a state i to a state j of an asset B leads to a transition matrix P_{ij}, which is added to the element Condition of the dimension Condition data. The result of the Asset structure perspective is the classification of assets into asset states. Furthermore, the effects of maintenance actions to changes in lifetime and asset state are simulated. The technical results are coupled by evaluating the maintenance actions concerning replacement and refurbishment costs (CAPEX). Cost rates are stored within the dimension Costs. In conclusion, the Asset structure perspective enables the coupling of technical and financial key figures.

The calculation of the transition rate depends on the selected method. Various methods are currently used, such as fuzzy algorithms (Osztermayer 2007), Markov chains (Konnov 2007; Thurner et al. 1998) and life tables (Fette 2008) (**Fig.** 7).

4.2.2 Network Risk perspective

The network risk perspective addresses the evaluation of Asset Importance, which also requires the coupling of technical and financial data. In this context, the results of the failure models and failure behaviors for specific assets have to be evaluated using cost data. *Importance* and *Risk* are evaluated using current data from the *Condition data* dimension. *Importance* prioritizes assets in respect to CAPEX planning and budget restrictions (Balzer et al. 2007; Fette 2009). However, a clear definition *of Importance* is still missing. The easy way to solve this is to use the fault statistics from energy data management. Otherwise, different parameters are used to evaluate Importance, such as *electrical energy not supplied* and the resulting costs, historical costs, maximum load, or the importance of customers with respect to possible damages (Balzer et al. 2007; Fette 2009; Schreiner et al. 2002, pp. 776 ff). The function *W(t)* is chosen to calculate the importance using the load factor of an asset. The following example represents the calculation of the *load coefficient* $LC(t)$ at time t. For the period Δt, the load factor $LF(t)$ is defined. $LF(t)$ describes the proportion of the current Apparent Power $AP_t(t)$ and the Rated Apparent Power AP_n. The foundation of $LC(t)$ is the result of the current measurement of the dimension *Electric Power*. **Figure** 8 presents the calculation of *Importance* as part of the dimension *Condition Data*.

Concerning risk asset management, risk is calculated as the probability of failure multiplied by the extent of loss in the case of failure. This refers to the probability of a faultless operation of a specific asset in a defined period beginning at the time of installation (or last maintenance service) to a defined data point in the future. The bases of risk determination are various failure models that can be derived from VDN interruption statistics (Obergünner et al. 2002). Risk evaluation is founded on the *Condition Data* dimension with relevant data for every single asset and component. The risk assessment also considers the effects of a default (interruption effects

