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How Operation Data Helps Manage Lifecycle Costs

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1 INTRODUCTION

Deregulation is afoot and increased competition, if not felt already, looks to be just around the corner. As the economic playing field for utilities changes, so do the structures and processes inside the companies. The retail business is being opened to competition first, especially for industrial and commercial customers. Therefore the distribution utilities must become more flexible, so that they can survive in these dynamic markets. Information technology (IT) is highly crucial for taking the key steps, namely, to increase the productivity of employees, to enhance the utility's relationships with its trading partners, and to improve the return on its capital assets.

Since their foundation many of the utilities have excelled more as a type of engineering company than as a retail or service company, and thus their IT systems have shaped accordingly. As for any retail and service business the efficient and effective use of information is what provides business value and strategic advantage. This holds in particular for the management of capital assets. Evidential for the growing utility IT importance is also the fact that even pure IT vendors, such as Microsoft, SAP, or Compaq, are running marketing campaigns exclusively addressing utility business [1].

To increase the return of capital assets implies to minimize the total cost of ownership, i.e., minimize the purchase, installation, operation, and de-installation costs. For utilities, however, it also means to find the right trade-off, firstly, between asset utilization and asset operating costs, and secondly, between asset utilization and planned or unplanned outage costs, due to maintenance work or a network failure, respectively.

Starting from the perspective of an overall asset management framework with a variety of applications (chapter 2), the paper first sets the context for one possible application – *contract and tender support* – (chapter 3). This in turn heavily relies on two other basic asset management applications - *the calculation and optimization of asset lifecycle costs and availability*. Chapter 4, being the core of the paper, elaborates on the latter applications to convey their value in dealing with above mentioned trade-off considerations. By comparing the data which utilities acquire already today (chapter 5) with the data and its quality required for these two applications (chapter 4.1), the potential usefulness of the existing mass of data as well as the gaps can be made explicit (chapter 6).

2 THE ASSET MANAGEMENT PERSPECTIVE

As a working definition for this paper assets are tangible investment intensive and/or mission critical entities, such as switch gear, transformers, power lines, or from a grid perspective even entire network nodes. Thus, Asset Management Systems (AMS) can be viewed as dedicated IT applications intended to support the management tasks of assets with the overall objective of maximizing the return on investment. This is in line with the definition of asset management stated by the Government of Victoria [2]: *"The process of guiding the acquisition, use and disposal of assets to make the most of their service delivery potential (i.e., future economic benefit) and manage the related risks and costs over their entire life"*.

An AMS ideally encompasses the support of management tasks during the entire lifecycle of an individual asset. I.e., it provides support for the planning phase of the asset (e.g., investment decision for the installation, replacement or refurbishment) as well as for the management tasks during the operation phase (e.g.,

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maintenance planning). A characteristic property of an AM application is that it typically needs data from both the utility's operations systems (substation automation systems, SCADA, EMS) and the finance and business systems (in Fig. 2-1 called back office).

The utilities' day-to-day operations of transmission and distribution networks involve specialized control systems that, so far, were shielded from market pressures and achieved unprecedented levels of service reliability. But they also had little or no ability to share data - either among themselves or with business applications. It is only recently that some applications (e.g., customer information systems) seem to penetrate into the systems once exclusively used by the operations department. For asset management, however, shared access to almost any utility data source is instrumental. A data warehouse can provide the means of making the data access for asset management applications look homogeneous despite the physically distributed and heterogeneous data sources.

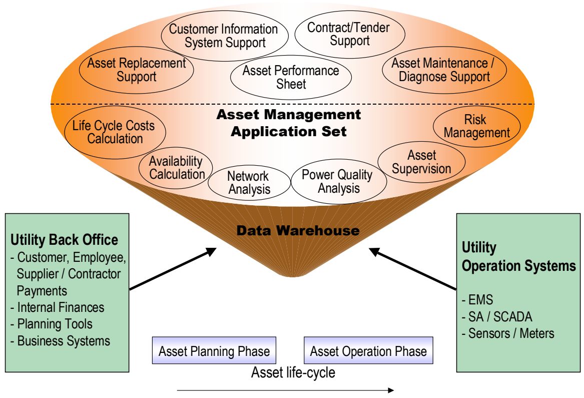

Figure 2-1: Asset management applications support the planning and operation lifecycle of assets and acquire their data from diverse sources within the utility IT system environment.

