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Anna Tanskanen

ANALYSIS OF ELECTRICITY DISTRIBUTION NETWORK OPERATION BUSINESS MODELS AND CAPITALIZATION OF CONTROL ROOM FUNCTIONS WITH DMS

Thesis for the degree of Doctor of Science (Technology) to be presented with due permission for public examination and criticism in the Auditorium 1382 at Lappeenranta University of Technology, Lappeenranta, Finland on the 26th of November, 2010, at noon.

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ABSTRACT

Anna Tanskanen

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Electricity distribution network operation (NO) models are challenged as they are expected to continue to undergo changes during the coming decades in the fairly developed and regulated Nordic electricity market. Network asset managers are to adapt to competitive techno-economical business models regarding the operation of increasingly intelligent distribution networks. Factors driving the changes for new business models within network operation include: increased investments in distributed automation (DA), regulative frameworks for annual profit limits and quality through outage cost, increasing end-customer demands, climatic changes and increasing use of data system tools, such as Distribution Management System (DMS). The doctoral thesis addresses the questions a) whether there exist conditions and qualifications for competitive markets within electricity distribution network operation and b) if so, identification of limitations and required business mechanisms.

This doctoral thesis aims to provide an analytical business framework, primarily for electric utilities, for evaluation and development purposes of dedicated network operation models to meet future market dynamics within network operation. In the thesis, the generic build-up of a business model has been addressed through the use of the strategic business hierarchy levels of mission, vision and strategy for definition of the strategic direction of the business followed by the planning, management and process execution levels of enterprise strategy execution. Research questions within electricity distribution network operation are addressed at the specified hierarchy levels. The results of the research represent interdisciplinary findings in the areas of electrical engineering and production economics. The main scientific contributions include further development of the extended transaction cost economics (TCE) for government decisions within electricity networks and validation of the usability of the methodology for the electricity distribution industry. Moreover, DMS benefit evaluations in the thesis based on the outage cost calculations propose theoretical maximum benefits of DMS applications equalling roughly 25% of the annual outage costs and 10% of the respective operative costs in the case electric utility. Hence, the annual measurable theoretical benefits from the use of DMS applications are considerable. The theoretical results in the thesis are generally validated by surveys and questionnaires.

Keywords: electricity distribution networks, network operation, outage costs, DMS, extended transaction cost economics

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List of publications

This thesis contains material from the following papers. The rights have been granted by publishers to include the material in the thesis.

I. Brådd, A., Lassila, J. and Partanen J. (2006), "The challenges of the network operation in the Nordic electricity distribution business heading for year 2030," In Proceedings of *IEEE PES Conference,* Botswana.

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III. Tanskanen, A., Bergman, J.-P., Jantunen, A., Saksa, J.-M. and Partanen, J. (2007*),* "Governance Structures of the electricity distribution network operation activities: towards a benefits-based analysis," *International Journal of Energy Sector Management*, Vol. 1 No. 4, pp. 307–321.

IV. Brådd, A., Jantunen, A., Saksa, J.-M., Partanen, J. and Bergman J.-P. (2007), "Electricity distribution network operation services - An analysis on market dynamics from the service provider's perspective," In Proceedings of *ICCEP Conference*, Capri, Italy.

V. Lassila, J., Tanskanen, A., Lohjala, J. and Partanen, J. (2009), "Unbundling of operation and network development activities in electricity distribution," *International Journal of Energy Sector Management*, Vol. 3, No. 4, pp. 383–405.

VI. Tanskanen, A., Raussi, T., Partanen, J. and Lohjala, J. (2010*)*, "Cost and benefit analysis for a distribution management system in electricity distribution networks," *International Journal of Energy Sector Management*, Vol. 4 No. 2, pp. 256–272.

Author's contribution

Within the publication entity, the author of this doctoral thesis has been the principal author and investigator in papers I–IV and VI. In Publication V, the main contributions in the manuscript were equally split between Dr. Lassila and the author of the thesis. However, Dr. Lassila conducted and processed majority of the experimental data from the case electric utility.

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Nummela, November 2010

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Nomenclature

Roman letters

a, b	outage cost factors (€/kW and €/kWh)
C	cost
c	unit cost
E	energy
f	fault frequency
i, I	network component(s)
j	electricity consumer
l	length
n	number
P	power
p	interest rate
t	(life, clearance, repair, reference) time
U	voltage, outage time (unavailability)
x	length of the network after the circuit recloser

Greek letters

Δ	change rate of losses
λ	failure rate
ν	symmetric error
τ	lifetime of the network

Acronyms

AMKA	Aerial bundled cable (low-voltage)
AMR	Automatic Meter Reading
AR	Autoreclosing
DA	Distributed Automation
DSO	Distribution System Operator
EMA	Energy Market Authority
EU	European Union
CAIDI	Customer Average Interruption Duration Index
CAPEX	Capital Expenditure
CEER	Council of European Energy Regulators
CC	Covered conductor
CHP	Combined heat and power
CIS	Customer Information System
CPI	Consumer price index
DEA	Data Envelopment Analysis
DAR	Delayed autoreclosing
DG	Distributed generation
DMS	Distribution Management System
GDP	Gross Domestic Product
GIS	Gas insulated switchgear
HSAR	High-speed autoreclosing
IEEE	Institute of Electrical and Electronics Engineers
INV	Investment

KAH	Keskeytyksestä aiheutunut haitta, Customer outage cost
KPI	Key Performance Indicator
LTP	Long-term planning
LV	Low-voltage
LVDC	Low-voltage DC
MAIFI	Momentary Average Interruption Frequency Index
MV	Medium-voltage
NIS	Network Information System
OH	Overhead line
OPEX	Operational Expenditure
PES	Power and Energy Society (IEEE)
PQ	Power quality
PV	Present value (of the network)
RV	Replacement value (of the network)
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control And Data Acquisition
SF_6	Sulphur hexafluoride
SPOC	Single Point of Contact
TCE	Transaction Cost Economics
TKK	Aalto University School of Technology and Science
TJSA	Toimittamatta jääneen sähkön arvo, cost of non-supplied electricity
TUT	Tampere University of Technology
VTT	Technical Research Centre of Finland
WACC	Weighted Average Cost of Capital

1. Introduction

It is expected that in the electricity market by the year 2025 the Finnish power consumption will grow by about 20 TWh. Nuclear power will account for about 50% of the additional electricity capacity needed, while the other half will be produced with bioenergy, natural gas and hydro and wind power. Also the share of domestic energy forms will grow – and imports will decrease (Finnish Energy Industries, 2010). As the amount of renewable energy sources is expected to grow, also the amount of distributed generation can be expected to increase from its current level.

In the electricity distribution networks, higher reliability and safety during major faults are expected of the future networks at reasonable costs. Climate change and restrictions concerning the use of impregnants will cause problems especially for the overhead lines in forests. In rural networks, also ageing of the networks poses a challenge. For the urban networks, land use and environmental issues become more challenging, and reinforcement of networks is necessary due to the increased use of electricity. Important solutions in the future networks are supposed to be the wide-ranging use of underground cables, high-degree utilization of communication and network automation solutions, considerably shorter protection zones and new topological solutions. In the long run, islanding enabled by the distributed energy systems and totally new network structures and solutions based on power electronics are supposed to improve the power quality and profitability (VTT, 2010).

Hence, cost-efficient and quality-conscious new thinking concerning the operation of electricity distribution networks is of paramount importance. By re-evaluating current network operation models new quality-driven requirements can be targeted trough conscious planning-, management- and operative functions.

Adding the dimension of creating a competitive network operation service market can be seen more challenging than the corresponding existing construction and maintenance service market. This is due to the fact that network liability issues are closely linked with the core capabilities within owning of assets, and the required competence level in network operations is generally higher. Development of new network operation models further generally requires more dynamic capabilities than the traditionally static capabilities within the firm.

Competence development in electrical utilities generally seems to focus on quality issues, whereas the current network operation competences in the service market generally focus on affecting cost factors. On the other hand, electrical utilities aspire to develop well-managed competences striving to improve quality factors. In the future, cost and quality issues cannot be developed independently from each other. Hence, the importance of capability development within network operation management will grow.

The changing business dynamics in the electricity distribution industry is analogous to the telecommunication industry of the early 1990s in Finland. Deregulation opens up new inter-industrial business opportunities and forces organizations to revise their strategies and operations. Also customer requirements, changes in competence structures and advanced network technologies are all affecting the development of network operation. Society in general is becoming more and more dependent on reliable and uninterrupted supply of energy. At the same time, customers are demanding lower fees on transmission and energy (Brådd et al., 2008).

From an electric utility supply chain perspective, generation, selling, transmission and distribution constitute the building blocks of the supply industry structure. Outside these vertically integrated functions, open markets exist in electricity generation and trade, whereas transmission and distribution functions are regulated natural monopolies (Viljainen, 2005). In economic words, the primary incentive for the regulated electricity market deregulation is to achieve market efficiency, especially by allocating efficiency through competition (Lu, Dong and Sanderson, 2005). This doctoral thesis is limited to address network operation models subject to competition in the regulated electricity distribution market.

Over the last decade, electricity markets around the world have been opening up to different degrees of deregulation and market competition. The objective of deregulation is to encourage competition between electricity energy suppliers, to provide the consumers an opportunity to freely choose their electricity supply service providers and to maximize social welfare (Dong, Wong, Zhou and Ziser, 2008). Further results of deregulation in more mature markets include unbundling of operations within distribution companies and extensive use of service providers in network operations.

The pioneers in the European restructuring were England and Wales, where privatization and deregulation came with the Electricity Act of 1989. Norway followed with the Energy Act of 1990, and the other Scandinavian countries, Finland included, joined this market during the 1990s. The restructuring process in the European Community is partly a result of these early national initiatives and partly a result of initiatives of the European Union (Wangensteen, Botterud and Flatabö, 2005).

Figure 1.1. Electricity distribution network markets where regulation takes outage costs and operating environment into consideration; these markets are involved in the network model analysis carried out in the doctoral thesis.

An overall view of the focus areas in the regulated electricity distribution business includes, as the first step, regulation of network investments (CAPEX), secondly, regulation of operative costs (OPEX) and thirdly, the regulation may also include outage costs. The scope of this thesis relies heavily on market conditions, and the regulative model takes also the outage costs into consideration. Hence, Figure 1.1 above highlights the primary market area to benefit from the results presented in the thesis, while other market areas will follow.

Regulated electricity markets are many times followed by unbundling of activities. Unbundling has been referred to as separation between the network business and production, trade, metering and sales of energy (Künneke and Fens, 2006), and the level of proper unbundling depends on market maturity. The unbundling levels include, in an increasing order of magnitude with respect to economic and legal separation, the following steps: administrative unbundling, management unbundling, legal unbundling, ownership unbundling; account unbundling, legal unbundling and ownership unbundling. In the European countries, the common models are legal unbundling and unbundling of accounts (Künneke and Fens, 2006). However, unbundling in the electricity distribution is not a phenomenon concerning Europe only; empirical results of ownership unbundling have been reported also from other markets, such as New Zealand (Nillesen and Pollitt, 2008). In its most advanced form (i.e. ownership unbundling), unbundling can be considered similar to outsourcing. Special attention should be paid to the implications of splitting a long-term network planning activity from the organization responsible for short-term network operation activities.

Regulative network business environment in Finland

In Finland, the Energy Market Authority is responsible for regulating 88 distribution network operators, 13 regional network operators and one transmission system operator. The first regulatory period commenced at the beginning of 2005 and expired at the end of 2007. The current regulatory period of price regulation in electricity network operation covers the years 2008–2011; the network operators are encouraged to increase the efficiency of their operations and to maintain a high security of electricity supply (Energy Market Authority, 2009). Figure 1.2 presents a map of the Finnish distribution network operators.

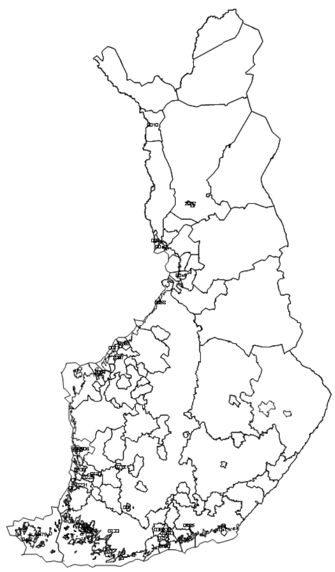

Figure 1.2. Map of the Finnish distribution network operators.

In addition to competitive pricing through improved efficiency, the quality of supply is also important to electricity end-users. The current regulation model also encourages system operators to improve the quality of electricity in two ways: by taking into account network investments in the capital base and by treating the losses caused to customers by interruptions as items comparable with costs (Energy Market Authority, 2009). According to the Electricity Market Act, electricity network operations must be legally unbundled from electricity trade and generation if the annual quantity of electricity transmitted to the customers through the network operator's 400 V distribution network has been 200 GWh or more during three consecutive calendar years. Positively, there are also some examples where distribution system operators under this threshold value have legally unbundled network activities. In June 2009, a total of 50 distribution system operators of 88 operators were legally unbundled in Finland (Energy Market Authority, 2009).

The Finnish electricity market consists of roughly 3.1 million electricity end- customers with a recent consumption peak load measured in January 2009 amounting to 13,250 MW. Electricity distribution prices have been relatively stable for several years. At the end of 2008, distribution prices excluding tax were on an average 3.7 per cent higher compared with the situation a year earlier.

Responding through new network operation models within electricity distribution

Up to 1995, the Finnish electricity market was closed and considered a natural monopoly (96/92/EC). Now, the regulator is pushing electrical utilities, with incentives and economic profit roofs, to optimize their business activities towards more efficient processes, while simultaneously balancing between a sufficient quality of electricity and low transmission costs. Regulative models in the Nordic countries are expected to increasingly highlight quality aspects during the next regulatory periods (Tahvanainen, 2010). The forerunner companies are responding to this challenge set by the regulator by re-evaluating the core functions in the electricity distribution value chain. For example, traditional functions such as network maintenance and construction presented below in Figure 1.3 have been outsourced to service providers. However, the question is, what is the case with the network operation function as regulatory incentives will push quality factors which are to their nature not cost decreasing, as basis for utilization of service markets.

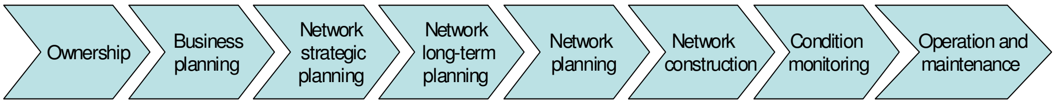

Figure 1.3. Value chain of the distribution business

Network operation, with the main activities presented below in Table 1.1, can be seen to include operation planning, network control, preventive maintenance, fault repair and customer service, and it can be modelled as an unbundled function subject to new business opportunities and challenges. New, optimized operation models are required to support the development of processes, and in order to be competitive, they should match and mix the requirements coming from end-customers, the regulator, service providers and related technologies.

Table 1.1. Content of network operation in electricity distribution

Planning and executing of network operations	**Control room activities**	**Preventive maintenance management**	**Fault state management**	**Auxiliary services**
Planning and executing of switching operations	Remote use of network	Planning of preventive maintenance activities	Receiving and analysing alarm and fault data	Customer service
Planning and executing of network proptection	Maintaining the online network coupling state	Maintenance work, inspections	Analysis on occurred fault sequence	Purchasing and maintaining data systems
Making and maintaining of instructions and manuals	Follow-up on current network status	Gathering network equipmen condition information	Locating and separating faults	Informing and communicating
Management of economics and investments	Management of planned outages		Minimizing the fault area and providing backup feeder connections	Developing the use of network automation

Establishment of new electricity network operation models requires utility strategy renewal, process development, determination of core businesses in order to know the direction into which the resources and capabilities in the organizations shall further be developed and implementation of supporting tools by which the new business model can be implemented in the utility. Recognized strategy approaches propose strategy renewal to include an external market analysis followed by an internal strategy analysis, process definitions and implementation of supporting tools. This approach will be followed in this doctoral thesis.