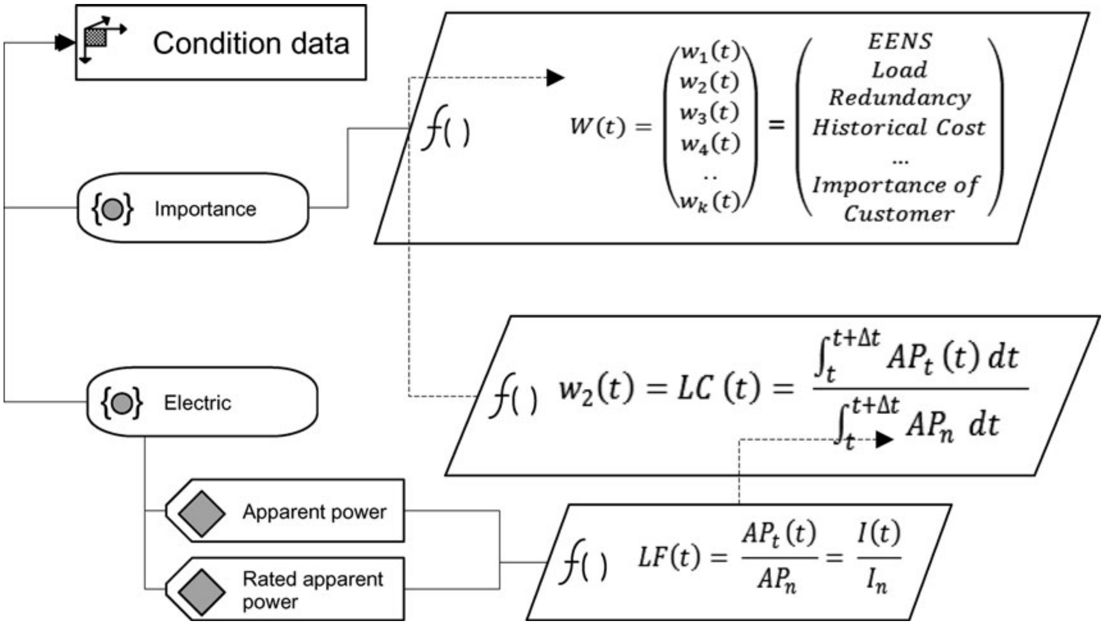

Fig. 8 Calculation of Importance

$$Risk\ of\ failure = \begin{Bmatrix} Force\ majeure \\ Regulatory\ risk \\ Strategic\ risk \\ Operational\ risk \\ Economic\ risk \end{Bmatrix}$$

$$Network\ risk = \begin{Bmatrix} Force\ majeure \\ Strategic\ risk \\ Operative\ risk \end{Bmatrix}$$

Fig. 9 Risk differentiation

and additional defaults), which are considered when evaluating *Importance*. Furthermore, these effects are evaluated in terms of money. The evaluation is based on the RCN, penalties to the regulator, or compensation payments. Payment rates are stored within the Cost dimension. However, their evaluation is not carried out automatically; rather, this is the result of an analytical process (**Fig.** 9).

4.2.3 OPEX perspective

The OPEX perspective addresses the management of original and regulatory cost rates. Based on the asset condition simulation, the required CAPEX and OPEX, which consider fair value and RCN data, are deduced. The short-term OPEX perspective addresses cost and revenue planning, which is based on the calculation of an efficiency score. The actual determination and prognosis of OPEX efficiency is grounded on the technical asset state. Furthermore, OPEX are influenced by demographic and legal developments especially of renewable energies that lead to changes in the grid dimensioning. Other technical parameters of the OPEX perspective are power density (power/km^2), connection density (connection/km^2), load density and power density/connection density per voltage density (**Fig.** 10).

4.2.4 Financial and Cost perspective

Both these perspectives represent the overall results using performance indicators, such as Economic profit, Earnings before interest after taxes, or Net operating assets (**Fig.** 11). Financial planning, which contains planning for new or replacement investments, is based on the results of the technical asset condition simulation.

Both perspectives are essential for the strategic assessment. The financial perspective is not isolated from the technical one. Indeed, Condition, Behavior, and Importance are the input variables for a financial evaluation. Furthermore, the fact that risk assessment and evaluation are not independent of regulatory requirements must be taken into account in order to ensure long-term quality and stability within the grid. The extraction of relevant data in a data warehouse integrates the different perspectives of technical simulation and their financial impacts. Moreover, these perspectives are not limited to one level, but rather refer to every single asset or voltage level. The data model is extensible to integrate other parameters that are used to simulate the behavior of an asset. In conclusion, the foundation is the data model with its defined dimensions, hierarchies, and elements, including their calculation rules. For this reason, the reference model builds a recommendation for action considering the implementation in an information system that is independent of current solutions.

4.3 Validation of the data model

The reference model is validated following the guidelines of Fettke and Loos (2004), Dietzsch and Esswein (1998), and Schütte (1997). Using a constructed modeler makes it impossible to validate the reference model in an intersubjective way. Braun and Esswein (2007) emphasized recommendation, reliability, and reasoning in order to determine the quality of a reference model. According to Fettke and Loos (2004, pp. 331 ff), a reference model is a technology to achieve a defined goal. Therefore, the model has to provide appropriate tools and methods for evaluation and implementation. In order to enable validation before the implementation was carried out, we used expert interviews to obtain statements about requirements and challenges. High quality was assured by inviting interview partners to evaluate the model both