Asset management applications thus build the bridge between back office and operations systems. Fig. 2-1 shows a number of asset management applications divided into two categories.

The first category, depicted in the top part of the ellipse consists of the applications that are directly visible by the user:

– *Asset replacement support*. Provides information helpful to decide on asset replacement vs. asset refurbishment. Information includes: current costs, accumulated downtime since commissioning, estimated future availability, estimated future maintenance costs, etc.

– *Asset maintenance and diagnose support*. Functionality includes maintenance scheduling, maintenance scenario comparisons (corrective vs. preventive vs. condition based), estimated aging, remote diagnosis, etc. (more details can also be found in [3]).

– *Asset performance sheet*. Basically provides the financial performance of an asset, i.e., the details leading to the actual return on investment figure. This could, for instance, be helpful to compare two network nodes (substations), e.g., one deployed with latest automation technology and the other one still with conventional technology.

– *Customer information system*. The set of customer oriented functions often found already today, such as outage management, work management, customer hot line.

– *Contract/Tender Support*. The dynamic markets require the ability to speed up sales and marketing tasks. Many customers want to have guaranteed statements with respect to power quality and availability and/or request such records of the past.

The second category - the helper applications - primarily supports applications of the first category and may or may not have a direct user interface:

– *Lifecycle cost calculation*. For details see chapter 4.

– *Availability calculation*. For details see chapter 4.

– *Network Analysis*. For different types of network operation and planning tasks, it is indispensable to have at least a power flow calculation available. More elaborate network analysis methods include security assessments, short circuit analysis, etc.

– *Asset Supervision*. This application is based on asset condition monitoring, whose results provide the figures for predictive, reliability-centered maintenance, and for asset condition assessment.

– *Risk Management*. Can provide probability figures for many of the information given in applications of the first category. It may also appear as a stand-alone package supporting the assessment of contractual risks.

– *Power Quality Analysis*. This application analyzes the power quality at certain points of the network and provides details of voltage swells, sags, or total outages. This information may be helpful for the outage management, for the customer complaint desk, or for generating quality clauses as part of customer contracts.

Central to many asset management applications are lifecycle cost and availability calculations. As a motivator for the detailed explanation of these vital parts the next chapter introduces a potential use case based on the contract/tender support application. It shows how it depends on the existence of lifecycle costs and availability prognosis.

3 THE POTENTIAL USE CASE: TENDER FOR A NEW CUSTOMER

In Switzerland, the full liberalization of the electricity market is planned for 2007, and big customers (over 20 GWh/year) will be provided open access to transmission networks already in 2001. However, the race among power providers for binding new customers has already started. For example, the Swiss second biggest transmission utility, ATEL, currently uses financial models for creating tenders for the big customers. To these potential customers ATEL offers the power at about 30% lower price compared with their provider's current pricing conditions. As the eventual new provider, ATEL pays the price difference to the current providers until the transmission access is open. This, of course, obliges the customer to change provider when it occurs.

The above example illustrates how changes in the marketplace affect the way of doing business. The Contract/Tender application from Fig. 2-1 provides the IT based decision support for a faster customer acquisition process likely to be required in the distribution utility business.

3.1 Use case background

The distribution utility with mainly retail business is shown in Figure 3-1. It may own some generation, but it also purchases the power from power providers (e.g., sub-transmission network or power producers). The network it owns is operated radial, but there are facilities installed (e.g., lines, substations) that enable temporary loops. The network is used to deliver the power to utility customers, which are the final consumers, such as industrial plants or aggregated residential consumers.

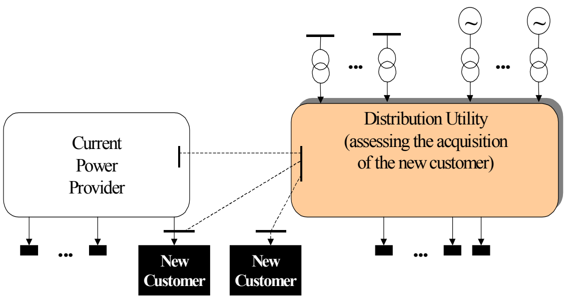

Figure 3-1: Illustration of the distribution utility wishing to acquire a new customer.