Dynamic companies in the electricity distribution industry are seeking for emerging potential opportunities and developing their resource base and capabilities to achieve competitive advantage in the future. To sustain their competitive advantage, firms have to recognize changes in their business environment, understand the forces behind them and find ways to benefit and comply with the external dynamics. External forces largely affecting the development of electricity distribution business and network operation include: climatic changes, regulation models, new network automation, growing customer needs and ageing distribution networks, and are discussed in detail in **Publication I.**

The analysis of external market behaviour in this doctoral thesis is strategywise followed in **Publication II** by an internal analysis of electric utilities' capability development and core competences using the resource-based view as the theoretical framework. Optimized business models are required to meet the external requirements, and there is a need to determine the core businesses for electrical utilities in order to know the direction into which the resources and capabilities in the organizations shall further be developed. The network operation activities presented above in Table 1.1 are discussed and analysed as capability groups of network operation management, control room activities and field work activities.

Boundary decisions and governance choices within electric utilities based on defined core competences and chosen capability development strategies are next analysed with the help of the extended transaction cost theory in **Publication III.** Transaction cost economics (TCE) can provide theoretical support for such a boundary decision analysis; however, it has been criticized for being static (Ghoshal & Moran 1996) and focusing on avoidance of the negative consequences of opportunism instead of value creation potential of the firm (Conner 1991). Such a theoretical approach is not sufficient for governance choice decisions in operative environments such as electricity network operation, where the domain can be defined as developing knowledge-based assets such as capabilities. Hence, the network operation governance choices will be founded on a different basis than TCE suggests, and the extended transaction cost economics frameworks will supportively introduce dynamic transaction and management costs. Capabilitywise, in this doctoral thesis, the extended TCE framework proves its importance in usage for governance choices of activities such as operations management, control room management and field work activities.

Continuing with the transaction cost economic framework, the study is extended to analyse the risks, costs and benefits of new network operation models experienced by the counterparts of electric utilities, that is, the service providers in **Publication IV**. Further, findings of an empirical North-European service provider survey are presented and analysed. Some reasons behind the identified market gap of control room services are discussed and future market development is examined. As one result of the empirical survey, service providers in the field of electricity distribution seem to be generally positive to the business model of offering control room services.

As a continuation of the chosen governance model for network operation, the analysis continues with unbundling considerations, primarily in-house, of highly interconnected network business functions in **Publication V**. Network functions subject to unbundling decisions are presented in Figure 3.4. Each of distribution business functions has to be organized efficiently. Typically the main functions are unbundled from each other, and each of them has economic indicators of its own. Special considerations are required in the internal unbundling of interdependent functions such as long-term network development and short-term network operation. The thesis presents empirical results of a legal unbundling model in Eastern Finland in Chapter 3.

Publication VI represents the last article in the doctoral thesis and handles the supporting tools, mainly the Distribution Management System, from a cost/benefit viewpoint in the chosen network operation model. New electricity distribution business processes, especially in unbundled or outsourced models, are today largely implemented by the use of common network data systems. The Distribution Management System (DMS) and Distribution Automation (DA) are widely used in network companies. DA can be defined as an implementation of technology to improve the reliability, availability and operation of the electricity distribution system, whereas the DMS is the decision support system that helps operational personnel to operate their distribution system both in normal and emergency situations. In practice, the DMS demonstrates the real-time electrical state of the distribution network, reports the operator of possible anomalies (e.g. faults, overloading), and proposes required actions. Implementing DA and systems such as DMS has been proved to improve the reliability of the system. Nowadays, many distribution companies focus on development of data warehouses and information management, which assist in defining the age and condition of the equipment; however, there is still lot to do to capitalize this information (Tanskanen et al., 2010). Development of analysis tools for electricity network data management decision making becomes key for successful business decision making. Many studies have previously been published regarding the achievable benefits of DA investments; however, similar benefit analysis results have not been reported for network control system functionalities in the DMS. As the importance of network availability increases, also the need for a quantifiable cost/benefit analysis grows in order to define the real value of network reliability. Hence, the main findings in this doctoral thesis are related to implementation of network operation models through an analysis and use of distribution management system (**Publication VI**).

1.1. Main objectives and research questions of the thesis

The main objective of the research is to present an interdisciplinary strategic architecture for development of network operation within electricity distribution. The thesis presents a methodology for re-evaluation and development of business models within electricity distribution network operation.

The fundamental research questions are presented below in Table 1.2.;

Table 1.2. Content of network operation in electricity distribution

Research questions
1) Does there exist conditions and qualifications for competitive markets within electricity distribution network operation?
2) Can an any mechanisms, limitations or actions needed for creation of such markets be identified?
3) Which external factors are to be considered in the electric utility for long-term development of operation? What is the extent of available supporting technological solutions in distributed automation?
4) What is the availability of supporting methodologies and applicability of theory for governance decisions in the regulated electricity business?
5) How to create a long-term industry development vision through modelling external and internal uncertainties?
6) Which internal strategic network operation capabilities are to be prioritized in different utility segments? Whether to develop the required capabilities and resources internally or to exploit and integrate external knowledge?
7) Does extended TCE theory support the analysis of governance structures within monopolized electricity distribution business? What governance structure choices for network operation are available in the deregulated market?
8) Does the chosen model of business unbundling help electric utilities respond to the external market drivers in the long run? How to achieve the minimum cost requirement in long-term planning without suboptimizing of short-term network operation? How to evaluate and implement the utility-specific appropriate unbundling level?
9) What are the key outage-cost-influencing applications of the Distribution Management System and which are their benefits? Which are the theoretical maximum levels of €-benefits from DMS functions? How to capitalize the identified DMS benefits?

The research topics include re-engineering of extended transaction cost economics to fit electricity distribution business governance decisions, suggestions for activity-based Key

Performance Indicators (KPIs) in the unbundled model of network operation and long-term network development and the cost and benefit analysis of DMS functions. Empirical results by case utilities and network experts are provided in the areas of proposed business models per utility segment, governance choice outcomes to theoretical validation, extended TCE evaluation from the service provider perspective, legal unbundling utility model and DMS benefit evaluation.

1.2. Scientific contribution and practical implications

The scientific contribution of the thesis includes a novel strategic architecture for network operation with the developed supportive theory and methods incorporating a cost and benefit case analysis for supporting DMS functions. In the Nordic market area, the result is a current topic for electricity utilities optimizing the operation of their increasingly intelligent networks according to the quality and cost targets set by the regulator.

The main contributions of the thesis include

- recommendations for network operation governance models in regulated electricity distribution business, where
    - the results suggest positive indications towards market governance within control room activities for small- and medium-size utilities where dynamic transaction benefits are greater than alternative dynamic management benefits supported by cases where dynamic management costs are higher than transaction costs
    - analysis is based on an extended transaction cost economics (TCE) analysis, including a proposal for networking-based distribution management system (DMS) Build-Own-Operate-Transfer (BOOT) concept for a control room model
- validation of the usability of the extended TCE theory for the governance analysis of electricity distribution networks
- application of outage-cost- and reliability-indices-based calculation for evaluation and capitalization of the selected DMS applications
- empirical validation of theoretical results both from the electric utility and service provider perspective in the areas of unbundling network activities, performance measurement and DMS benefits

The main contributions listed above have been presented and published in international academic journals during years 2005–2010. Theoretical contributions include further two Master theses in the research area (2004, 2009), international publications in academic journals (one Literati price awarded publication, 2008) and theoretical validation of the extended transaction cost economics theory in the network operation environment for a governance structure analysis (field crew management, control room activities, operations management).

Further, the main practical contributions include proposals for network operation models per electric utility segment based on a resource-based framework (rural, urban, mixed environment) and economical benefit calculation of DMS outage-related functions (fault reporting, fault location and restoration, reconfiguration, field crew management) for the implementation decision of advanced network operation models.

From the electric utilities' perspective, special practical outcomes from the research are available in the areas of internal network operation capability development, control room governance structure decisions, implementation and management of internal unbundling models and decision support for DMS cost and benefit evaluations. Parallel, practical results for service providers cover risks and opportunities in control room business models, technological solutions for service offering in development of long-term network operation and considerations for strategic capability development within network operation. Results and methodologies presented in the thesis have been validated through expert interviews, web surveys and electric utility case studies. Validation has generally been included in each publication. However, new results from national web-survey (spring 2010) regarding special topics within network operation and DMS considerations are included in section 4.5.

1.3. Summary of publications

The publication entity is composed of six scientific publications and will be shortly presented in the current chapter. The publications have been written in a predefined order following defined research questions as part of the Porterian business hierarchy levels. However, timewise, all publications have not been published in a chronological order, as the lengths of publication processes have varied in different journals. Within the publication entity, the author of this doctoral thesis has been the primary (responsible) author in all the above publications, with the exception of Publication V, where the main contributions in the manuscript were equally split between the authors. In-depth interviews and surveys have been performed during the research period by the author providing validation to many of the received results.

Publication I *The Challenges of Network Operation in the Nordic Electricity Distribution Business Heading for Year 2030*

Publication I discusses the external driving forces affecting the network operation in the distribution networks in the Nordic environment during the coming decade. Altogether, five key functional elements and almost 40 functions of network operation were analysed and scored during the research in the light of the presented driving forces. The study proposes a generic evaluation method for prioritization of external impacts on selected network operation activities for development purposes within electric utilities. The evaluation method is used in Publication V changing the focus of evaluation from network operation to long-term network development. The evaluation method is validated by a case company, Suur-Savon Sähkö Oy. In this publication, the author has played a primary role in writing and presentation of the manuscript at an international conference.

Publication II *The strategic activities of electricity network operators within changing electricity distribution industry*

Publication II introduces the network operation functions addressed in the thesis and the underlying competences. The strategic fit towards external market mechanisms is analysed by the use of the resource-based view, and generic capability development scenarios for electric utility segments are presented. The author has played a primary role in the overall writing of the manuscript by providing the industry-specific content and performing the interviews in the case electric utilities.

Publication III *Governance structures and Capability Development within the Electricity Distribution Network Operation*

Publication III concentrates on the boundary decisions and governance choices of electric utilities within network operation based on the extended transaction cost economics framework. The study considers both the costs and benefits of different governance choices and examines which of the activities could be outsourced and which ones are preferred to be kept in-house. Our findings demonstrate that the activities of the companies operating in the electricity distribution business differ in terms of potential long-term efficiency effects when sourced from the market or made in-house. The determinants of the governance choice depend partly on the nature and strategic importance of the activity in question. Operations management seems to be a function to be kept in-house in the current market situation, whereas there are clear potential benefits that can be attained by outsourcing field work activities. The results related to the governance of control room activities instead are more complicated.

In this publication, the author has played a primary role and has had the overall responsibility of the manuscript. The co-authors from Lappeenranta University of Technology's School of Business have brought in-depth insight into the utilization of the TCE method.

Publication IV *Electricity Distribution Network Operation Services - An Analysis on Market Dynamics from the Service Provider's perspective*

Publication IV addresses the risks, costs and benefits from the service provider's perspective, whereas the theoretical framework of the study is based on transactional cost economics. Findings of an empirical North-European service provider survey are included. The findings have been presented in an international conference by the author. The author has played a primary role in the planning, writing and presenting of the manuscript.

Publication V *Unbundling of Operation and Network Development Activities in Electricity Distribution*

Publication V primarily discusses internal governance choices within electric utilities and presents a market geographic overview on unbundling phases in different markets. The study presents a framework for evaluation and implementation of unbundling within electric utilities and is validated by a case company, Suur-Savon Sähkö Oy. In this publication, the author has been the second author, whereas writing of common areas have been shared between authors. Otherwise, the primary author has largely focused on the function of long-term network development whereas the author of this doctoral thesis has focused on the function of network operation.

Publication VI *Cost and Benefit Analysis for a Distribution Management System in Electricity Distribution Networks*

Publication VI examines the key outage-cost-influencing applications (fault location and network restoration, fault reporting, field crew management and reconfiguration) of the distribution management system (DMS) and analyses the benefits provided by them. The objective of the study is an evaluation of their influence on outage costs deriving from the adoption of automatic equipment in managing distribution systems. The benefits are calculated in terms of outage costs for each of the above-presented applications and compared with the investment cost, including the annual cost of maintenance, of the DMS. The empirical results and validation of the theoretical calculations are performed by an electric utility, where the DMS benefit evaluation is taking place.

The study shows that by capitalizing the applications of the DMS, it is possible to acquire considerable benefits in outage costs. It is shown that the greatest cost-based benefits are obtained from the fault location and field crew management applications. The case study shows that the DMS can reduce the operation costs of utilities. In this publication, the author has played a primary role in writing of the manuscript. One Master's thesis has been written within the subject by the secondary co-author.

2. Research methodology and structure

The study is based on research results published in international journals and presented in international conferences during years 2005–2010. The publications are written in a network operation business hierarchy sequence grasping the overall framework of business mission, vision, strategy, planning, management and process execution (tools) of electricity distribution network operation business models. However, the focus of this study is on selected research questions addressed in the strategy, planning, management and process execution levels of network operation.

Methodologies applied include expert interviews, qualitative business insights, scenario-based works, workshops (university and case companies), building of models and company-based conversations. The research structure is presented below in Figure 2.1.

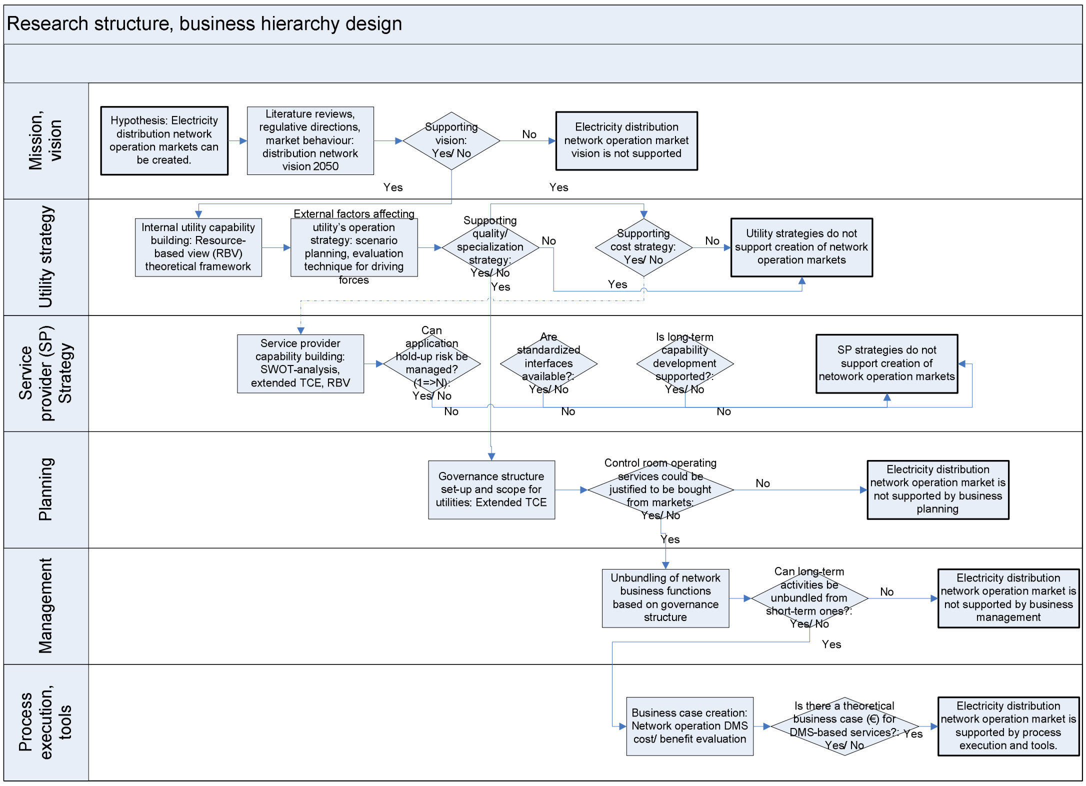

Figure 2.1. Research structure.

In the literature, deregulation and regulation are occasionally used as synonyms; however, this thesis makes the following distinction between these two terms: Deregulation describes the opening of electricity generation and selling to competition, while regulation deals with the active monitoring and supervising of network operations within electricity transmission and distribution. Regulation aims to mimic *virtual* competition in the monopoly sectors where actual competition otherwise would be absent.

Further phases in market restructuring typically include: a) identification and unbundling of core network activities in natural monopolies, b) introduction of competition to the non-core network services and c) implementation of regulation of natural monopolies (Viljainen, 2005). The increasing amount of asset owner politics in natural monopolies striving for larger profits and development of quality requirements (electricity, customer services) are further drivers pushing new market dynamics. Hence, in the business mission and vision layer of the thesis, existing network operation market obstacles are evaluated and new theoretical frameworks are proposed to support the set hypothesis that electricity distribution network operation markets can be created.