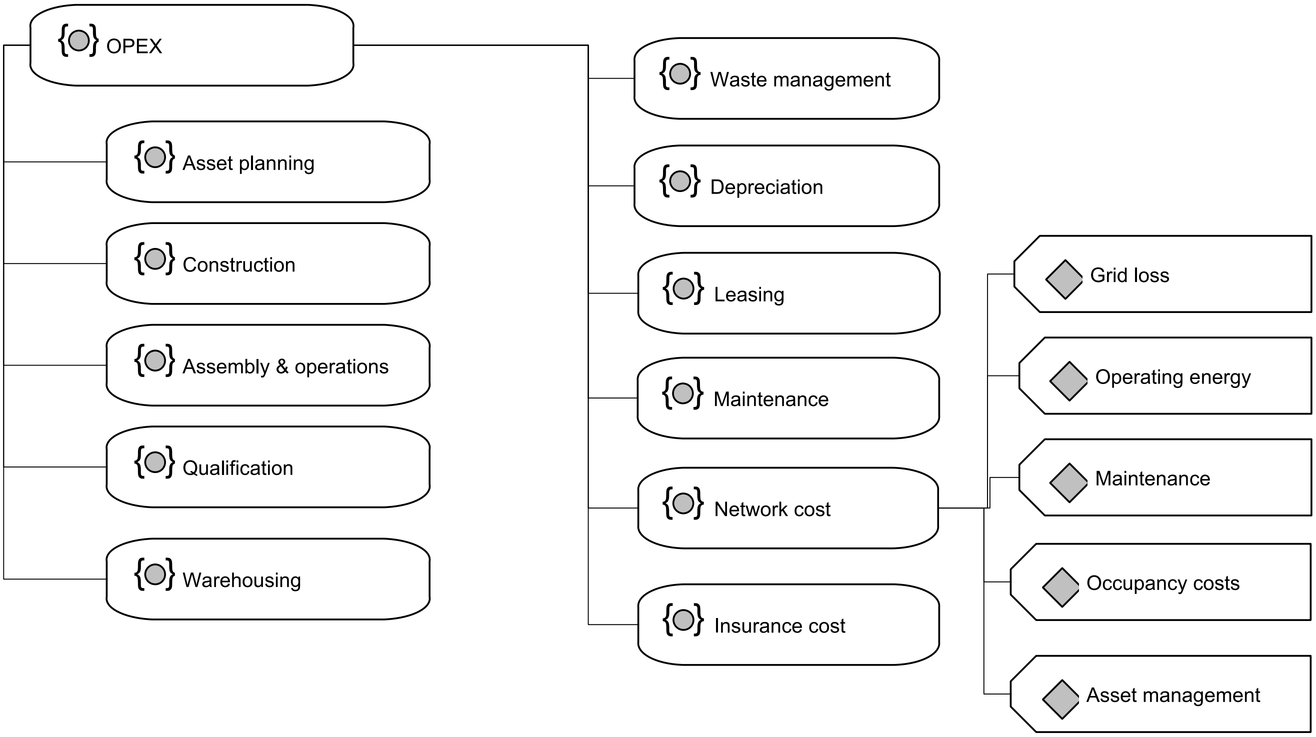

Fig. 10 OPEX perspective

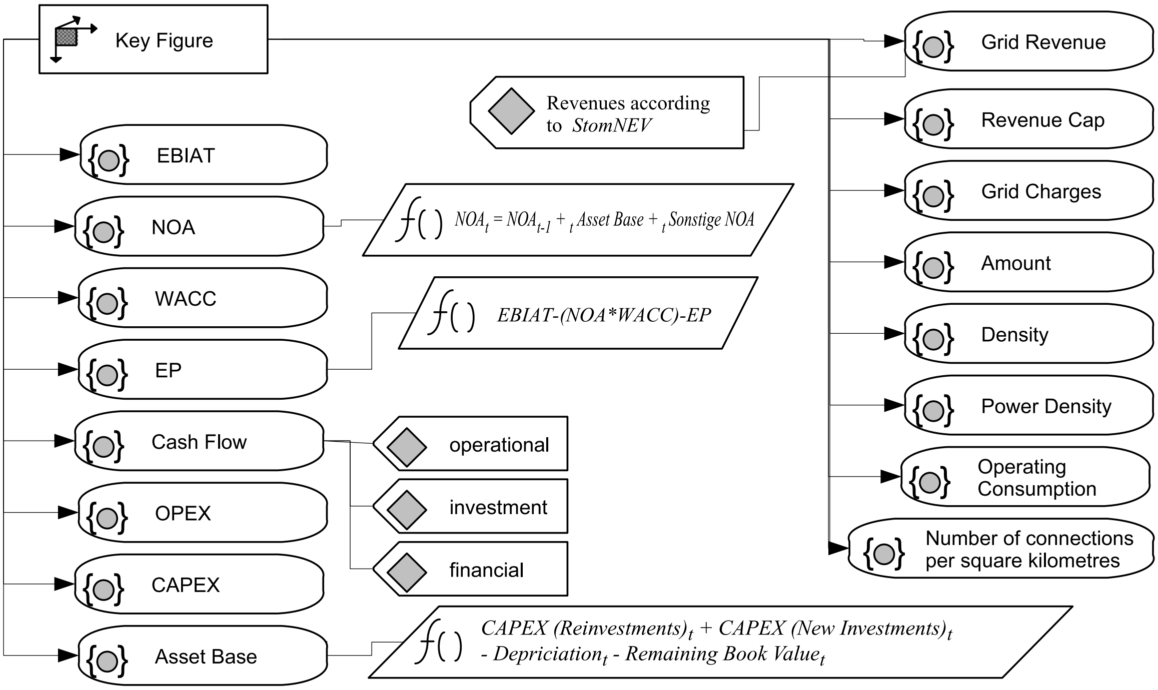

Fig. 11 Financial perspective – representation of *Economic profit* (EP)

from a functional and from a technical perspective (**Fig.** 12).

Four-hour interviews took place with various participants from TSOs (11 persons), a regulator (1 person), and consulting companies (10 persons) that focus on analytical solutions in the utilities industry. The instrument to gain reliable information was