Now, consider a new customer issuing the call for tenders. The customer may either be the final consumer or another distribution utility. It may also either be a customer wishing to change his current power provider, or an actually new customer, such as a new factory. In any case, from the distribution utility perspective it will be *the new customer*. There may or may not exist a physical link from the distribution utility to the new customer (dashed links in Figure 3-1).

As a side note, utilities are also forced to renegotiate contracts with existing customers, just to be able to keep them. The application descibed below can be thus used for elaborating the existing contracts, too.

3.2 The AM application

The asset management application is used when the utility wishes to process a tender for the new customer. The application evaluates the utility network operation and assets based on two different sets of aspects. First, the technical feasibility, and second, the economic figures.

The technical feasibility investigates whether the customer's load demand can be satisfied at all, and in a secure manner. For this purpose, the power flow calculations are performed for different scenarios, i.e., for the combinations of the following parameters:

- the distribution of needed increment of production (uniform vs. custom, utility-owned production vs. power providers);
- the topological configuration of the network; and,
- if currently no physical link exists between the utility network and the new customer, the location of the substations likely to be used for the future connection.

A scenario is valid, or feasible, if the network can be operated within the prescribed limits such as voltage or current. It may also happen that with the current network assets there is no feasible scenario for the new customer load profile, simply because the network has insufficient capacity. In this case, the planning manager can intervene by setting the assets plausible for upgrading (e.g., transformer, circuit breaker). Hence, this would then represent one more scenario.

The resulting set of technically feasible scenarios is then evaluated in order to estimate their economic value and impact on network availability. If the utility already has a scenario power flow calculation and/or validation tool, its outputs can be fed into the asset management application. The same applies to the scenarios introduced manually, by a utility expert.

3.3 User interaction with application

The marketing manager adds the potential new customer data (e.g., load profile, location, required price-availability ratio, etc.). The demand for scenarios generation and comparison is sent to the operation / protection engineer, who sets some parameters and performs network calculations. If a new link is to be constructed, or if an asset is to be upgraded, the planning / construction engineer should intervene too. Hence, from the individual user's point of view all user groups (sales persons, protection engineers, construction and planning engineers) do their work as usual. However, the system handles all the "individual" parts as the composites of the logical business artifact "tender for customer xy". From all the generated scenarios, the application keeps only the feasible ones. Those *valid* scenarios are further processed within the combined basic modules – lifecycle costs and availability calculation – as described in Chapter 4. Among others, the application finally shows the *estimated* lifecycle costs, the corresponding network availability figures and risk probability of the above estimation, for the processed scenarios. The produced information helps the marketing manager in selecting the scenario on which the final tender is based.

4 CALCULATING AND OPTIMISING AVAILABILITY AND LIFECYCLE COSTS

The main benefit of the combined basic modules – lifecycle costs and availability calculation – is their generic ability to compare different scenarios by considering financial as well as technical criteria. The generated output consists of the expected lifecycle costs LCC, the availability, and the risk (i.e. the LCC uncertainty) of these figures for a set of scenarios to be investigated. For example, an envisioned grid extension or substation refurbishment could be realized in several ways ("scenarios") that need to be compared with respect to expected lifecycle costs, availability, and their respective risks. However, it would then be up to the utility to decide on the scenario that represents a suitable trade-off between a satisfying availability and acceptable costs.

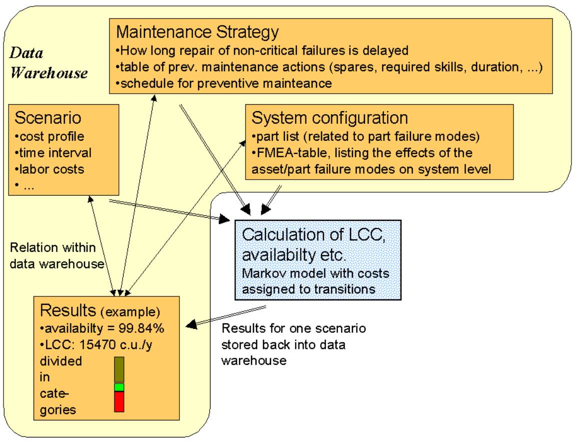

Figure 4-1: Diagram of the principal input and output data flow of the LCC and availability calculation algorithm.