2.1. Market overview for regulated network business

The step toward liberalization has been undertaken under the belief that competition would promote market efficiency and price reduction resembling the microeconomic model of perfect competition, in which social welfare would be the highest possible and the price the lowest (Bompard, Lu and Napoli, 2006). Competitive electricity market can be considered straightforward and economically attractive; however, there have been many complex issues involved with the formation and operation of competitive markets. Examples in many markets exist where lack of investment in infrastructure has led the power system stressed close to its stability limit, as a result of profit maximization efforts (Dong, Wong, Zhou and Ziser, 2008).

China, the world's second largest producer of electricity with an installed generation capacity of 500 GW in 2005, represents an electricity market that is so far deregulated in the generating segment of the industry. The next level of competition will be wholesale competition, followed by retail competition, in which all energy will be traded through bidding. The purpose of the electricity market reform in China is to accumulate the experiences about the electricity markets and to prepare introduction of competition of higher level in the future. By 2020, the Chinese electricity market has been developed for more than 20 years, and it is evaluated that at that time all energy should be traded through bidding. Moreover, large consumers will be allowed to choose their own suppliers (Song and Zhang, 2007).

Developing markets in Europe such as the Romanian electricity market are also liberalizing operations. Romania's National Strategy for the Energy Sector development aimed at accelerating privatization in the electricity production and distribution sectors by 2004, where the distribution activity would be entirely privatized, as well as about 25–40% of energy production in thermal power plants. Furthermore, an institutional and regulatory framework aligned to the EU requirements for introducing market mechanisms in the electricity sector and developing commercial relationships in the electricity market have been created. By 2003 it was estimated that the electricity market has been liberalized up to 33% (Budulan, Rugina and Bogzianu, 2003).

The recent blackouts around the globe have provided an impetus for improving the operational reliability of large-scale power systems. One example of this is the setup of the first Electric Reliability Organization for the North American grid in accordance with the 2005 Energy Policy Act (Zareipour, H., Canizares, C. A. and Bhattacharya, K., 2007),. Operational reliability management is a highly challenging task, and even more so in the presence of competitive electricity markets, with both financial entities and the physical load or asset owning players. Since system and market operations strongly interact, any change in the system operational reliability impacts the economics and vice-versa (Geuler, Gross and Nelli, 2007).

In Poland, a consensus exists that the Polish power industry should be privatized. However, there are many ideas on how to lead the privatization process. Strategic questions prevail such as: (1) How to proceed with the integration of power production and distribution companies?, (2) Should integration be achieved by privatization or rather by government initiatives before privatization takes place?, (3) What form of privatization is the better solution: by strategic investors or public share offers? (4) Should we allow for horizontal and or vertical integration?, (5) What measures should be taken to avoid monopolies, with excessive market power? and finally, (6) Should the government preserve control over such a strategic industry? Further, market monopolization by network operators has occurred, exploiting flaws in the Energy Law resulting in a situation in which less than 1% of customers have changed their suppliers (Mielczarski, Siewierski and Wedzik, 2005).

In Canada, the Ontario wholesale competitive electricity market opened on May 1, 2002. The transmission system has remained regulated and the local regulator, Ontario Energy Board (OEB) determines the transmission and distribution tariffs. The distribution system is also regulated by the OEB, with 91 local distribution companies delivering electricity to the retail customers (Zareipour, Canizares and Bhattacharya, 2007).

Finally, overall market behaviour and regulative frameworks support the vision of extensive competitiveness in the electricity network business heading towards year 2050, whereas competition in the operation activity is one spear in the path of competition. Deregulation activities progresses many times according to 1) Wholesail and retail, 2) Unbundling, 3) Network activities, 4) Network operation).

Common strategy approaches taken in the thesis in the evaluation of natural monopolies of electric utility and service provider strategy layers include a SWOT analysis, a resource-based view and extended transaction cost economics. Electric utilities are grasping for ways to achieve competitive advantage by identifying the gap between external market factors and internal capabilities. Market power is harmful to competition and it is necessary to identify the potential for its abuse, and such findings have important policy implications. In recent years, much research has been done on investigating the potential for market power abuse in pool-type electricity markets, in which the sealed bid auction and uniform price rule are used. In general, market power is referred to as the ability of a market participant to profitably maintain prices above a competitive level for a significant period of time. Market efficiency is obtained through competition. Market power is undesirable as it is a symptom of an uncompetitive industry and can lower economic efficiency. While the manifestation of market power abuse is usually associated with a higher price above cost, it can also be lower quality of products or services compared with what would be found in a more competitive environment (David and Wen, 2001).

The planning level of business hierarchy utilizes the extended transaction cost economic framework to define the relevant scope of non-core network activities for implementation of markets and hybrid markets. Oliver E. Williamson, the 2009 Nobel prize winner in economics, has in his research defined the content of transaction cost theory as "the means by which to breathe operational content into governance and organization" (Williamson, 2010).

At the management level, electric utilities have identified the non-core network activities and focus on how to implement the desired unbundling model. Special considerations are addressed to unbundling of strongly connected long-term functions from short-term network functions. The theoretical analysis is followed by an empirical case utility where unbundling of such dependent functions has been implemented.

Finally, at the bottom process execution level, power system applications enable the operation of network management activities. A case study is introduced with a benefit analysis of DMS.

Deregulation has resulted in the creation of much larger markets under the control of an independent system operator. This will result in more buses and other devices to monitor and control the power system. Simultaneously, the entry of new players into the market and the increase in power transfers will result in even more data to manage. Finally, system operators will come under increased scrutiny since their decisions, such as whether to curtail particular transactions, can have a considerable financial impact on market participants (Overbye and Weber, 2000).

The power system operations applications that are used in the modern electric utility control center are highly specialized applications that have traditionally been installed as stand-alone systems that interface to the power system through the use of remote terminal units (RTU) using communication protocol-based interfaces. These protocol interfaces are not well suited for integration of the power system applications with the business applications of the utility. On the business side for nonreal time systems such as finance, customer information systems, and asset management, the information technology (IT) industry has been advancing at a tremendous pace to provide application integration technology based on web services and service-oriented architecture middleware that dramatically decreases the complexity and programming effort to build and maintain an integration infrastructure that enables these applications to cooperate in the execution of the utility enterprise's business objectives. Because of the highly specialized nature of power system operations applications, the cost of applying these generic IT solutions has remained quite high (Mackiewicz, 2006).

Presently, the following demands emerge with the development of electrical automation: (1) standardization, (2) integration and (3) on-line and off-line resource sharing. Therefore, to achieve uniform, highly extensible and standard graphic systems has been one of the evolving directions of power system applications (Wang et al., 2008). Further challenges include the scope and accuracy for detailed simulations, and optimization of the power system is severely limited by available computing power (Sheng et al., 2005).

2.2. Research design

The research within the thesis combines both positivistic and hermeneutic approaches for design of a strategic architecture for network operation within electricity distribution business. First, the research logic is divergent from the top-down business hierarchy approach within the strategic architecture of network operation functions in Publications II–IV, whereas it is convergent with the control room and DMS application functions in Publications V–VI.

2.2.1. Research strategy

Deductive analysis is present mainly in Publications I–IV, where capability-based requirements are analysed as a basis for extended transaction cost economic evaluation of network operation governance alternatives. In the convergent part of the thesis, on the other hand, an inductive analysis is adopted for the outage-cost-based calculation in order to perform a cost and benefit analysis of the DMS functions for the case rural electricity utility. The result of the use of the theoretical decision-based research through induction is thus a new network operation business model for the regulated network business.

Within the context of ontology, the author has acted as an analyst, a contributor and a facilitator in data collection, scenario works in laboratory and expert interviews with the concerned case electric utilities in the action analytical research part. In the decision-based research part, the author has participated in network specific data collection, calculated all the outage-based costs and conducted validative expert interviews with the case electric utility. Action-analytical approaches are combined with scenario works and network expert interviews in Publications I–IV, and followed by use of mathematic models in publications V–VI. The data for the basis of analysis in Publications I–IV have been obtained mainly through results from the scenario works in laboratories by co-operative electric utilities, literature reviews and network expert interviews. Similarly, the data in Publications V–VI are based on industry-specific network outage statistics provided by the local energy market authority, network parameters from the participating case electric utilities and network expert interviews.

The hermeneutic research part considers subjectivity issues with respect to the analysis of results by starting the scenario works by introducing a wide range of co-operative electric utilities from urban, rural and mixed environment operating utilities. Also, in Publication IV, where the network operation services are SWOT analysed from the service provider's perspective, the empiric part of data was primarily gathered by web questionnaires from market actors in both Nordic and North-European areas. Further, in the convergent part of the analysis, the empirical validation of results is mainly conducted by one case electric utility chosen to represent a typical Nordic rural mainly overhead line network with a positive mindset as to meeting changes in the operating environment. Here, the number of sample cases is relatively small due to the extensive data acquisition and calculation part of the positivistic analysis. However, the case electric utility has been chosen as a typical segment case for a rural network operator in the Nordic area. In this sample operating environment, the positivistic results calculated can be considered objective, especially, as the validation of results by case company supports the cost values presented. Thus, the outage-cost-based benefits calculated in Publication VI will most probably be different for urban electric utilities. This is mainly due to the differences in the network structure, the use of network components, parameter focuses in SAIDI and CAIDI, and the geographical spread of network. However, the results in Publication VI can be considered indicative also of more pure urban operating environments. New calculations could be considered for the purposes of outage-cost-based benefits in urban environments in the further research.

2.2.2. Research approach

In the thesis as a whole, the research is analytical by nature, breaking down from external market drivers to strategic internal capability development within the network operators, concerning also external and internal boundary decisions based on the use of the extended transaction cost economics. Network operation governance alternatives are first approached hermeneutically through the use of scenario works and hypotheses, after which the slightly market positive control room function is further evaluated by positivistic methods. Two main research approaches are thus utilized in the thesis; i) action analytical research and ii) decision-based research. The main research approaches are visualized below in Figures 2.2 and 2.3.

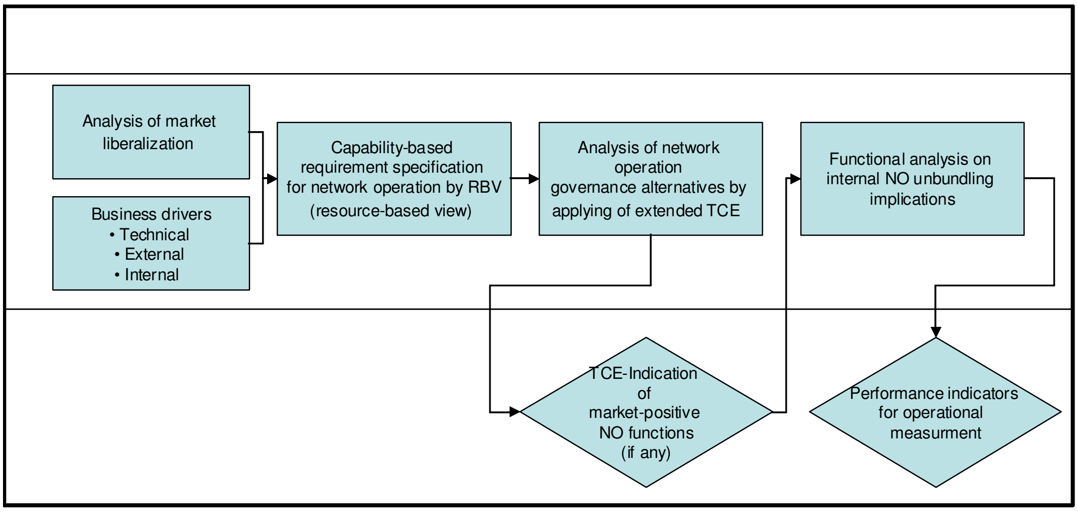

Figure 2.2: Illustration of the research procedure in the hermeneutic part of the thesis.

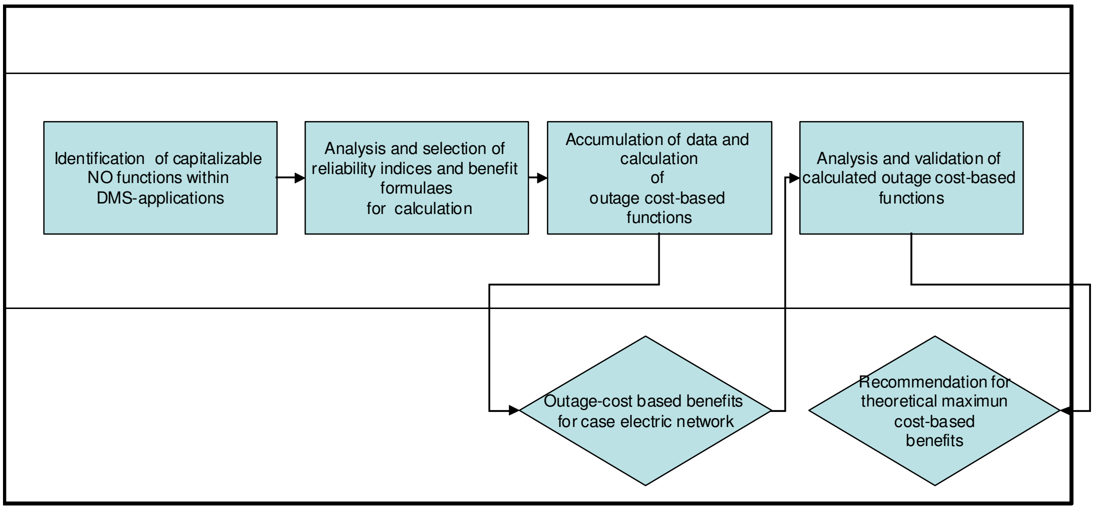

Figure 2.3: Illustration of the research procedure in the positivistic part of the thesis.

The thesis addresses a new potential business area supported by regulation within electricity distribution, where available industry-specific data are scarce. As a strategic architecture for electricity distribution network operation models in ex ante deregulated electricity markets, the thesis provides new information within applicable sciences for the practical network business. Within the framework of addressed research questions in the thesis, the results function as indications to development activities or planning of such in electric utilities and at external service and system providers. The thesis can thus be further categorized from the perspective of data usability target as normative, that is, providing support for decision making. It also follows that the benefit perspective forms a central evaluation criterion for the selection of research methodologies and results achieved in the thesis. The DMS benefit evaluations in the thesis based on the outage cost calculations propose theoretical maximum benefits of DMS applications equalling roughly 25% of the annual outage costs and 10% of the respective operative costs in the case electric utility. Hence, the annual measurable benefits from the use of the DMS application support within new business model set-ups are considerable.

The type of the data presented in the thesis is mainly qualitative in the hermeneutic-based Publications I–IV, whereas the data are increasingly quantitative in the positivistic-based Publications V–VI. The validity period of the results in the thesis follows country-specific regulative cycles; however, the trends show that the regulative prerequisites needed for implementation of such network operation models are generally repeatable by their nature (regulation including CAPEX, OPEX and outage cost statistics, in this order). Hence, even though the current Finnish regulation for some unforeseen reason alienated from the current quality perspectives within the outage costs, the implementation of the new network operation models would probably be valid in less advanced regulative markets. Based on the results of the thesis, the extended transaction cost economics has been applied to a new function-based analysis of capabilities within the electricity distribution business. Hence, the positivistic research in the thesis includes theoretical research aspects as to the further development of the extended TCE theory by inductive conclusions of the existing theoretical framework. Verification of the evidence for the results derived from the extended transaction-cost-based theory could be approached through falsification attempts of the current hypothesis.

3. Results of research

This chapter summarizes the results of the research. The proposed methods are generic by their nature, whereas the results are area and electric utility specific. Chapter 4 localizes the results to the Nordic environment with empirical validation. The research structure follows the business hierarchy model presented earlier in Figure 2.1.

3.1. External strategy considerations and vision of long-term development of electricity distribution network operation models

Research in the area of long-term development of electricity distribution network operation models includes the conference manuscript of "The challenges of the network operation in the Nordic electricity distribution business heading for year 2030" presented in the PES Conference in Botswana, 2006. The research questions addressed include: a) Which external factors are to be considered in the electric utility for long-term development of operation?, b) What is the extent of available solutions for the expected challenges?, c) How could electric utilities evaluate the impacts of external forces on their company? and d) Can any external force impacts be highlighted?