created from different interview guidelines that consider technical as well as functional aspects. The interviews were problem-centered and thus they allowed specific statements about the universe of discourse rather than being focused on closed questions. The discussion base was a presentation with the following task-related questions:

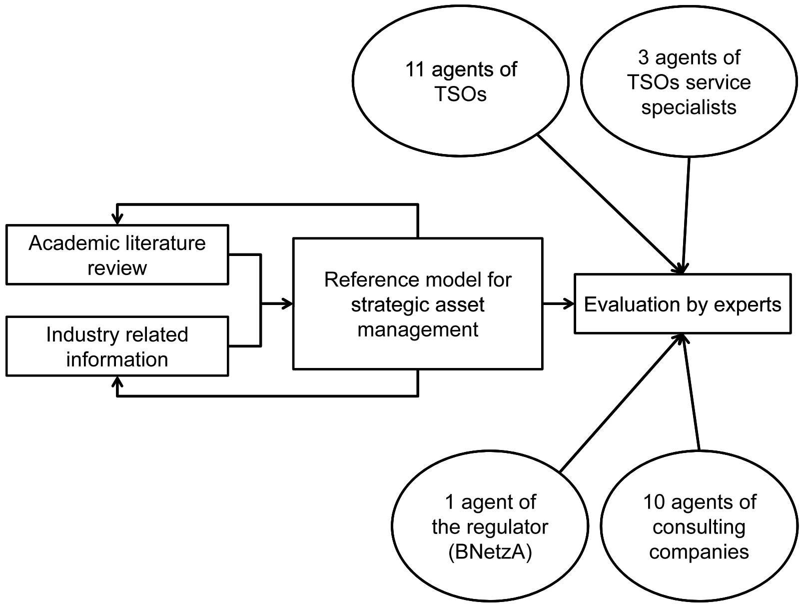

Fig. 12 Research phases for reference modeling in strategic asset management (adapted from Jaeger and Reinecke 2009, p. 37)