The comparison and subsequent optimization of different scenarios relies on an algorithm which can calculate the average availability and the mean annual costs for a given system configuration (composed of assets), a given maintenance strategy [4] and an asset/scenario-specific cost profile (Figure 4-1). The cost profile assigns the downtime costs (e.g., incurred by penalties, lost energy deliveries) to the fault symptoms, i.e., to the different degrees of degraded system performance [5]. The main information base for the calculations is the detailed FMEA table (FMEA stands for *Failure modes and effects analysis*) which contains

- failure modes of assets and/or their parts, specifying the resulting impact on, e.g., grid level,
- time until repair starts, how long it takes, and how long it then takes to resume operation again,
- material costs,
- personnel required, etc.

From this FMEA table and the other input information shown in Figure 4-1, the algorithm creates a Markov model with some extensions [6]. For instance, in addition to standard Markov models for calculation of availability and mean time to failure (MTTF), the costs resulting from a failure are included. The calculated results for the individual scenarios (as well as the FMEA table, in the first place) are stored in the data warehouse (see chapter 4.1), which remembers the origin of the input information by building relations among database objects.

After the desired figures for all requested scenarios of a system configuration and/or maintenance strategy are calculated, the optimization steps (or in other terms the trade-off considerations) are done with interaction of the user. Figure 4-2 shows how the LCC results from different scenarios are displayed together to ease the comparison. In addition to the presentation of LCC figures one can also obtain the other results in graphical form: availability expressed in downtime per year, MTTF figures, or risk curves. On a cost axis the risk curve shows the probability to exceed the costs [7], thus displaying the uncertainty of the cost prognosis caused by random failures and by imprecise knowledge.

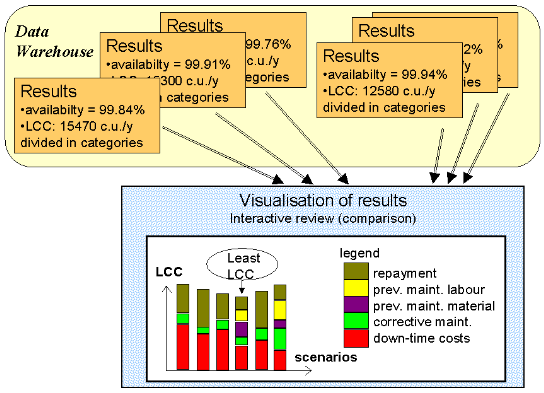

Figure 4-2: Graphical presentation of the LCC for various scenarios based on the data coming from the data warehouse.

It is often useful to permit a human expert to (re-)view the individual results. The visualization program thus allows to navigate through the results, not only for the marked (i.e., best) scenario but also for all the other scenarios. This allows favoring a scenario different from the one proposed by the LCC calculation. Reasons could be personal weighting factors that were not included in the calculation or facts that are hard to quantify and have not been included either. For example, despite its more promising LCC figures a substation built from assets of an unknown supplier shall not be considered because it is too risky for the utility to deal with equipment where they have no experience at all. The trade-off considerations might conclude in choosing a scenario with slightly higher LCC if, for instance, its higher availability or lower risk is more convincing.

To give an impression of the ability of the method to quantify cost savings, an example GIS switchgear station consisting of ten bays is considered. The results show that a reduction of the initial costs of the secondary equipment by 3% is possible without any loss of dependability. This is achieved by avoiding unnecassary redundancy in the physical layer of the process- and the interbay-bus [6].

The quality of the LCC prognosis and consequently the quality of all the results is dependent on the quality of the data found in the FMEA table (e.g., failure rates). The prognosis can be improved substantially by replacing the originally estimated, but subjective, data with statistically calculated values based on a periodical refinement by using the acquired operational data within the utility. This is even more important because subjective estimates of different parts probably contain the same systematic errors, so that they must be treated as statistically correlated. Thus, an availability and LCC analysis based on subjective data will bring about results with a large uncertainty [7]. It is therefore much better to use failure rates that are based on statistical evaluation of operational data.