The methodology in the study included a literature review, an interview of network operation experts within the case electric utility Suur-Savon Sähkö Oy, a presentation of an indicative score analysis for evaluation of impacts and finally, a fill-in of score analysis by the research team and comparison of practical score results with the literature. The study analyses how driving forces, such as climatic changes, ageing networks and the growing needs of customers affect the network operation. Some of these challenges can be handled by solutions and innovations presented including renovation methods for the ageing distribution network, laying of cables, environment-friendly implementation of 20/1/0.4 kV three voltage level distribution system, extensive utilization of network data systems, use of network automation and new building techniques.

According to the study, network automation, changes in the competence structure regarding buying of services and customer needs will have key impacts on network operation in the future. Table 3.1 presents the outcome of the scored driving forces and network operation function dependencies in the case electric utility, SSS Oy.

Table 3.1. Generic evaluation method for the analysis of impacts of key external forces on selected network operation activities (presented here with scores of the case electric utility SSS Oy).

OPERATION FUNCTION	Aging networks	Customer needs	Climatic changes	Regulation	Changes in competence structure (retiring personnel)	Changes in competence structure (buying services)	Cabling / Covered conductors	Rebuilding new lines to the roadside	1000 V low voltage technology	Network automation (components)	Network automation (data systems)	Automatic meter reading (AMR)	New network building techniques
Normal state management - planning of network operation													
Planning of network operations	2	4	4	4	4	4	4	2	1	4	4	3	1
Manual switching operations	3	4	4	2	2	3	3	4	1	5	5	3	2
Network protection	4	4	4	3	3	3	5	3	4	4	4	1	1
Making and maintaining of instructions and manuals	2	2	4	3	4	3	2	2	3	3	4	3	4
Preparing for major disturbances	4	4	5	4	4	4	4	4	2	3	4	2	3
Co-operation with national grid and neighbour companies	2	1	3	2	2	2	1	1	1	3	2	1	1
Reporting (authority, organizations)	1	4	3	5	2	2	1	1	2	1	5	5	1
AVERAGE	**2,6**	**3,3**	**3,9**	**3,3**	**3,0**	**3,0**	**2,9**	**2,4**	**2,0**	**3,3**	**4,0**	**2,6**	**1,9**
Normal state management - control room activities	**2,1**	**2,3**	**2,4**	**1,8**	**2,9**	**3,1**	**1,5**	**1,4**	**1,6**	**3,1**	**4,0**	**3,0**	**1,1**
Fault state management	**2,5**	**3,3**	**2,4**	**1,4**	**2,5**	**3,5**	**2,4**	**2,3**	**1,6**	**2,9**	**4,1**	**1,9**	**1,5**
Preventive maintenance	**4,4**	**2,3**	**2,8**	**1,4**	**2,8**	**3,3**	**2,2**	**2,2**	**2,0**	**3,2**	**3,6**	**1,1**	**2,4**
Other functions	**1,7**	**3,8**	**2,3**	**2,5**	**2,5**	**2,8**	**1,3**	**1,3**	**1,5**	**2,8**	**3,7**	**3,0**	**1,5**

Five key functional elements and almost 40 functions altogether were analysed and scored during the research in the light of the presented driving forces. The scores and analysis of the key functional element *planning of network operations* were discussed in a greater detail. The same score and analysis method was used for the evaluation of the remaining four key functional elements.

Finally, the main contribution of the study is a score framework for a long-term analysis of external forces towards the interdependent network operation functions. The empirical results of the paper can be considered a general reference point when evaluation of driving forces is carried out in network companies. Limitations of the study include limited empirical validation of scored results, potential bias within evaluation and analysis covering mainly rural distribution networks (urban areas not covered). Interpretation of the indicative numerical scores received in the analysis framework to financial figures (€-based results) would enable wider generalization of the score analysis for a decision basis in electric utilities.

3.2. Network operation strategy building, capability development and core competences within electric utilities

Teece et al. (1997) state that when developing an organization and its capabilities, continuous interaction between the internal asset portfolio and the external environment is essential in building sustainable competitive advantage. Hence, when firms meet new challenges as a result of changes in regulation, technology or markets, they have to reconfigure their capability portfolios to match new requirements. Thus, in Section 3.2 the doctoral thesis continues the earlier analysis of external market forces (Section 3.1) by a study of network operation internal asset development.

Research in the area of strategic network operation capability development includes the manuscript published by Tanskanen et al. in the *International Journal Energy Technology and Policy*, Vol. 6, No. 4, 2008 titled “The strategic activities of electricity network operators within changing electricity distribution industry” and the ISPIM conference manuscript of “The strategic activities of electricity network operators within value networks” presented in Athens, Greece, 2006. The research questions addressed cover: a) What does the network operation market look like today and which are the market drivers?, b) Which internal strategic network operation capabilities should be developed in different utility segments?, c) How to create a long-term industry development vision through modelling external and internal uncertainties? and d) Whether to develop the required capabilities and resources internally or to exploit and integrate external knowledge?

The methodology of the study takes the scenario approach presented below in Figure 3.1 followed by in-depth interviews with 10 managers and CEOs of Finnish small-, medium- and large-sized electrical utilities (2005). The resource-based view of the firm (Barney, 1991) is used as the theoretical framework in assessing the future requirements of the changing electricity business environment.

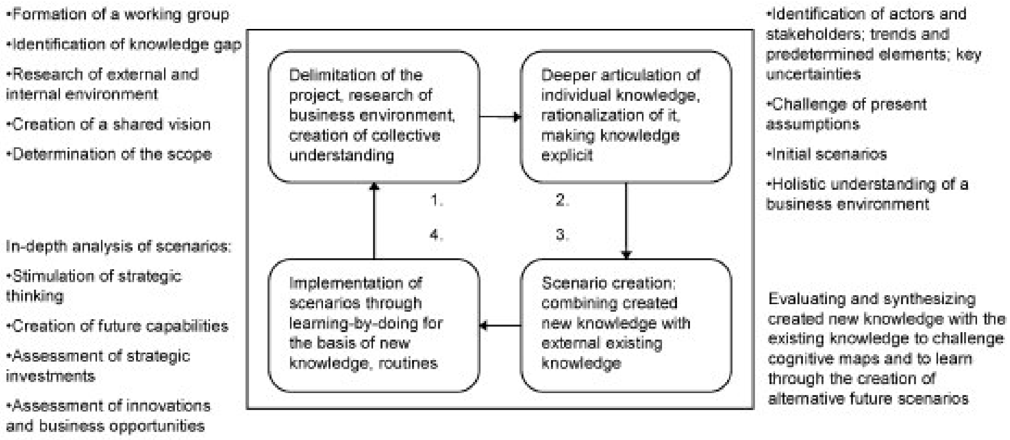

Figure 3.1. Scenario process applied to capability development within electricity distribution network operation.

According to the resource-based view of the firm (Barney, 1991; Peteraf, 1993), firms differ to a large extent because of their unique resources. The firm's existing resources and knowledge base can also be seen as a platform for growth opportunities (Kogut and Kulatilaka, 1994).The study describes present network operation business processes of electrical utilities and proposes ways for capability optimization as part of future business models for electric utilities and services providers in the field of electricity network operations. Network operation capability requirements are analysed from the organizational viewpoint, the operational and technological viewpoint and the legislative viewpoint. Capability characteristics and requirements in these areas forming the framework for new network operation models include resource-type (blue-collar vs. white collar), process management (especially with several value network parties), existence and utilization level of network data systems and legislative requirements related to the responsibility of the operating manager.

Practical results include network operation models for electric utility segments presented below in Table 3.2 and an analysis of cost and quality implications following from the chosen network operation model.

Table 3.2. Proposed network operation capability development areas for electric utility segments in rural, urban and mixed environments.

Suggested capability development	*Who?*	*General utility type*	*Development focus and nature*
Develop control room proceedings	Utilities with low network operations frequency (few planned interruptions and few middle-voltage faults)/ with economic constraints regarding data system investments/ and control room resources approaching retirement.	Rural electrical utilities with relatively compact network (minimise costs) Urban utilities (maximise quality by continuous development).	*Focus*: Competences and resources *Nature*: Development of competences is slow and no external new market player can bring solution. Resource development relatively fast.
Develop current field work proceedings	Utilities with challenges balancing 24/7 resource need with day-time resource need/ with need to minimise end-customer harms related to major disturbances/ with blue-collars approaching retirement age and lack of knowledge within use of mobile solutions.	Rural electrical utilities with vast network Urban electrical utilities	*Focus*: Resources and Competences *Nature*: Resource development relatively fast
Network operation management	Utilities that wish to optimise business for end-customer needs. Requires extensive partnering due to specialisation in both field work, control room work, and customer service.	All	*Focus*: Competences *Nature*: Competence development slow.

Capability development within network operation activities can be described as a highly quality-driven function, whereas similar capability development in functions subject to market behaviour such as fault repair and network construction is linear with a straightforward cost-quality dependency. The differences in cost and quality dependencies among some unbundled network functions are described below in Figure 3.2. Hence, requirements of network operation performance are higher than those of for example fault repair and preventive maintenance. The cost of network operation increases and decreases as a function of quality; however, a certain bottom level for costs is defined through investment in DSM.

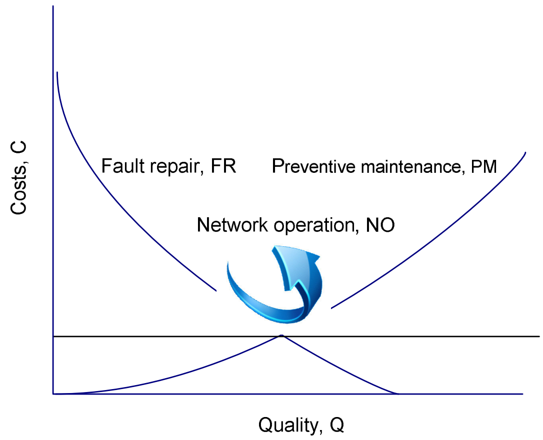

Figure 3.2. Presentation of cost and quality dependencies for unbundled functions fault repair, preventive maintenance and network operation.

Depending on the strategy chosen by the electric utility, the utilities can position themselves on the cost-quality scale presented in Figure 3.2, based on which suggestions for capability development within network operation activities can be done.

The cost–quality scale is a way to present the strategic decisions made in the electrical utility about prioritizing the balancing of sufficient quality and minimizing of costs. Factors considered within the cost–quality parameters include: network investments (CAPEX), operational costs (OPEX), network availability, electrical occupational safety, quality of voltage, losses and end-customer services. Based on the electrical utility's position on the cost–quality scale, this section further proposes strategic competences that should be further developed as part of working processes in the segmented electric utilities.

As an implication of the examination, the control room business models of urban utilities are suggested to be developed as core capabilities, internally or by partnering, from the quality maximizing perspective. Urban utilities are suggested to develop process-based network operation management competences where control room and field processes are streamlined and performed by the best field management and control room resources available. Process targets should be set based on end-customer needs.

In rural utilities with large and decentralized networks, the development of current field work proceeding is suggested to be prioritized. Secondly, control rooms are suggested to be integrated in order to concentrate all remote network operations in one point where routines and continuous work load allow a positive competence development. Small rural utilities with relatively compact networks, on the other hand, are suggested to develop control room proceedings primarily from a cost-minimizing perspective. Establishing common control rooms with suitable partners is proposed as one solution.

Mixed-environment utilities deal with the challenges and expectations identified in both urban and rural utilities. They are thus encouraged to extensive networking with specialized partners in order to optimize both control room and field operations. Hence, capable network operation management in this business environment is of essential importance.

Finally, capability development within network operation is suggested to be developed in the competence areas of operation management (all utility segments), control room activities (rural utilities with compact networks and urban utilities) and field work activities (rural utilities with vast network and urban utilities). Ways to implement capability development within the utility segments will be analysed and presented in Section 3.4 by the use of extended transaction cost economics. Limitations of the study include easy generalizability of network operation capability development actions within utilities through lack of proposal of quantifiable meters for the follow-up of competence development, cost impact evaluations per utility segment and prioritization of development actions per utility segment (example: development of network operation management is relevant to all utility segments whereas specific for urban utilities: development of both control room activities and field work processes). Research in the related field within concepts for laying of underground cables and proposals of operational models has been reported by Tahvanainen (2010), and practical experiences from control room service provision by international service provider and will be discussed in this thesis in Chapter 4.

3.3. External strategy considerations: SWOT analysis of network operation services at the service provider

Primarily empirical and qualitative research results in the area of network operation strategy considerations at the service provider have been presented in the International Conference of Clean Electrical Power (ICCEP) in Capri, Italy, 2007. Research topics included the following: a) What are the reasons behind the market gap between supply and demand of electricity network operation services from a service provider’s perspective?, b) What risks should be considered within offering of control room services from a service provider's perspective, c)

How could the restrictions be tackled? and d) Is there potential for control room business from a service provider's perspective?

The phases in the study included a literature review, selection of service providers to participate in the survey, preparation and implementation of a questionnaire for service providers, an analysis of empirical results and comparison of practice to theory. As literature in the area of strategy considerations at electricity distribution service providers proved scarce if not non-existing, the lack of theoretical framework can be seen as a limitation of the study. Service providers invited to participate in the survey included Sydkraft (Sweden), Elektrosandberg (Sweden), Eltel Networks (Finland), Empower (Finland), Nuon (Netherlands), SAG Netz- und Energietechnik (Germany), Quanta Services (United States), Amplex (Denmark) and ETV-EROTERV Rt. (Hungary).

The study builds on analysing the risks, costs and benefits experienced by service providers if they were to start providing specialized control room activities for electricity distribution networks. Identified risks, costs and benefits seen by service providers related to offering and buying of network operation services are presented below in Tables 3.3 and 3.4. By identifying the factors currently hindering the service providers to provide specialized control room services, consequently, work can be started to either minimize or eliminate the experienced difficulties.

Table 3.3. Summary on risks, costs and benefits identified by service providers in an international survey on providing network operation services.

Risks	Costs	Benefits
Integration of different data systems applied by electric utilities (technology)	Competence development in-house	More comprehensive solutions → added-value to customer
Difficulty to budget initial investments	Competence development through acquisition and utility spin-offs	Better customer focus → support to customer's internal processes
Sharing of responsibilities if field work is not included	Marketing	Development of internal capabilities
Customer behaviour → one customer is not enough	Development of cost structure for stand-alone control room services (no field services included)	Long-term agreements
Competitor behaviour	Technology investments for system integration	Possibility to affect and develop network availability with own actions
Investments compared with service agreement duration		
Setting of price level for new service scope		
Competence development not to be scattered to several systems		

To sum up, the nature of risks experienced by a service provider is related to the market behaviour, technology integration and management of investments in the competence development versus the length of customer agreements. From a solution perspective, many of these risks depend on the choices made by electric utilities and are thus hard to solve by the service providers themselves. Cost issues focus on technology and competence investments. Further, the experienced benefits are to some degree common with those identified for electric utilities, which in one way supports the target of creating a win-win partnership model with common targets. Table 3.4 summarizes the risks, costs and benefits service providers identified at the electric utilities related to buying of network operation services.

Table 3.4. Summary on risks, costs and benefits for electric utilities identified by service providers in an international survey on providing network operation services.

Risks	Costs	Benefits
Market uncertainty – lack of several service provider options	Restructuring the organization	Cost-efficiency in system transactions, economics of scale
Exit management – how to manage if competence is once outsourced/external and no in-house competence longer exists	Development of internal service buying competence	Development resources from external organization
Local network knowledge of external partner is not the same	Teaching the service provider internal processes	Better quality through centralized competence
Responsibility of network operation still remains in the electric utility (legislation)		Possibility to focus on core competences such as asset owning strategies
How to ensure communication and common targets between long term network development (internal) and network operation (external)		

At the electric utility, the nature of the identified risks is related to the competence losses (local network knowledge, data system knowledge), legislation and strategic corporate governance through synchronizing the long-term network planning objectives (make or buy: make) with network operation (make or buy: buy). These risks are, with an exception of the one related to legislation, largely manageable through internal actions.

To conclude, the main challenges to resolve as part of conceptualizing network operation control room services include

- finding a cost-efficient solution for network data system design and integration,
- creating a long-term capability development strategy for DMS and SCADA competence accrual
- creating a long-term service level agreement limiting the risks for both parties (taking into account regulatory constraints, service quality effects on the quality of electricity supplied and responsibilities within network investments).