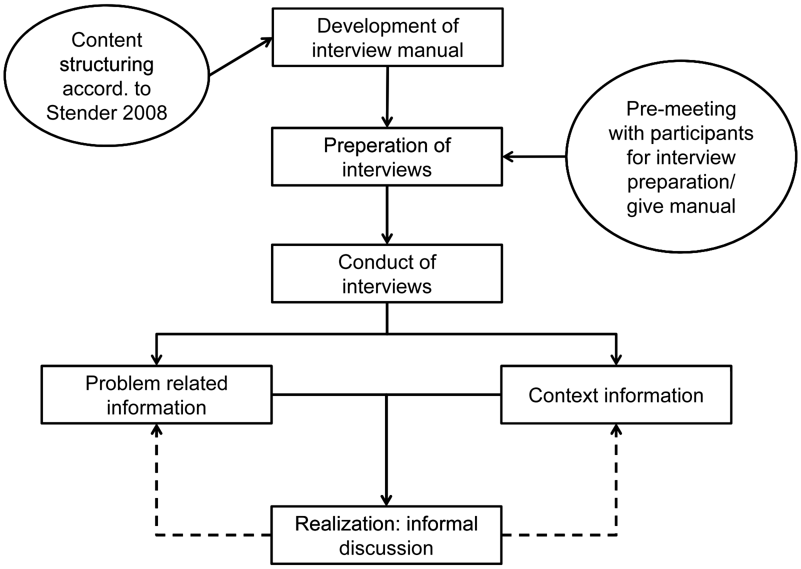

Fig. 13 Phases of the interview (modified from Jaeger and Reinecke 2009, p. 41)

- Which tasks were realized automatically/manually?
- Which tasks in the different perspectives have a high/low priority?
- Are important tasks missing from the reference model?
- Which tasks should be automatically executed and presented graphically?
- Which activities are covered with single suitable tools?
- Does reporting represent the focus of current asset management?

In addition to the exact answers, the functional capabilities and appropriateness of the reference model were also discussed.

Participants received an interview manual in a pre-meeting. This interview manual was based on the discussion of Stender (2008). Therefore, participants were prepared in the second discussion. Additional materials and approaches, and even experiences, had to be researched to determine the respective status quo. Within the interview sessions, participants had no limitations on what they could discuss. As a consequence, they had the chance to formulate problem- and context-relevant information in an open-minded atmosphere where spontaneity was not limited. Additional information could also be documented. The interviews took place locally. The model was mapped using the regulatory reports of the *BNetzA* and standardized reporting. Concerning the technical aspects, model mapping was conducted by three consulting firms that provide information systems solutions for utilities companies. The focus of the mapping was on the collection, integration, and interpretation of the data (**Fig.** 13).

The interview evaluation followed the four-eye principle. It concentrated on content analysis, while different interpretations were clarified in direct discussions with the interview partners (**Fig.** 14). The interview minutes were collated, which lead to the presented results. After an introduction to the modeling notation of ADAPT, participants confirmed the enumerated elements from the data model as the ones essential for building up the current asset management reporting carried out in MS Excel. Validating the regulatory requirements was easy because the structured reports were available. After the first validation, a prototype was developed that contained the dimensions of Costs, Electric Power, and Condition Data. Data were adapted from one of the TSOs. Based on the example data of a high voltage circuit breaker, the model was mapped and evaluated against the *IEC 61000-430 Class A Standard*,[3] Power Quality Measurement. The result was that the model fulfills the technical requirements of the IEC standard. Moreover, the model provides even more detailed data on condition and cost. Therefore, a more detailed test with IEC 61000-4-30 is possible which means that a certification can be obtained. Within this context, the level of abstraction was discussed, e.g., which machineries should be part of the data analysis to enable a more detailed and exact simulation. It

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[3] The IEC Standard supports the compatibility of energy-generating tools and machinery. It measures parameters such as frequency, vibration curves, reactive power, or voltage changes in order to make them comparable independently of third party tools.

[4] In the context of this paper, neither company names nor tools are mentioned.

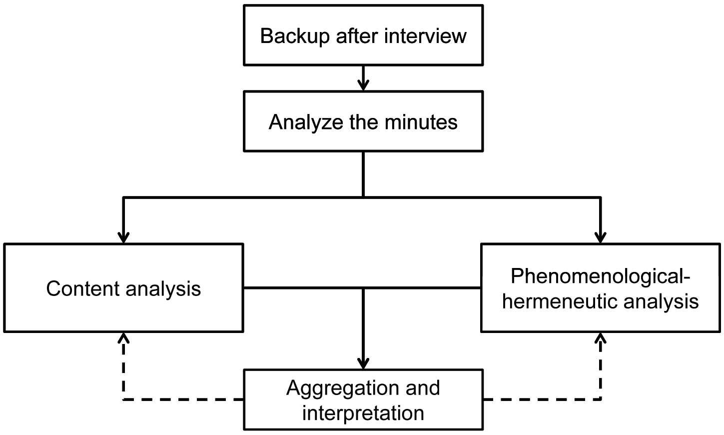

Fig. 14 Phases of the data evaluation (modified from Jaeger and Reinecke 2009, p. 53)

became obvious that further discussion about this topic is necessary.