When assets, or more precisely, systems where these assets are part of, are in operation, operational data is to be collected (Figure 4-3) and entered into the data warehouse. In the best case this happens automatically, in that the data warehouse is integrated with the utility's operational and back office systems. For example, the overall downtime due to an asset failure is extracted from the SCADA system by looking at the time tags of the tripping instance and the later closing of the circuit breaker. Similarly, the costs for the repair action are derived from the repair report entered into one of the back office systems.

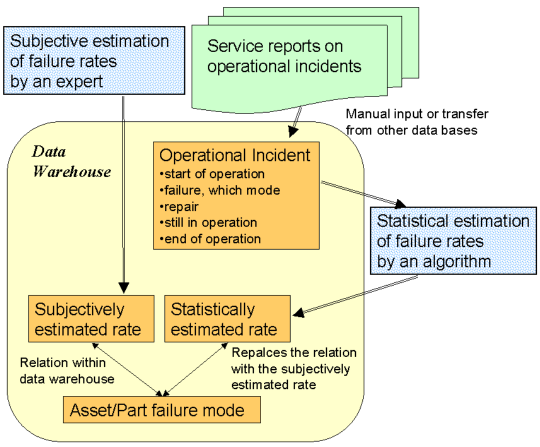

Figure 4-3: Process of replacing subjective input data by statistically evaluated operational data.

Operational data are populating the data warehouse in the form of objects called *operational incidents* and help to refine the FMEA table. They consist of, e.g., part identification (serial number), date and time and the type of incident with some additional information. The types of incidents reported and stored are

- Start of operation
- Failure detected (which failure mode)
- Repair finished (working time, labor and material costs, duration of repair)
- End of operation without failure
- Still in operation without failure

The last type of incident is necessary because an unbiased statistical estimate can only be created if the operating time without failure is correctly counted.

The algorithm of statistical failure rate estimation evaluates all the operational incidents concerning one asset and condenses the information into the observed time and number of failures. Further details on the algorithm can be found in [7].

4.1 Organization of the Data Warehouse

Depending on the type of analysis chosen and the strategic goal that has to be reached by the application, requirements on the data necessary for the analysis can be formulated. In the case of a contract/tender support application different scenarios are evaluated with respect to their expected power flows, availability, and maintenance costs. The data necessary for this application comes from different sources, e.g. technical data from proprietary systems like EMS, SCADA, or sensors and financial data from the back office. This data has to be combined into a centralized data storage, a *data warehouse*, so that it can be used in a consistent way by the targeted application. The role of the data warehouse is thus to collect, structure, and integrate different kinds of financial and technical data and to make it accessible in a consistent manner for one or several applications, e.g. the ones shown in Figure 2-1. This also includes bookkeeping of historical data, e.g. already realized refurbishment activities or extensions. The amount of data coming from proprietary systems can be considerable so that the process of introducing new data into a data warehouse should be automated as much as possible. This process is defined either on an event-driven or a regular basis. Service reports from the different nodes in the network can for example be sent to the data warehouse once every month. This incoming data has in general to be preprocessed, i.e. cleaned, filtered, and perhaps aggregated, before it is stored in a predefined structure in the data warehouse.

In order to implement a data warehouse, the conceptual, logical, and physical level have to be considered. The conceptual model describes information resources and analysis tasks within an organization. The logical level handles the actual *data models*, source data model and data warehouse model. The physical level interprets the data warehouse architecture as a network of data stores, data transformers, and communication channels. In the following, we concentrate on the logical level with a description of the data models. The most important technologies used nowadays for data modeling and implementation aspects are relational database and object-oriented techniques. The relational approach has become a quasi-standard regarding modeling as well as the database platforms and is likely to remain so in the near future [8]. The relational model allows the representation of static facts: objects in the real world are modeled by entities, and their interactions by relations between entities.

The asset management application described in this paper, requires the following kinds of data (Figure 4-1):

- a description of the possible topological configurations of an electrical network,
- a description of the possible scenarios concerning maintenance and operation planning,
- data from the failure modes and effects analysis (FMEA).

The data model itself is structured into three corresponding sub-models, called *system*, *scenario*, and *failure* model, respectively. The *system model* describes the network including the assets it is composed of and how these assets are connected. For each type of asset additional manufacturing information is provided, e.g. manufacturer, prices etc. This description is used to produce several system configurations given a set of scenarios to assess the material and investments costs for the planned extensions. The *scenario model* includes additional non-technical data such as operation and maintenance strategies and financial data like customer and supplier payments. The *failure model* defines failure rates for the assets and FMEA-related data. In FMEA, for each asset is recorded how it fails and what the effects on the entire network are. Failure rates describe quantitatively how often an asset fails within a system configuration. Such failure rates are either obtained on a statistical basis or estimated by experts as confidence intervals. A basis for statistical rates could for example be the collected and analyzed failure reports.