Limitations of the study include a) a modest number of responses gained from the service providers (4 in total), b) a focused (bias) selection of service providers (such service providers were chosen that were known to have interest or actions in offering network operation services), c) limited/narrow availability of reported literature in the field of network operation service provision within electricity distribution business and thus d) limited theoretical value-add as main results are derived from practice. Hence, the practical contribution of the study includes mainly reports from international service provider practice and validation of theoretical assumptions. Similar practice-originated surveys for service providers have not been reported to the knowledge of the author during the research period 2005–2010. The above-identified risks, costs and benefits of control room services will be localized and incorporated in different partnering-based control room operating models in Chapter 4.

3.4. Extended transaction cost economics for planning of network operation governance structures in electric utilities

Transaction cost economics (TCE) examines a firm's boundary choices from the efficiency perspective. Coase (1937) argued that organizing production through contracting arrangements with other firms involves transaction costs. According to Coase (1937), the most apparent cost of using market relationships is "that of discovering what the relevant prices are." Other transaction-related costs are for instance negotiating and monitoring costs. When the costs of using markets are higher than the costs of organizing production inside the firm, it is more efficient to coordinate activities through internal organization. In addition to polar modes of governance, namely market governance and internal organization, transactions can be governed also by using the 'hybrid' governance structures, such as partnerships and alliances (Williamson 1991).

The results of the research in the area of transaction cost economics based governance structures of electricity distribution network operation models have been published by Tanskanen et al. and awarded in the *International Journal of Energy Management* under the title "Governance structures and Capability Development within the Electricity Distribution Network Operation, 2007" and firstly presented at RADMA Conference, Windermere, England, 2006. Research questions within the topic include: a) Does extended TCE theory support the analysis of governance structures within monopolized electricity distribution business?, b) Which are the governance structure choices for network operation in the deregulated market?

and c) Could any network operation function be outsourced and which ones are preferred to be kept in-house?

Moreover, the study is based on a four-staged process, which consists of 1) in-depth interviews of experts in the area of electricity distribution network business, 2) an analysis of the findings by researches specialized in the area of electricity network markets, 3) an interpretation of the findings to the extended transaction cost economics framework by researchers of electricity markets, business administration and economics and 4) verification of the results by electricity network business experts. The research design includes in-depth interviews (2005) with ten managers and CEOs of Finnish electrical utilities, an analysis and interpretation of findings and verification of results by electricity network business experts.

Transaction cost economics has been criticized for being static (Ghoshal & Moran 1996) and focusing on avoidance of the negative consequences of opportunism instead of value creation potential of the firm (Conner 1991). As Loasby (1998) points out, the advantages springing from the development of capabilities may justify the increase in transaction costs. Langlois (1992) extended the transaction cost framework to include also the dynamic transaction costs that are "costs of not having the capabilities you need when you need them." Jacobides and Winter (2005) see capabilities and transaction costs fundamentally intertwined; Heiman and Nickerson (2002) and Leiblein (2003) suggest integrating the capability view and transaction cost perspectives in the governance choice analyses. Blomqvist et al. (2002) further developed the extended transaction cost framework to include also the benefits of dynamic transactions and management.

Hence, the study by Tanskanen et al. evaluates the usability of and continues the work done by Blomqvist et al. (2002) for examining firms' boundary decisions. Blomqvist introduced six categories of costs and benefits related to the governance structure choices. Management costs and benefits are results of internalizing activities (make or buy: make) and transaction cost follow the outsourcing activities (make or buy: buy). The determinants of the extended transaction cost framework are as follows: static transaction costs (STC), static management costs (SMC), dynamic transaction costs (DTC), dynamic management costs (DMC), dynamic transaction benefits (DTB) and dynamic management benefits (DMB).

Static transaction costs (STC) are typically costs and risks related to the use of resources from the market. Hold-up risks related to the dependency of one service provider are further examples of static transaction costs. Examples of other STCs are costs related to searching of suitable partners, right market prices and agreement expenses. STCs can be generated from each of the following capability forums; operations management, control room activities and field work activities. Hence, static transaction costs are always costs to the utility in the case when markets are used. Internal coordination costs together with monitoring and measuring activities form the static management costs (SMC).

Dynamic transaction costs (DTC) on the other hand are costs to the utility that are present when activities, such as fault repair, are bought from service market. DTCs are related to teaching and learning within activities when markets are used, and they are present strongly in operation management activities. The related dynamic management costs (DMC) are again internal costs for the utility when some new capability or process is developed and taught within the own organization. DMCs are high for example when developing new capabilities within the network data system management.

By broadening the scope of traditional transactional cost economics, we are also concerned with dynamic transactional and managerial benefits. Dynamic transaction benefits (DTB) are gained through the firm's capacity to absorb knowledge from external sources when markets are used. Benefits such as economics of scale belong to this category, such as cost per activity, and thus play a very important role in the analysis. Within network operation, DTBs can be gained through strategic partners or networks for example within field works or control room activities. Dynamic management benefits (DMB) on the other hand represent the benefits gained from learning and developing in-house, by not using the markets.

When defining different possible governance structures of electrical utilities, the study follows the model of dynamic transaction and management cost-based choice illustration developed by Blomqvist et al. (2002). The contribution of Tanskanen et al. is to integrate the dynamic transaction benefits and dynamic management benefits to the model. By doing this, the study aims also to operationalize the model within the context of electricity distribution business. The study considers both costs and benefits of different governance choices and examines which of the activities could be outsourced and which ones are preferred to be kept in-house. Figure 3.3 illustrates the overall scope of the network operation governance structure study and the capability groups addressed.

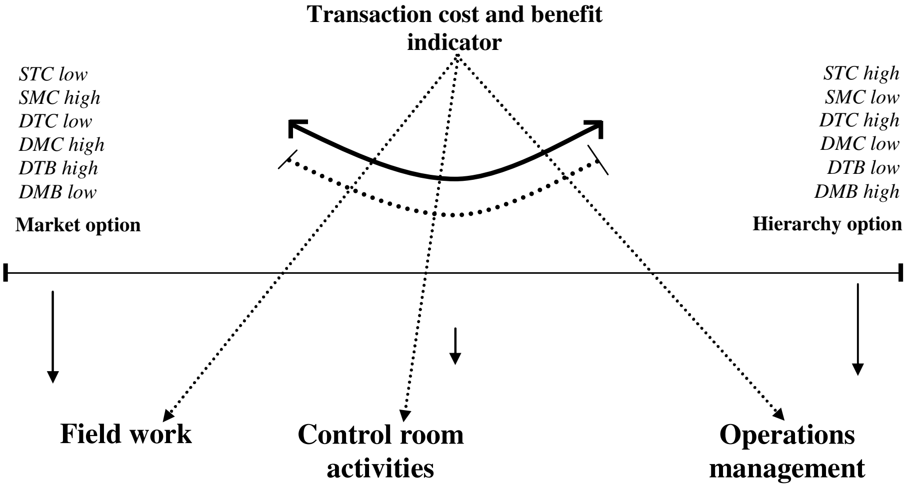

Figure 3.3. Illustration of the dynamic transaction and management cost- and benefits-based alternatives.

Within the framework of the analysis and step three in the research process, the following results in Table 3.5 were obtained.

Table 3.5. TCE analysis of the defined capability forums within network operation.

Effects *low / medium / high*	**STC**	**SMC**	**DTC**	**DMC**	**DTB**	**DMB**
Operations management						
Small utility	high	medium	high	medium/ high	low	medium
Large utility	high	low	high	medium	low	high
Control room activities						
Small utility	high	high	low/ medium	high	high	medium/ low
Large utility	medium	medium	low/ medium	high	medium	medium/ high
Blue collar field work						
Fault repair						
Small utility	low	medium	low	low/ medium	high	low
Large utility	low	low	low	Low	high	low
Blue-collar 24/7						
Small utilities	low	medium	low	medium	high	low
Large utilities	low	low	low	low	medium	low
Field management in major disturbances						
Small utilities	low	high	low	medium/ high	high	low
Large utilities	low	medium/ high	low	medium	high	medium

As an example of the analysis we will briefly present the obtained result row for operations management. Here, we firstly find that static transaction costs are high, since there are few or none partner alternatives in the service market. Hence, the thinness of the markets increases the risk of being dependent on those few companies operating in the markets, and may further result in undesirable effects in terms of service prices and quality. Moreover, the costs of finding a suitable partner are high as is also the required resource specificity. The risks are obvious. Continuing with internal static management costs, it follows that the costs related to monitoring and measuring the internally governed actions are relatively low. Examples of activities belonging to this group are planning and optimizing activities, preparing of guidelines and instructions, follow-up on targets regarding the quality of energy, and the use of capacity. SMCs are higher for small utilities because the management cost per activity and per person is higher.

Regarding the use of markets within operation management services, the DTCs are high, since learning and negotiating costs for the use of service providers would be high for the utility. There are no functioning markets for operation management services. On the other hand, internal development of the new capabilities in the area of operation management is far easier than acquiring them from the markets. Hence, DMCs are lower when compared with DTCs. Still, DMCs are again higher for small utilities because of the lack of economies of scale.

DTBs for the use of markets within operation management would be low due to the fact that there are no markets for operation management, and thus no remarkable learning opportunities from external parties could be gained by the electrical utility. No significant value-added for managerial capabilities could hence be provided from services. If, however, any DTBs could be found within the operation management services in the future, they would probably arise from the specialized operation planning capabilities. DMBs represent here the benefits that the utilities would reach with internal learning and development efforts. Again, the benefits would be higher for large utilities due to the economies of scale, because more internal development and learning would be made possible than in small utilities.

As a conclusion, we see that the cost-benefit relation of the operation management suggests that the use of external service market does not seem to be the first alternative. Smaller utilities would however attain more benefits from the market option than large utilities, since their SMCs and DMCs are higher. The cost and benefit indicator points towards the hierarchy side in the operation management activities.

The main findings include the fact that the extended transactional cost economics theoretical framework and research design, indeed, support the analysis of governance structures and make-or-buy decisions. The study brings not only the transaction costs but also the benefit-side and the dynamic aspects of boundary choices under assessment.

Our findings demonstrate that the activities of the companies operating in the electricity distribution business differ in terms of potential long-term efficiency effects when sourced from the market or made in-house. The determinants of the governance choice depend partly on the nature and strategic importance of the activity in question. The results of the research indicate that *operations management* activities are among core functions for electrical utilities. Hence, there is reason to conclude that it is advisable to develop operations management capabilities in-house in the current market situation, where there are clear potential benefits that can be attained by outsourcing field work activities. The results related to the governance of control room activities are more complicated and provide opportunities for new markets. Control room service models will be further discussed in the thesis in Chapter 4.

Table 3.5 summarizes how transaction and management costs together with benefits are present in the central network operation capabilities. As this is the outcome of the entire analysis, it is intentionally presented in an illustrative and simplistic way in the study. By enlarging the matrix in Table 3.5 so that all the activities of each capability forum (y-axis) as well as all the governance structure factors (x-axis) were presented, the table would indeed show all of the possible subresults. However, these activities and factors are intentionally left out from this final summarized set of results.

Tanskanen et al. acknowledge that reality is more complex with market uncertainty and that the presented study is an illustrative framework where asset specificity and opportunism are all included and the roles thus summarized in the static transactions cost category. For further details, the activities within operation management, network control room activities and field work could be incorporated into Table 1.1 for an analysis against each governance structure. Hence, the approach of the authors has here been to provide a framework for the basis of further evaluation and studies, not expanding it with all the static transaction dimensions. By incorporating of the activity-level under the three capability forums into Table 1.1 for governance structure analysis, this could serve as a more solid rationale for the selection of options in the first steps of using the analysis tool.

The analysis is an explorative study from one industry. By comparing similar considerations in other sectors of energy industry and the application of quantitative research setting would shed more light on the generalizability of the findings of this study. However, for instance the recent 2009 economics Nobel prize winner O. E. Williamson in transaction cost economics has not reported results related to the specific extended transaction cost economic framework. Implementation aspects of control room models will be analysed and localized for Finnish electric utilities in Chapter 4.

3.5. Management of unbundled network operation models – theory and practice

The results of the research in the area of unbundling of electricity distribution network operation models have been published by Lassila et al. in the *International Journal of Energy Management* under the title "Unbundling of Operation and Network Development Activities in Electricity Distribution," 2009. Unbundling has previously been referred to as separation between network business and production, trade, metering, and sales of energy (Künneke and Fens, 2006). However, in this study, the scope of unbundling covers explicitly the separation of activities within the network business; namely the network operation and development (including long-term planning).

Four different levels of unbundling have been identified; each of these levels depends on the market maturity. The unbundling levels include, in an increasing order of magnitude with respect to economic and legal separation, the following steps: administrative unbundling, management unbundling, legal unbundling and ownership unbundling.

The administrative and management levels of unbundling represent largely the current state of utilities in the Nordic countries with no existing techno-economical restraints on market and regulative behaviour. Typical features for administrative and management unbundling levels include account-based separation of network functions, minor changes in operations and agreements based on mutual trust (one holding company). The administrative unbundling model is an alternative to developing electricity distribution business, where the foundation for cost management and regulative reporting is defined. Obtainable benefits through a shift from the administrative unbundling to management unbundling are slight and include possible competence development as part of more specialized organizations.

The third level of unbundling represents legal unbundling, where network activities are legally separated. Benefits from the legal unbundling model include an opportunity to improve network performance through set-up of a controlled supplier-buyer model and prepare the organization for future outsourcing alternatives. The case study presents a legal unbundling model, whereas empirical conclusions suggest that the expected benefits have been obtained and special caution should be taken when modelling of information flows and set-up of common performance targets prior to cut-over. A further change in ownership unbundling may in general include benefits related to outsourcing to an external partner with expectations of higher and specialized competence and smaller operative costs (OPEX).

Research questions addressed in the study by Lassila et al. include: a) Can internal restructuring of short-term network operation and network development be recommended, and if so, with any limitations?, b) How will the chosen model of business unbundling help electric utilities respond to the external market drivers in the long run?, c) How to define common business targets and performance indicators without activity suboptimization? and d) How to evaluate and implement utility-specific appropriate unbundling level?

Based on the literature and an empirical case, the study presents a framework for decision-making in utilities where unbundling considerations are taking place. The paper analyses the implications of splitting long-term network planning activity from the organization responsible for short-term network operation activities. The proposed framework includes an analysis of impacts of external forces, set-up of common targets and performance models and alignment of responsibilities in the new organization. The empirical results and validation of the proposed framework is performed by an electric utility (Suur-Savon Sähkö Oy), where legal unbundling of activities has taken place; the study includes expert interviews and a theoretical analysis. Different levels of unbundling (administrative, management, legal, and ownership unbundling) in the electricity distribution business are presented as part of the literature review.

The scope of the analysis and the strong dependencies between network operation and planning are presented below in Figure 3.4:

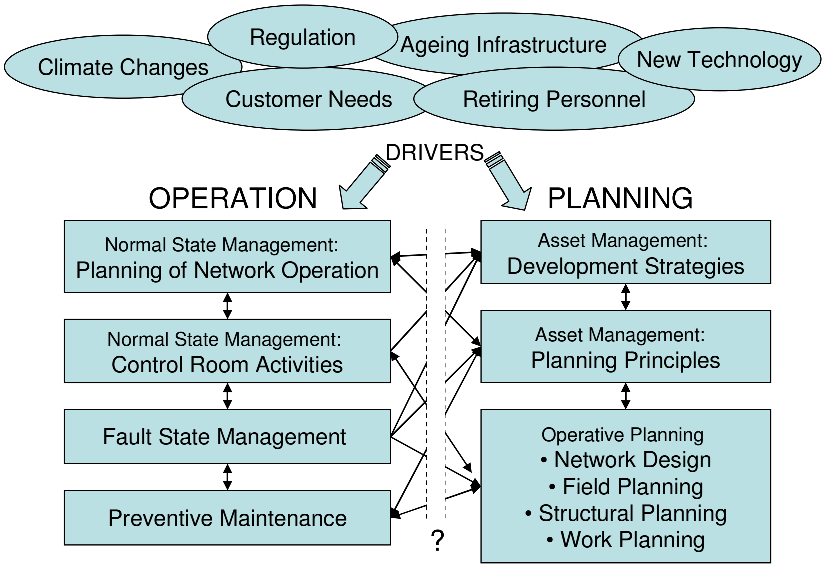

Figure 3.4. Interconnections between network operation, network planning and electricity distribution business environment.

Factors strongly impacting the unbundling of distribution network activities are regulation, tightening customer demands, business owner policy, ageing networks and climate change. In the empirical part, the study applies a methodology for evaluation of the impacts of external forces, previously presented by Brådd et al. (2006). The case utility SSS has made large-scale rearrangements to meet these challenges.