This discussion proved the functional fulfillment of the reference model. Furthermore, the analytical process was supported by the reference model. It also became obvious that the process models, e.g., the network valuation, are not used in practice, but only discussed in the literature. By contrast, TSOs use the experience of their employees to determine planning measures and take decisions.

The discussion with the consulting company revealed that the current solutions are not standardized as required.[4] Instead, many solutions are closely related to MS Office solutions or are part of a developed structure with an operational machine control centre. Facing the increasing data volume, local databases have been developed and have meanwhile migrated to a database. Currently, no TSO uses an automated ETL tool so that the consolidated data are assigned to a manual process with repeated data entries. Automated ETL and the integration of financial, technical, and geographical data are seen as the main challenges. Current data models represent short-term ad hoc requirements and do not follow a standardized approach using a data warehouse design. One of the main topics in the discussion was the awareness of flexibility. The interview partners stated that the reference model is more flexible than current databases are. However, they see problems with regard to implementation, especially project implementation time and ETL automation. Furthermore, the discussion revealed that current reporting is an extensive and error-prone process that influences data quality and leads to a high number of administrative efforts, which justifies the effort to implement the reference model.

The interviews took place in an open-minded atmosphere in which not only the reference model was discussed but also the experiences the interview partners had made in their field. In conclusion, the reference model was considered valid regarding its functional and technical aspects, and its technical practicability was asserted. It is now seen as a recommendation for implementation. For this reason, it reveals the character of a reference model.

5 Conclusion

This paper's goal was to improve information supply and to overcome the current separation between the technical and financial perspectives in grid asset management. Therefore, a reference model was designed to address the demands and challenges within the TSOs.

Assessing and storing data in a multidimensional model meets the requirements of regulatory reporting and incentive price regulations. Therefore, technical data have to be coupled with financial ones, which is explicitly carried out in the hierarchical dimensions of Capital Equipment and Voltage Level. This hierarchical description enables coupling between strategic decisions and their impacts on operational tasks and vice versa. Assessing single components and their aggregations builds the foundation to define cause-effect chains in an integrated system. Using the modeling notation of

Abstract

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Integrated Information Supply for Decision Support in Grid Companies

Increasing regulatory requirements such as price cap regulation have increased the importance of strategic grid asset management. Empirical studies reveal that information supply and consolidation are error prone and long-term processes. The reason is the missing automation of extraction, transformation, and loading. The current gap does neither fulfill the requirements of regulatory nor the necessity of standardized reporting. Furthermore, a detailed planning is not enabled and the calculation of key figures is extensive. Currently, a framework that considers the coupling of financial and technical key figures, the coupling of strategic and operative key figures as well as the integration into information systems is not existent. Therefore, this paper addresses the design of a reference model as a recommendation for action to integrate the asset management within information systems. It is validated by expert interviews. Moreover, it provides information to integrate relevant financial and technical artifacts from distributed systems. Simultaneously, it provides recommendations for implementing a Business Intelligence architecture in the context of strategic decision support.

Keywords: Business intelligence, Reference modeling, Utility business

ADAPT enables the modeling of dimensions, their hierarchies, and their calculation rules for every key figure. This is necessary to integrate the diverse data sources of asset management into a BI system and to overcome the bottleneck of information supply.

However, the designed reference model has not yet been implemented. In fact, the model is based on practical knowledge and experience, but so far it has only been validated by domain experts. A reference model has emerged which still needs to be practically applied to achieve learning rates and improvements. On the other hand, the model is currently in discussion with a leading TSO to improve data supply, collection, and reporting for decision support. The reference model especially supports regulatory reporting. In addition, criteria were presented in this paper to outline the value proposition of an implemented reference model, i.e. the reduction of functional effort, improvement to data quality, and time reduction in the decision process.

In the context of the Business and Information Systems Engineering discipline, the mentioned criteria can be used to further evaluate the advantages of the designed reference model. This would represent an important further step towards practical implementation. Regarding Design Science Research, there is still a need for further research on evaluation, which is an important subject of modeling research, as described by Frank (2007).

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