Existing standards such as IEC 61360 [9] and ISO 10303-212 [10] specify the description of components and their services. Our data model can be easily integrated with these standards using the concepts of specialization and/or generalization. If the description of a component in the standard is more general than what has been proposed in our data model to describe assets, the asset description becomes a specialized object of the standard description. If our model adds important services to the standard description, a new asset description is generated being a specialization of two parent descriptions: the standard as well as our original model.

Summarizing above, the data model defines the structure of the data that is stored in the data warehouse. In this section, the most important kinds of data required for optimizing asset management strategies have been stated. Once the data selection phase is closed, it has to be investigated what kind of data is electronically available and what the quality of this data is.

5 CURRENT DATA AND DATA FLOW WITHIN A DISTRIBUTION UTILITY

The example distribution utility, for which the data acquisition and information management principles are described, operates a network consisting of two 50 kV rings, with 13kV radial networks (temporary loops possible), and the 0.4kV consumer voltage level.

5.1 Operational Data

The utility collects and evaluates operational data primarily for the judgement of the network status. Most of the data, with the exception of the measurements from transformer stations at the medium voltage level and the decentralized power production plants, is continually acquired and stored by the SCADA system. By means of a data transfer utility, the raw data is periodically exported from the SCADA data base into ASCII files, put on a storage medium (floppy disks) and archived for potential later usage, e.g., for the production of statistics, for technical investigations, and for cross-checking of power flow calculations.

Operational data are acquired at the following points in the network:

- Infeeders into the utility network
- HV/MV transformers in substations
- HV bays in substations
- MV bays in substations

The measurements of operational data from transformer stations at the medium voltage level and the decentralized power production plants are usually acquired by portable, dedicated local recording devices, e.g. simple registration units (paper tape based), or numerical data loggers. The data at a particular point is recorded for a month or longer and collected on a monthly basis. The devices are installed by the personnel from the operations and maintenance department, during their periodic site inspections of the transformer stations. The personnel responsible for the quality management of the network take over the data evaluation and the management of the data archive. In order to determine operational data (average load, peak load, etc.) of big customers, used, for instance, for grid extension considerations, the data from the metering equipment provides valuable input. This, usually monthly collected, data is entered into a dedicated software application to roughly estimate the customer's load profile.

The currently collected operational data falls into two categories, the analog measurements, and the status indications. The measurements include:

- Voltage
- Current
- Active power
- Apparent power
- Outside temperatures
- Transformer oil temperatures

The status indications are confined to:

- Tap changer position
- Circuit breaker position indication

In addition to the above the utility conducts quality related measurements, e.g., harmonics, (according to EN50 160) with dedicated measuring equipment.

The registration of the measurements is done based on a 15-minute interval. Each measurement is time tagged (date and time). The following evaluations and key figures are derived from the measurements:

- Load curves
- Hourly maximum
- Minimum and maximum per given time period
- Maximum winter load
- Load factor
- Degree of utilization

5.2 Disturbance Data

Besides acquiring and evaluating above mentioned operational data, which is considered more of a routine type of work, the utility collects the disturbance data generated by the protection relays after a network disturbance or failure. The disturbance data collection is done through remote data access (dial-up modems) to the disturbance recorders and/or relays from a dedicated central protection workplace, where also the subsequent evaluation of the data is carried out. The disturbance records and possibly existing event logs captured from the protection relays are normally stapled or attached to the reports described below.

In general, each disturbance requires that a disturbance report be written. This is a plain document generated by any word processor and contains information such as:

- Affected system part
- Cause of disturbance
- Duration of disturbance
- Average power loss
- Course of actions

The administration of all the utility data - measurements, status indications, disturbance data, and reports - is done manually up to now. The data is stored at a central data archive within the operations department in all its proprietary formats and in either electronic or paper form.