The unbundling of network operation and long term network development is an alternative in the cases where common business targets are agreed on and cost efficiency can be measured. Long- and short-term target differences can be harmonized through strong common regulatory requirements set by the asset owner company. In the case study of SSS, the internal legally unbundled model had acknowledged theoretical targets and indicators, but they were not actively in use. Benefits recognized from the legally unbundled model by the two companies include an increase in knowledge of the service cost levels and information of know-how of each subcontractor. This helps to set long-term targets and develop the business.

Successful distribution business management requires understanding of different technologies and their economic effects. Distribution networks are characterized by a long time span and a strong mutual dependence of the investments. In general, a planning assignment can be characterized as a minimization task of the present value of the investment, loss, outage and maintenance costs occurring during the planning period as presented in the equation below (Lakervi and Holmes, 1995).

$$C_{\mathrm{tot}} = \int_{0}^{T} \left(C_{\mathrm{capex}}(t) + C_{\mathrm{opex}}(t) + C_{\mathrm{outage}}(t) \right) dt \tag{3.1}$$

Where

C_{tot}	Total costs
C_{capex}	Capital costs
C_{opex}	Operational costs
C_{outage}	Outage costs
T	Lifetime of network

To achieve the previous minimum cost requirement, there have to be reasonable targets and performance indicators for each network activity, both network planning and operation, even if the activities are not inside the same company. Colliding interests in the new unbundled model can generally be avoided if economic and technical targets are mainly set by the regulator for both network development and operation activities. Table 3.6 summarizes the targets and indicators proposed in the study.

Table 3.6. Targets and indicators for long-term planning and operational activities

PLANNING PERSPECTIVE

Target		Indicator
Strategic planning and asset management		
minimum cost in the long-run	-	Investment costs, OPEX, outage costs
positive development of network value	-	Present value of the network
growing the business	-	Replacement value of the network, distributed electricity
improving power quality	-	PQ indices, outage costs
decreasing compensation fees	-	Long-lasting interruptions
company-wide strategy known	-	Recognized and congruent planning principles for whole personnel
Resource management	-	Enough labour and material resources to develop network
Technical goals		
reliability	-	Number and duration of interruptions, amount of customer compensation fees
voltage quality	-	Customer complaints
Planning phase		
faster planning process	-	Number of planning tasks per day
better quality planning process	-	Need for re-examination of planning targets, customer satisfaction
more economic planning solutions	-	Total costs of targets, less expensive network connection fees for end-users
suitable planning solutions for each environment	-	Costs, reliability indices, easier solutions for network operation Easier solution to next plannig phase (e.g. to field planning) No need for renovation or reinforcement before lifetime is in the end (e.g. planning of low-voltage network), customer satisfaction

OPERATIONAL PERSPECTIVE

Target		Indicator
Resources (cost-effective use of network, labour and IT)	-	Organization costs, outage costs and loss costs
Management of connection and load state	-	Response time in fault situation
Maintenance, inspections (replacement of older components)	-	Number of component failures
Fault management (outage cost minimization)	-	Duration of faults

Finally, the main steps in the above-presented framework for utility decision-making considering different types of unbundling include identification, specification and implementation of the appropriate unbundling model. Identification of the proper unbundling level is based on the long-term strategy to manage external drivers combined with owner interest and a need to meet requirements of specialization. Specification of the chosen unbundled model requires harmonization of target setting and performance measurement. Implementation of common targets and performance meters is carried out through agreements and enabled by proper information systems.

As a practical implementation, the application of the proposed framework for decision-making and lessons learned can support electric utilities when planning for unbundling and strategic target-setting in the unbundled business model. The study presents experiences of reorganized network business activities in a pioneering market area with a long experience of outsourcing. The detailed analysis of internal re-organization within one electric utility can facilitate further restructuring phases. Practical take-aways with respect to implementation of unbundled models including SLA agreements and process modeling including data flow among unbundled parties will be presented later in Chapter 4.

3.6. Operative use and distribution system management benefit analysis within electricity distribution network operation

The results of the research in the area of operative tools within electricity distribution network operation models have been published in the *International Journal of Energy Management* under the title **"**Cost and Benefit Calculation Analysis for a Distribution Management System in Electricity Distribution Networks, 2010." The study examines the key outage-cost-influencing applications (fault location and network restoration, fault reporting, field crew management and reconfiguration) of the Distribution Management System presented below in Table 3.7 and analyses the benefits provided by them. The aim of the study is an evaluation of the influence on outage costs deriving from the adoption of automatic equipment in managing distribution systems.

Table 3.7. Main functionalities in a DMS application

BASIC MONITORING	FAULT MANAGEMENT	OPERATIONS PLANNING
Topology supervision	**Event analysis and fault location**	Scheduled outage planning
Network state monitoring	Fault isolation	Volt/var optimization
Field crew management	**Fault restoration**	**Reconfiguration**
	Fault reporting	
	Customer service	

Research questions within the study include: a) What are the key outage-cost-influencing applications of the Distribution Management System and which are their benefits?, b) Which are the theoretical maximum levels of €-benefits from DMS functions?, c) Can such benefits actually be obtained? and d) How to capitalize the identified DMS benefits?

As a basis for decision-making regarding investments within development of network operation models, comparable financial data are required. Current legislative models within electricity distribution already incorporate OPEX, CAPEX and DEA (Data Envelop Analysis) figures among others for evaluation of electric utility performance from different perspectives. However, as the intelligence of distribution networks is rapidly increasing through investments in distributed automation and utilization of developed automation, also the quality requirements for the operation of network will grow. Parallel developed tools, such as DMS, are required to support the management of intelligent distribution networks. Here, outage management and outage-cost-based analysis lies in the core of network operation. Moreover, as a basis for SLA creation and definition between NO control room parties, common financial target levels are required. Hence, common methodology for electric utilities as for service providers analysing business potential and uncapitalized financial benefits within development of network operation functions is in place. Table 3.8 below summarizes the outage-cost-based methodology for capitalization of DMS benefits, which will be presented next.

Table 3.8. Summary of the methodology for outage cost benefit evaluation

Phases of methodology	Content
1) Accumulation of data	a) network parameters from utility, b) outage cost parameters from the local Energy Authority (note: weighted customer distribution), c) actual SAIDI values for analysable network from utility (or selection of generic SAIDIs) and d) new SAIDI values or estimates for network from utility after DA implementation with DMS.
2) Selection of benefit formulae	a) selection of reliability indices to use (SAIFI, CAIDI, SAIDI), b) evaluation of validity for chosen indices for selected DMS applications and c) incorporation of chosen parameters in outage cost equations.
3) Calculation of outage costs (k€/ feeder, a)	a) outage cost per each feeder part without DMS application, b) outage cost per each feeder part with DMS application, c) sum of total feeder length outage cots, d) fault reporting application: outage cost per feeder part per selected period of years (here 40 a) and sum of total feeder and e) multiplication of outage cost benefit with actual feeder amount.
4) Analysis of results	a) identification of interdependencies between DMS applications (e.g. earth faults and utilization of DMS fault location vs. field crew management) and b) comparison with actual annual costs (OPEX, outage costs).

Cost and benefit calculations in this study are thus made for a typical North European rural medium-voltage network. The benefits are calculated in terms of outage costs for each of the above-presented applications and compared with the investment cost, including the annual cost of maintenance, of the DMS. The empirical results and validation of the theoretical calculations is performed by an electric utility (Suur-Savon Sähkö Oy), where the DMS benefit evaluation is taking place.

The equations used for calculation are presented below:

$$IC_{\text{unan, an}} = \sum_{i=0}^{I} \sum_{j=0}^{J} CA_{i,j} \overline{P}_{i,j} \left(t_i A_{j,\text{kWh}} + B_{j,\text{kW}} \right) \quad (3.2)$$

where $IC_{\text{unan,an}}$ are the interruption costs of the unannounced and announced interruptions, $CA_{i,j}$ is the number of customers in the customer group j affected by the outage i, $\overline{P}_{i,j}$ is the average interruption power [kW] of the customer of the customer group j caused by the interruption i, t_i is the interruption time of the outage i, $A_{j,\text{kWh}}$ is the outage cost parameter A

[€/kWh] for the customer group j for unannounced and announced outages, $B_{j,\mathrm{kW}}$ is the outage parameter B [€/kW] for the customer group j for unannounced and announced outages, I is the number of interruptions during a certain time period and J is the number of different customer groups.

Interruption costs for short interruptions can be calculated by the following two equations:

$$IC_{High-speedAR} = \sum_{i=0}^{I} \sum_{j=0}^{J} CA_{i,j} \overline{P}_{i,j} A_{j,High-speedAR} \qquad (3.3)$$

where $IC_{High-speedAR}$ are the interruption costs of the high-speed auto-reclosings, and $A_{j,High-speedAR_i}$ is the outage cost parameter A [€/kW] for the customer group j for high-speed auto-reclosings.

$$IC_{delayedAR} = \sum_{i=0}^{I} \sum_{j=0}^{J} CA_{i,j} \overline{P}_{i,j} A_{j,delayedAR} \qquad (3.4)$$

where $IC_{delayedAR}$ are the interruption costs of the delayed auto-reclosings and $A_{j,delayedAR}$ is the outage cost parameter A [€/kW] for the customer group j for the delayed auto-reclosings. Other formulae utilized in the calculation include among others SAIFI, SAIDI, annual investment cost and present value calculation and these are fully referred to within the original publication.

Initial data used within the calculation process included a) specific network and cost parameters provided by the local energy market authority and the case electric utility and b) empirical average reliability indices presumptions given by the case electric utility's interviewed network experts. Basic feeder conditions in calculation include: 1) the medium-voltage network is a neutral-isolated system, 2) short-circuit faults can be located by the DMS application, 3) because of the neutral-isolated system, earth faults cannot be located by the DMS application by calculation of fault currents and 4) 2/3 of all faults in the distribution network are earth faults.

The case electric utility's medium-voltage network is represented by 5 MV feeders, each of them being 40 km long. The mean power of the feeders is 800 kW and the average failure rate is 7 pcs/100 km, a. The key outage parameters used in calculation of the cost of interruption are 1.34 €/kW and 12.85 €/kWh. For the case network, SAIDI is 90 min under basic conditions, which can be considered typical for a network of this kind.

The study shows that by capitalizing the applications of the Distribution Management System, it is possible to acquire considerable benefits in outage costs. It is shown that the greatest cost-based benefits were obtained from the fault location and field crew management applications, Table 3.9. The study suggests the use of outage-cost-based calculations supported by a SAIDI analysis for evaluation of DMS application benefits. This benefit evaluation method is supported by the current economic regulation and overall cost management in utilities.

Table 3.9. DMS application outage cost benefits per case electric utility's average feeder

Application	Benefit (k€/feeder, a)
Fault location and restoration	2.5
Fault reporting	0.5
Reconfiguration	1
Field crew management	1.5
Total benefit, all applications	**5.5**

In the case electric utility SSS, the actual cost benefits achievable of the DMS were calculated according to the methodology presented in Table 3.8. The benefits of each DMS application presented in Table 3.9 were then further multiplied by the actual number of feeders in the network (235). Thus, in the case of SSS, the cost-based benefits achievable from the addressed DMS applications equalled roughly 25% of the annual outage costs and 10% of the respective operative costs. As such, the annual measurable theoretical benefits from the use of DMS applications are considerable.

The calculations are based on network experts' SAIDI assumptions carried out for a specific overhead line network operating in a specific European rural medium-voltage environment. Sharing of utilities' de facto SAIDI results as a basis for calculations would in the future analysis decrease the need for subjective expert assumptions.

One further limitation in realization of the calculated benefits in fault location application is the fact that currently in a typical medium-voltage neutral-isolated system, where fault location is based on measuring the fault current, earth faults cannot be located by the application. However, by configuring settings in modern earth fault relays, it is possible to treat the earth faults as short-circuit faults. Thus, also the earth faults can be located by the DMS application and the cost benefit becomes even greater.

4. Analysis and contributions

In Chapter 4 the practical implications to the electricity distribution industry of the results presented in Chapter 3 will be discussed and analysed. Focus is here shed on the governance, management and executing business hierarchy levels of network operation models (Figure 2.1). While Chapter 3 was generic methodologywise, Chapter 4 will analyse the conclusions locally with empirical validations. In Chapter 4 the focus of network operation model analysis lies on control room functions and therein also the DSO (Distribution System Operation) definition is introduced parallel to the more widely used term NO (network operation).

4.1. Summary of the results

In the doctoral thesis, the content of network operation functions have been defined in Chapter 1 in Table 1.1. The main functional areas include: a) planning and execution of network operation (including field work), b) control room activities, c) management of preventive maintenance, d) fault state management and e) supportive functions such as customer services. Countries with supportive regulation including considerations for outage costs, which in the first hand can benefit from the results in the thesis include the U.K. and the Nordic countries (Figure 1.1, Chapter 1).

The definition of network operation functions is followed in Chapter 2 by a literature review, market analysis and introduction to research areas. External and internal factors affecting the strategic long-term development of network operation are analysed in Publications I and II. Main drivers pushing the development of network operation include: a) network efficiency (intelligent networks), b) quality (network availability) through management of outage costs and c) capability increase within utilities. Enhanced efficiency within the operation of electricity distribution networks is enabled through implementation of advanced technologies and increasingly automated networks (AMR, pole-mounted circuit breakers, remote-controlled disconnectors). Examples of such efficiency-enabling technologies are presented shortly in Section 3.1 and in (Brådd et al., 2006).

Hence, both the increasing intelligence of future distribution networks and the legislative incorporation of quality mainly through outage-cost-related measurements will set pressure on network operation capability development within electric utilities. Capability development scenarios within electric utilities are presented in Section 3.2 and in Brådd et al. 2008, where capability development can be achieved by internal actions, external networking or a combination of both.

Thus, it becomes important to evaluate restructuring alternatives within electricity network functions , and depending on the chosen capability development strategy of the utility, there are several ways to proceed with the structuring of the utility's company boarders, that is, governance structures. Methodologies to support such a restructuring analysis within electric utilities are presented in Sections 3.4 (governance structures) and 3.5 (unbundling of network functions; case study) of the thesis and in (Tanskanen, et al., 2007) and (Lassila et al., 2010). It also follows from the governance structure alternatives that service providers in the market could offer specific missing capabilities; however, related risks, costs and benefits should at the same time be identified at the service provider's side (Brådd et al., 2007).

Special considerations on unbundling of demanding tightly interconnected network functions such as long-term network development and hour-to-week based network operation are analysed further in Lassila et al., 2010. Here, the close connection between network investment decisions and operative network actions in the utility have to be secured. Especially within external unbundling models the importance of a functioning Service Level Agreement (SLA) among the contractual parties is clear; however, same responsibilities should be considered also in internal models.

In unbundled models where one party is responsible for network investments and the other one of network operation the difference between objectives can be visualized through an example. In the example the network operation responsible would like to invest in remote-controlled disconnectors in the network and pole-mounted breakers to increase network flexibility, however, network flexibility is not in the economical interest of the party making the investment decision. However, through the use of long-term service level agreements between parties, such operative investment decisions could also be part of the network operation function's responsibility.

In the development path of regulative electricity distribution network models, investment and operative cost measurements of electric utilities are many times followed by inclusion of annual outage costs. Outage-cost-based calculations, on the other hand, are supported by specific applications within the distribution management system (DMS) discussed in Section 3.6 and in

(Tanskanen, A. et al., 2010). Table 4.1 below summarizes the main results within each research area.

Table 4.1. Summary of the areas of research and the main results of the doctoral thesis.