In order to improve the efficiency of collecting, evaluating and administering the data in the future, the utility plans to deploy a larger number of the previously mentioned dedicated data loggers. But instead of archiving each logger's output separately the utility intends to put the data into an operations department wide central relational database. This requires the data to be uniform and yields a standardized starting point for the eventual data evaluation, but also enables for an improved administration process. But more importantly in the context of this paper; if the central relational database were established, it would become possible to link it to a data warehouse such as described in chapter 4.1

6 CONCLUSIONS AND OUTLOOK

By comparing the data collected today with the required data for the kind of application described in this paper it can easily be seen, that, theoretically, most of the information is available within a utility. However, its format is highly heterogeneous and so is its accessibility. Important data, for instance a detailed description of the network topology, has been painfully put together over many years and may now reside in a certain inaccessible, since proprietary and monolithic, application. It is not hard to imagine that a utility would be more than reluctant to purchase a system where such information needed to be entered again. Furthermore, much useful information (e.g. outage-related data and conclusions) is currently found in textual form only and buried within reports, work order forms, or manually assembled statistics.

All of the technical difficulties mentioned above make it extremely challenging to easily introduce a system as proposed in chapter 2. Let alone the internal, historically evolved, barriers between individual utility departments and their partly orthogonal objectives.

With respect to Swiss distribution utilities this leads to the conclusions that on short term, more individual, but state-of the-art, IT applications and tools would provide advantages for the activities of the utilities' departments, while at the same time paving the way for AM systems of the future. In order to prepare for a smooth transition to the upcoming IT systems and applications we strongly recommend that utilities pay careful attention to the interoperability issues of the IT systems they are about to purchase, replace, or enhance. The potential rewards of AM applications as described in this paper should be an incentive to develop a utility IT strategy that puts highest priority on the ability to reuse different data for applications only vaguely anticipated at this moment in time. This holds true especially in the case of the upcoming intelligent primary equipment and advanced monitoring systems. It would be a sin to deploy such equipment and systems if the accompanied software did not adhere to the open software systems philosophy.

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7 BIBLIOGRAPHY

[1] K. McCumber, Winning ideas for utilities (special joint advertisement by Microsoft Corporation, Compaq, and Utilities IT magazine, www.itforutilities.com/ideas/introduction.html)

[2] Asset Management Series: Principles, Policies and Practices (prepared by the Victorian Government as part of the Management Improvement Initiative, November 1995; available at http://home.vicnet.net.au/~assetman/welcome.htm)

[3] V. Lohmann, O. Preiss, Less impact of power failures due to substation automation (CIRED 1999, 15th Intl' Conference, 1.-4. June, Nice, France)

[4] S. Draber, Modeling the influence of intentionally delayed repair on reliability and LCC (Proceedings of the International Conference on Parallel and Distributed Processing Techniques and Applications, PDPTA'99, Las Vegas, Nevada, USA, June 28 - July 1, 1999. H.R. Arabnia (ed.), vol. VI, CSREA press, ISBN 1-892512-14-9, pp. 2731-2737)

[5] S. Draber, B. Eschermann, Dependability evaluation of a computing system for traction control of electrical locomotives (2nd European Dependable Computing Conference, Taormina, Italy, October 2-4, 1996, Lecture Notes in Computer Science, 1150: 129-140, Springer Verlag)

[6] S. Draber, Reliability-oriented design of a distributed control system for high voltage switch gear stations (Proceedings of the FTCS-27, The Twenty-Seventh Annual Symposium on Fault-Tolerant Computing, Seattle, Washington, USA, June 25-27, 1997, ISBN 0-8186-7831-3, pp. 385-389, IEEE Computer Society)

[7] S. Draber, Risk Analysis of Exceeding Guaranteed Limits of RAM-related Costs (ESREL 99, International Conference on Safety and Reliability, Garching, Germany, September 13-17, 1999. G.I. Schuëller & P. Kafka (eds.), Safety and Reliability, Balkema, Volume 1, pp. 277-282)

[8] D. Proudfoot, D. Taylor, How to turn a substation into a database server, (IEEE Computer Applications in Power,1999, pp. 29-35)

[9] IEC 61360-2:1998-04 Standard data element types with associated classification scheme for electric components

[10]ISO 10303-212 Industrial automation systems and integration – Product data representation and exchange: Part 212 Application protocol – Electrotechnical design and installation