Areas of research	Main results
1. DSO future mission and vision (literature reviews, expert interviews)	- identification and analysis of external factors and DA solutions pushing the development of DSO - future regulative schemes will support quality-conscious organization of DSO
2. DSO strategy (resource-based view, scenario works, capability development)	- cost and quality dependencies within network business functions as basis for strategic capability development decisions - reconfiguration of DSO capability development portfolios for electric utility segments
3. DSO planning/governance (extended TCE, make-or-buy)	- evaluation of extended TCE framework applicability to electricity distribution governance decisions - governance indications for DSO functions: DSO field activities (market), network operation management (hierarchy) and control room functions (slightly market)
4. Service provider strategies on DSO services (SWOT analysis, international survey)	- strategy challenge: DSO capability development to be developed prior to offering of service and long-term customer commitments - international survey: positive mindset indicated for offering of DSO services - missing standards for data system integrations within electricity business is viewed as considerable risk
5. DSO management (processes, performance measurement, SLAs)	- presentation of decision framework, common business targets and performance indicators for support of unbundling activities among long-term network development and network operation functions - indications show that unbundling of functions is achievable; however, integration level of data between functions is critical - case study on unbundling implementation in electric utility; modelling of data flow processes crucial for success
6. DSO execution (DMS, outage cost calculation, capitalization of functions)	- application of reliability indices and outage cost calculations for basis of DMS function capitalization - the largest outage-cost-based benefits from DMS applications for a typical North-European feeder were calculated for fault location and restoration and field crew management - theoretical maximum outage cost benefits indicate 10% annual OPEX savings for selected DMS functions

All in all, the accumulated pressure to develop future network operation capabilities will focus on capitalizing the benefits from advanced network intelligence and quality increase within fault management and outage costs. The network operation function scalable to meet and combine these needs is the control room activities function. Previously in Section 3.4, the results within extended transaction cost economics suggest slightly market positive transaction parameters for control room activities such as low static transaction costs, high static management costs, low dynamic transaction costs, high dynamic management costs, high dynamic transaction benefits and low dynamic management benefits. The following Sections 4.2, 4.3 and 4.4 will address specific implications within the governance, management and executive level of network operation models within electricity distribution networks (Table 4.2).

Table 4.2. Analysis structure of the main results areas within the network operation business hierarchy.

Network operation business hierarchy (Fig. 4 Ch. 2)	Research question	Section of analysis
Planning (governance)	What governance models for NO capabilities are supported by extended TCE analysis (market vs. hierarchy)? Does the extended TCE support analysis of governance structures within electricity network business?	4.2 Capability-based extended transaction cost analysis of NO control room models
Management (processes, performance measurement, SLA)	Can internal restructuring of short-term network operation and network development be recommended, and if so, with any limitations?	4.3 Unbundling of interdependent network business functions (long-term network development vs. network operation
Execution (tools, data systems)	How to capitalize beneficial network operation functions (outage cost evaluations, DMS)?	4.4 Outage-cost-based analysis on capitalization of NO functions within DMS

4.2. Capability-based extended transactional cost economics analysis for governance models

Future requirements for efficient and increasingly quality-conscious distribution network operation suggest that there either exists today typically a gap in current control room capabilities or an unused capability potential to take into use for economic capitalization. Either way, the literature, regulative development and technological development all support the fact that network operation requirements of today will not be the same as those a couple of regulative periods ahead. A capability increase within NO control room activities is required.

The extended transactional cost economics (TCE) theoretical framework and the research design support an analysis of governance structures and make-or-buy decisions within the electricity distribution business. The TCE framework is primarily a tool for distribution system operators (DSOs), where the two extremes (static vs. dynamic, make or buy) are actively weighed and analysed. It follows that the TCE analysis is not as beneficial for the analysis of governance in the case of service providers (markets), where the market extreme is the basis for existence. Hence, in the discussion below, the TCE results are derived from a DSO perspective, if no other information is provided.

Hence, in the next sections, governance structures within network operation will be analyzed first from the DSO perspective and then from the service provider perspective.

4.2.1. Extended TCE analysis of control room activities at the asset manager

In the light of the transaction cost-based analysis operations, management seems to be a function to be kept in-house in the current market situation, whereas there are clear potential benefits that can be attained by outsourcing field work activities. The results related to the governance of control room activities indicate benefits from market or networking governance. Summarized TCE results are presented in Table 4.3. Utilities with less than 15 000 customers are here considered *small*, whereas utilities with 80 000–100 000 customers are considered *large*.

Table 4.3. Summarized results of the extended TCE analysis for network operation capabilities

NO Capability	Extended TCE parameters						Governance outcome
	STC	SMC	DTC	DMC	DTB	DMB	
NO management							Governance: Hierarchy
NO Field work activities							Governance: Market
NO control room activities (small utility)	high	high	low/ medium	high	high	medium/ low	Governance: Slightly market
NO control room activities (large utility)	medium	medium	low/ medium	high	medium	medium/ high	Governance: Slightly market

Control room activities face a somewhat different market situation than the operation management function described in Chapter 3, since in certain special conditions, control room services have been bought to some minor and restricted extent. However, the major difference is related to the ownership and maintenance of expensive assets such as network data systems, which is reflected by high or medium SMCs.

STCs are moderate or high due to scarce partnering possibilities. Static transaction and management costs regarding control room activities differ between small and large electric utilities mainly due to the difference in proportion of the invested fixed asset (network data systems) compared with capitalizable benefits from system usage. Making contracts is challenging, and it is also difficult to change the supplier of network data systems. STCs are in this case higher for small utilities than for large ones because large utilities have generally a better risk tolerance. Resource specificity can neither be neglected. Internal SMCs are however also high or moderate because of the use of expensive network data systems. Small utilities find higher SMCs than large utilities because of a smaller number of activities to which the same data system can be applied.

DTCs would be low or moderate in the sense that if there were markets within control room activities, the development costs for the utilities would be low because of the specialized capabilities that the service providers could offer regarding an extensive use of network data systems. Network data system activities are quite generic, even though there are differences between the systems of different suppliers. DTCs could theoretically be minimized if all market players used more or less the same data systems. Regarding the dynamic transaction costs, it is natural that the experienced start-up costs for electric utilities are not significant. These identified costs are related to developing the internal buying competence of services and teaching the service provider the internal processes. However, costs are also inevitable if the organization has not been restructured yet.

DMCs would on the other hand be high, since internal development of new capabilities within control room activities would involve the learning of extensive use of network data systems and the use of network automation, both involving remarkable investments. The DTBs for a utility would be high, if a service market existed as a result of gaining the concentrated best knowledge, but especially because of the economics of scale in the sense of decreasing costs per activity. Here, small utilities would experience greater DTBs than large utilities. Large utilities see higher benefits than small utilities in the sense that by conscious internal development of control room capabilities, they could possibly broaden their business and offer control room services also to other utilities. For small utilities, no remarkable strategic benefits are gained through internal development of control room proceedings.

Based on our analysis, we see that in general the management and transaction costs and benefits regarding control room activities are at the level where the suggested governance choice is clearly neither a pure market solution nor a pure hierarchy choice. However, especially small utilities should focus on network operation capability building, whereas the results suggest that small utilities would find the use of service markets more attractive than large utilities. From the service provider's perspective, on the other hand, the market potential springs from those small- and medium-size utilities where transaction benefits are greater than alternative management benefits and of course cases where management costs are higher than transaction costs.

Finally, the question follows, which utility types are those to benefit most from a purely market or intermediate form of the networking-based control room model. As a result of a network operation questionnaire sent to all network operators (93) in Finland in May 2010, the distribution network utilities segmented their working environment to relate to either an urban environment, a rural environment or a mixed environment. With an answer rate of 39%, a sample of the top actual average annual outage costs during years 2005–2006 in 2007 monetary value and per network for the participating electric utilities is shown below in Table 4.4.

Table 4.4: Summarized top-ten average outage costs per network length during years 2005–2006 for electric utilities taking part in the survey (Energy Market Authority)

Electric utility	Average outage cost, years 2005–2006, in 2007 monetary value (k€)	Average outage cost per network (0,4 kV, 1–70kV, 110 kV) length (k€/km)	Utility segment
A	2104.7	1.02	Mixed environment utility
B	2043.8	0.66	Rural utility
C	3595.3	0.53	Rural utility
D	2308.7	0.51	Mixed environment utility
E	6015.5	0.49	Mixed environment utility
F	1130.4	0.46	Rural utility
G	202.4	0.45	Mixed environment utility
H	1393	0.42	Rural utility
I	9734.6	0.40	Rural utility
J	24143.3	0.40	Urban utility

Given the statistics above in Table 4.4, it occurs that quality increase possibilities with respect to actual network length are highest among rural utilities and mixed environment utilities. Also the given outage cost statistics for the sample utilities support the findings for a capability development focus within control room activities in the first hand for small- and medium-sized utilities in rural and mixed environments for a governance analysis in the extended TCE analysis.

From the efficiency increase approach, on the other hand, the following statistics in Table 4.5 are calculated from the Energy Market Authority basic data for the sample utilities with top OPEX costs during years 2003–2006. Here, the diversion between top-ten average controllable OPEX costs depending on the viewpoint (division per customer number vs. network length) is considerable. Rural utilities top the average controllable OPEX list with respect to customer amount, whereas urban and mixed environment utilities top it with respect to network length. Also, many of the rural utilities present in the top average OPEX list are also found in the top average outage cost list in Table 4.5.

Table 4.5. Summarized top-ten average controllable operative costs (years 2003–2006) per customer number during years 2005–2006 for electric utilities taking part in the survey (Energy Market Authority)

Electric utility	Average controllable operative cost, years 2003–2006, in 2007 monetary value (k€)	Average operative cost per customer number (0,4 kV, 1–70kV, 110 kV) length (k€/km)	Utility segment
S	1924.9	0.24	Mixed environment utility
F	1699.6	0.17	Rural utility
M	4371.9	0.17	Rural utility
K	522.4	0.16	Rural utility
I	16274.4	0.16	Rural utility
V	12571.4	0.15	Rural utility
L	7928.1	0.15	Rural utility
G	1499.5	0.14	Mixed environment utility
H	2577.2	0.14	Rural utility
X	1924	0.13	Rural utility

Hence, it follows statisticswise that it is the rural utility and mixed environment segments that have most to gain from outage management cost savings within network operation. As a finding this is not surprising nor new; however, supporting efficiency increase possibilities with respect to controllable operative cost savings (Table 4.5) indicate additional synergies within DMS functions such as field crew management. Within NO control room activities, outage management economical savings can further be calculated by reliability indices within outage cost handling DMS applications. Such outage-cost-based calculations for validation of fault management savings will be presented in Section 4.3.

Electric utilities experiencing special need for quality improvement within outage cost management have several alternative NO control room models to evaluate. Alternative network operation control room operating models with defined model targets, risks, benefits and cost elements are presented below in Table 4.6. The control room models presented below, hence, represent different governance models within the scope of extended TCE framework including hierarchy-based (make-or-buy: make) control room development, some networking-based control room solutions and a fully market-based (make-or-buy: buy) control room solution. The main analysable models include: a) internal centralizing of control room functions, b) external outsourcing of control room functions, c) external utility alliances of control room activities and d) external implementation of DMS BOOT (Build-Own-Operate-Transfer) model for control room functions.

Table 4.6. Summarized operative models (A–D) for NO control room activities (model targets, risks, costs and benefits from electric utility and service provider perspective)

NO control room model	Electric utility	Service provider(s)
A) Internal centralizing of control room functions	N= 1	N= 0
Model targets	Improvement of cost efficiency, quality, capabilities, "focus on core competences"	-
Model risks	Key resources not moving to centralized control room	-
Model cost elements	CAPEX and OPEX savings.	-
Model benefits	Critical network information kept in-house, cost savings	-
B) External outsourcing of control room functions (incl. SCADA)	N > 1	N ≥ 1, one main partner (SPOC)
Model targets	Purchase of dedicated and specified DMS knowledge (quality value-add) with competitive pricing, streamlining of partner chain "one partner manages all"	Providing of best knowhow for all-in-one outage management concept, alliance between DMS system supplier, fieldwork service provider responsible of 24/7 network availability and electric utilities.
Model risks	Silent network (core) information transfer to externals, dependency on selected outsourcing partner, lack of competition, responsibility of the network operation still stays at the electric utility according to current legislation	Multiple customers required for cost efficiency, level of standardization for integration of data systems developing, accrual of competences (DMS and SCADA), customer willingness to commit to long-term SLAs
Model cost elements	Balance sheet (CAPEX) savings (DMS at service provider), increase in OPEX (if DMS is operated by service provider)	Considerable data system investment costs, balance sheet increase, SCADA-DMS integration
Model benefits	Avoiding of utility specific DMS investment, committed and long-term partner, benefiting from better utilization of network DA through competitive DMS-competences (outage cost savings), standardized reports, development power and new concepts	Possibility to develop and offer new value-added DA- and DMS-related network services to electric utility, ~ Smart grid concepts

Table 4.6. Continued. Summarized operative models for NO control room activities (model targets, risks, costs and benefits from electric utility and service provider perspective)

C) External utility alliances of control room functions (alliance =N)	$N \geq 2$	N= 0
Model targets	Improvement of cost efficiency, quality, capabilities, "focus on core competences"	-
Model risks	Unclear business logic for the utility with overall responsibility of the alliance/ process development/ system integrations?	-
Model cost elements	OPEX and CAPEX reductions in all utilities depending on alliance service contents.	-
Model benefits	No rivalling competition (avoidance of hold-up risk with service provider) nor difference in business interests among monopoly utility partners. OPEX and CAPEX reductions per N. Benefiting from alliance best practices	-

Table 4.6. Continued. Summarized operative models for NO control room activities (model targets, risks, costs and benefits from electric utility and service provider perspective)

D) External implementation of DMS BOOT model for control room functions (Build-Own-Operate-Tra.)	N ≥ 2	N ≥ 2,
Model targets	Enabling of DMS usage and benefits without initial system investment, benefiting from market best practices within BOOT project members. SCADA operation stays at utility.	Main partner "neutral" participates mainly with DMS investment and SCADA integration funding purpose for development of national infrastructure with predefined annual return on investment, after pre-defined operation period the invested DMS is transferred to other new owner. Additional partners: 24/7 service provider and DMS system-supplier.
Model risks	DMS operation competence owner unclear	Successful integration of network data systems proves more time consuming and pricy than anticipated (standardized interfaces are not fully ready),
Model cost elements	Increase in OPEX, no DMS CAPEX investments, however, data system integrations (if not fully covered by funding party) in CAPEX.	Annual return on investment for funding party, service provider or electric utility invests in DMS operator(s)
Model benefits	Smaller and less-risky NO business model change "nothing is taken away" than that of outsourcing control room activities. If operative model is not satisfying exit from alliance	Service provider avoids initial data system investments and provides DMS services and reports. "Neutral" party (municipality, national electricity market organization) heads the sensitive outsourcing project. Transfer of DMS after agreed operation period can be done based on experiences either to electric utilities or service provider. The neutral party actively supports the implementation of standardized electricity distribution data system integrations (follow-up on national TIEKE standardization project).

A newer approach for the build-up of DMS-based control room models could be that of model D in Table 4.6; the BOOT concept (Build-Own-Operate-Transfer). Within infrastructure development, especially in the developing countries, the BOOT concept is used in order to fund and develop the infrastructure; the concept has been applied for instance to hydropower projects. The concept of BOOT involves an arrangement by which a private developer builds an infrastructure facility using limited or non-recourse financing in return for the right to operate the facility and charge users a fee in order to generate a commercially acceptable rate of return (15% or more) on investment. The private developer owns and operates the project for a specified amount of time (years), after which ownership is transferred to the government without compensation.

Financing is typically ‘engineered’ into complex financing packages involving multiple financiers (co-financing), and guarantees and insurance being provided by governments, export credit agencies and/or development banks. Financing is done usually on a limited or non-recourse basis, which means that borrowings remain on the balance sheet of the company that owns the project and security for the loans is limited to the project itself. Revenues generated by the project repay project debt and provide the required rates of return demanded by the investors/financiers (Australian Mekong Resource Centre, 2010).

As a result of a previous interview (2005) with ten Finnish case electric utilities, it appears that electric utility strategies support the initial demand of network operation markets according to the presented electric utility segments of rural, urban and mixed operational environment. However, as Tahvanainen (2010) in her doctoral thesis points out regarding the expected development of service purchasing from independent service providers from the present year to year 2015, the *number of outsourcing cases* within for example control room activities is not expected to grow. Further, Tahvanainen proposes that within the cabling management concept, the network operation functions, fault situation management and both manual and remote-controlled fault isolation and restoration would be possible to outsource to firms that are specialized in network operation services.

Electric utilities that are evaluating the option to buy control room services could primarily look into the following steps: a) restructuring the organization, that is, field work operations to form a unit of their own, b) analysing the current in-house cost structure of the control room organization, that is, what does it cost today, c) calling for the market price from service providers and d) evaluating the available market options. If the market options prove cost-efficient and sufficient qualitywise, a long-term agreement with defined service levels (SLA) and mutual exit possibilities can form the basis for sharing of risks and common business targets. The long-term agreement is as such a prerequisite for the initial investment in competence development required of the service provider.

4.2.2. Extended TCE network operation governance considerations for service providers

It follows that the embryonic market-favoured governance structure for control room activities is primarily accomplished through lower DTCs than the alternative internalized DMCs. Furthermore, from the benefit-side, DTBs for smaller utilities are higher than alternative DMBs. Continuing, the practical realization of DTCs and DMCs as a basis for analysis differs between large and small electric utilities. The difference lies in the status of dynamic capability management of the utilities as well as the starting situation of data system availability and utilization, such as DMS. However, as a contradiction, for example the benefit experienced by electric utilities related to the economy of scale within transactions can be identified as a risk for the service providers. The risk is derived from the fact that a service provider also needs a critical mass of control room customers (risk number 4 in Table 2) in order to be able to offer services with competitive prices enabling small dynamic transaction costs (DTCs) for utilities.

During the research period of 2005–2010, major Finnish electric utilities have strategically centralized control room functions, simultaneously strengthening their dynamic capabilities. Also renewals of strategic network data systems have taken place. It follows that the differences in DTC and DMC results between small and large utilities have increased from the period when the results were viewed. In other words, DMCs within large utilities where centralizing of functions and system renewals have taken place are today lower than the results shown in Table 14. Hence, for large utilities this change within DMCs in fact swings the governance pendulum towards the hierarchy extreme, even though DTBs still can be identified.

This then means from the service and DMS system provider perspectives that the focus on control room service development should be on small utilities, where DTCs still are lower than alternative DMCs and DTBs prevail. As major risks identified in Chapter 3 in the service provider survey, also in the realization of control room services for smaller utilities the network data system design and plan for implementation needs to be carefully looked at. Equally valid points to consider are also the creation of long-term capability development strategy for DMS and SCADA competence accrual and a sufficiently long-term SLA.

Depending on the chosen network operation capability development strategy of the electric utility control room, models for service providers to consider include models B, C and D presented in Table 17. From the risk minimization perspective of service and DMS system providers, the BOOT model implementation (model D) for control room services could be the preferred option.

Service providers that are evaluating the option to broaden or develop the current field work service scope to include also control room activities could a) be proactive in piloting new services, b) support the development of standard interfaces between network data systems and end terminals and c) develop advanced SLA agreements. Alternatively, a fast market entry with required competence could be attained through an acquisition of control room organization. Either way, a functioning control room service market requires several service providers and encouragement for competition.

Considering the research period at hand between 2005–2010, advanced models of network operation in the field of control room activities have been concerned with only minor activities and grass-root efforts in Finland. On the other hand, control room service activities are currently provided in other infrastructure industries such as telecom, as is the case for example in Sweden.

4.3. Unbundling of interdependent network business functions (long-term network development and network operation)

The regulating authority affects the creation of new unbundled business models such as this of network development and network operation through the following incentives and sanctions:

- The defined short-term incentives set the basis for business targets of the network operation function.
- .The urge to minimize the operative costs affects the cost structure of network development and operation in different ways.
- There are predefined principles for allocation and usage of money for network development and operation.

However, in practice, the overall management of network performance can become very complex in cases where highly interconnected unbundled long- and short-term activities with independent techno-economical targets are to be managed by different parties. Harmonization of network management in advanced unbundled models is firstly achieved through identification and specification of common target setting and performance measurement. Secondly, implementation is carried out through solid agreements and information systems in place.

Examples of common targets and indicators for long-term planning and operational activities were presented in Table 3.6. Technical goals related to network reliability and voltage quality are largely common for both functions. Further, because of the strong role of economic supervision in distribution business there are incentives to decrease outage costs by both technological solutions (underground cabling, new primary substations etc.) and operative actions (faster reconnections and fault repair, network automation). From an asset management point of view, a balance and incentives between long-term planning and short-term operation activities for network reliability have to be defined so that long-term total costs can be minimized. From a sensitivity perspective, depending on the chosen time span of the performance period to be assessed, the indicators can be prioritized in different ways. Without common asset management guidelines for separate partners working with network planning and network operation, conflicts in interests may occur in definition of target levels. In the end, what makes the difference is that the identified common targets are not only identified, but implemented and in use.

Let us now shortly highlight the practical take-aways for implementation with respect to set-up of SLA agreements and the importance of process modelling including data flow among parties. Responsibility management is implemented through preparation of appropriate agreements for the level of unbundling in question and further enabled through network information systems. It has been argued that one common factor in successful outsourced programs has been an ability to maintain transparent and direct communication with everyone involved in the activities across the organization and with the contractor (Allen and Chandrashekar, 2000). Information shortages between parties in an unbundled model where both activities are highly dependent on information systems can lead to fatal network situations. Key points to consider in implementation of internally unbundled models include:

- preparation of a detailed IT-related, long-term SLA agreement; including common targets, performance measurement indicators, definition of a performance reference point

- determination of common factors behind investment decisions; must be in line with the decisions of outage costs (example: investment in substation or increase in field mechanics)
- information management and modelling
    - o close collaboration between unbundled parties; securing sharing of silent information
    - o serious information system challenges and information shortages can be avoided when information flows and common proceedings within network data system interfaces (GIS, SCADA and DMS) and towards other operating functions such as network construction and maintenance are specified prior to set-up of an unbundled model.
    - o Establishment of a two-way feedback-process between long-term network planning and network operation. Examples: feedback from network operations to the investment decisions made by long-term planning to avoid unproductive network investments. Network reliability statistics feedback from network operation to planners.

Practical results indicate that successful progressing in unbundled long-term planning and network operation models is not be recommended without proper information management processes in place.

4.4. Evaluation and capitalization of control room functions within DMS applications

In unbundled electricity distribution network operation models, the results within the case electric utility SSS calculated according to the methodology presented in Chapter 3 indicate that the DMS can reduce the operation costs of utilities. By capitalizing the applications of the Distribution Management System, it is possible to acquire considerable benefits in outage costs as shown above (Table 3.9., Section 3.6). In this case, the most beneficial DMS applications based on the calculated results are fault location and field crew management. The considered calculations, however, are very sensitive to the quality of initial data analysis and KAH parameter (cost of outage experienced by the customer) usage. The study of DMS benefit evaluation finally capitalizes the expected benefits and requirements identified for the development of advanced DSO models and described previously in the business hierarchy structure in this thesis. As Table 3.5. in Section 3.4 indicates, there is a general competence gap regarding utilization of dynamic transaction benefits within governance analysis within small electric utilities. In a very concrete way this is can be the case within day-to-day operation of DMS. In the worst case the purchase of a DMS can lead to serious financial challenges in electric utilities that fail in capitalizing the expected benefits. The critical value of DMS benefit evaluation is time *t*. However, prior to any DMS capitalization attempts there lie the structuring actions related to unbundling of interrelated functions within the utility. The results show that a DMS is justified for DSO management; however, capabilities for capitalization of benefits are scarce. Moreover, from the viewpoint of the service provider, it is the DMS that shows the potential business market value.

Achievable cost benefits of the use of the DMS applications compared with the required DMS and relay investment costs are presented in the light of the case electric utility's actual feeder amount and hence illustrated in Figure 4.1.

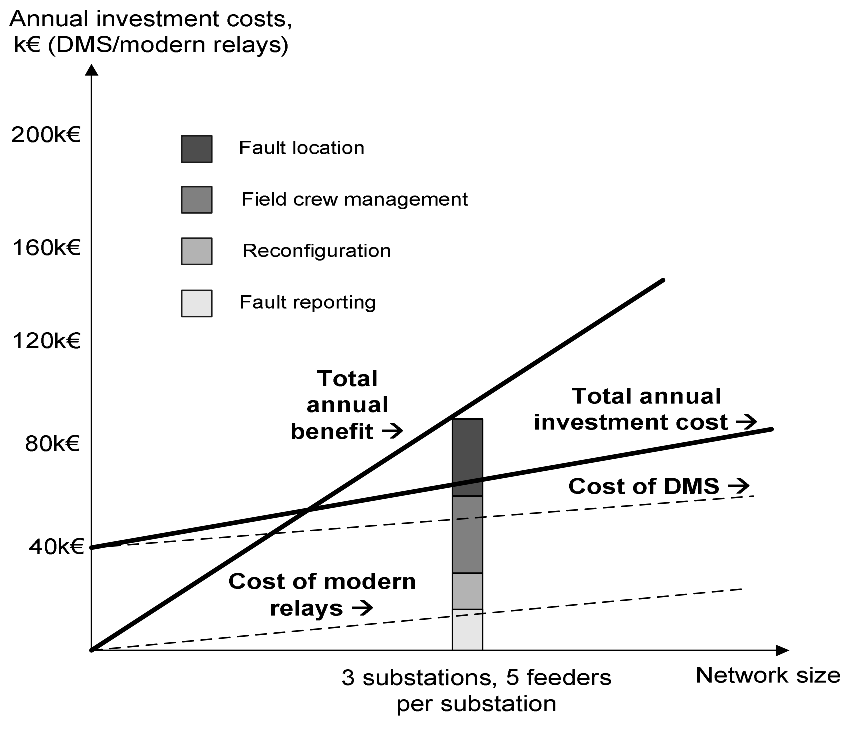

Figure 4.1. Annual investment costs of the DMS and relays in the case electric utility's chosen network section (15 feeders) compared with the benefits achievable from the DMS applications.

Figure 4.1 illustrates a theoretical distribution of DMS-related annual investment costs and their breaking point with the expected maximum level of benefits. The theoretical maximum level of benefits can be modelled to represent different utility cases for example by modifying the amount of automation in the network, which in turn affects SAIDI in each DA and DMS function. Hence, a purchase of a DMS does not automatically trigger an access to the DMS benefits.

The interviews with the case utility SSS imply that DMS is suitable for normal conditions, and the availability of benefits is emphasized in normal situations such as a single fault location and reporting. By contrast, the benefits are currently far more marginal under extreme conditions, such as in the case of major disturbances as significant problems were experienced with fault reporting and fault location applications. According to the case utility SSS, the theoretical cost benefits at the feeder level presented in Fig. 3 are realistic, however, not yet reached. The reasons behind the gap to maximum benefits largely depend on the problems with fault reporting and malfunctioning of fault location in major disturbances. Thus, in a utility where half of the faults are assumed to be caused by major storms, the benefits acquired from the DMS are evidently smaller than the theoretical situation in Fig. 4.1.

Overall theoretical maximum cost benefits viewed in terms of annual OPEX saving in a typical Finnish rural distribution network are presented in Table 4.7. These figures are calculated according to the methodology presented in Table 3.8 for the case electric utility in Chapter 3.

Table 4.7. Summary of the outage-cost-based benefits per DMS application with respect to OPEX and limitations experienced by the case rural electric utility.

DMS application	Saving, %,a, OPEX	Saving, %, a, outage costs
A) Fault location and restoration	4.6	11.5
B) Fault reporting	0.9	2.25
C) Reconfiguration	1.8	4.5
D) Field crew management	2.7	6.75
APPLICATION TOTAL	10	25

Continuing, it is interesting to compare the calculated theoretical DMS cost benefits with other running annual costs in rural utilities operating within similar network conditions. As seen in Fig. 4.2., benefits achievable from DMS applications can be substantial compared both with the present outage costs and operational expenses. Figure 4.2 presents the average value of outage costs (M€,a) during years 2005–2006 and the average value of operational expenses (M€,a) during 2003–2006 in the case company SSS Oy.

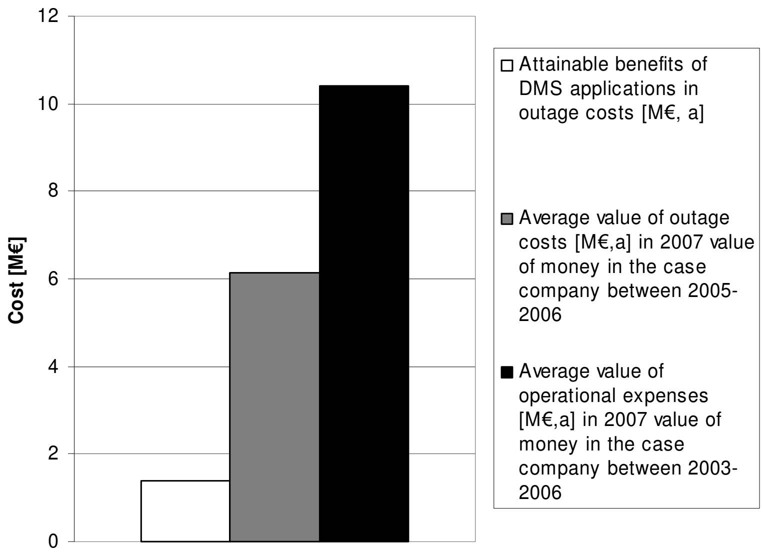

Figure 4.2. Outage costs and operational expenses of Suur-Savon Sähkö (SSS) compared with the benefits achievable from DMS applications.

In the case of SSS, the cost-based benefits achievable from the addressed DMS applications equals roughly 25% of the annual outage costs and 10% of the respective operative costs. As such, the annual measurable theoretical benefits from the use of DMS applications are considerable. The interviews with SSS confirmed that the actual value of capitalized benefits is currently less than 1.4 M€,a mainly owing to the malfunctioning of the applications in major disturbances.

In the light of these calculated considerable yearly OPEX and outage cost savings (Table 4.7 and Figure 4.2) some consideration should be given to the sensitivity analysis of the presented methodology. Firstly, the network parameters specific for each electric utility are very sensitive to calculation results. A theoretical feeder is normally different than that of an actual feeder in the network with respect to the actual structure and power. However, numerically this is challenging to take into account in theoretical calculations. A practical example would be the fact that in short feeders with high powers the outage costs will remain small. A second viewpoint to evaluation of sensitivity includes that of fault frequency. The higher frequency of faults in the network, the higher the possibility of cost savings in the form of DMS benefits.

Finally, also the parameters used for the calculation are sensitive with respect to t_i. In cases where t_i for interruption duration is considerable as in major storms or blackouts, there are also considerable benefits to be achieved and the calculation is thus quite sensitive. In order for DMS benefits to be actually capitalized in these extreme conditions, the proper utilization of application should be ensured. On the other hand, t_i is linear by nature, whereas in cases with short interruption times also the benefits are limited as well as the level of sensitivity.

Distribution utilities that are considering purchase of DMS are encouraged to estimate the achievable DMS benefits according to the presented methodology. On the other hand, distribution utilities with a DMS already in service are encouraged to evaluate the actual benefits especially in field crew management and fault location applications in the hope of possible quick wins.

The interviews of network experts support the obtained theoretical calculated results; however, these maximum levels of cost benefits have not yet been reached in the case utility SSS. Empirical findings from the case utility show further that the DMS is best applicable to normal conditions such as single fault location, whereas in emergency situations, the benefits are only marginal. Moreover, the importance of qualitative indirect benefits such as customer service and occupational safety factors were highlighted as important benefits within distribution management systems in the interviews.

Outage cost parameters as such are defined by the Energy Market Authority, and can thus vary from country to country. However, the methodology presented in this study for outage-cost-based evaluation is generic. Further practical experiences show that the DMS investment size is many times proportional to the actual network size (feeder amount) and the required amount of distributed automation (DA). Thus, also the amount of capitalizable cost benefits from the DMS is proportional. Many studies have previously been published regarding the achievable benefits of DA investments; however, similar benefit analysis results have not been reported for network control system functionalities in the DMS. Hence, this study complements the literature available in the field of DMS analysis.

4.5. Validity of research

By verification of the theoretically obtained cost and benefit results within the outage-related calculation of the DMS applications in Publication VI, the central research paradigm can be characterized as positivistic. Hence, also the repeatability of the research and the assessment of the results are reviewable in the final publication. Based on the statement of the research paradigm being mainly positivistic within the context of the main results, it follows that the level of scientific evidence is reasonable and adequate. The nature of the results in the thesis is reflected by positivistic approaches including empirical material and statistical analysis especially in Publication VI. Thus, the results obtained in the thesis can be considered mean values in the analysed sample material, whereas the results in individual samples (electric utilities) can actually vary from the results obtained. One implication of this examination could be to minimize the amount of identified variation by including several case analyses into the context of the cost and benefit analysis of outage-cost-based DMS functions in Publication VI.

Theoretical results presented in the doctoral thesis have further been validated according to appropriate research methods. The validation on the results have been performed mainly through in-depth interviews with electric utility representatives, electronic surveys and participation of the case electric utilities in writing of the publications. The results from validation have mainly been presented in each publication and briefly in Chapter 3. However, empirical validation on the DMS findings in Section 4.4 and general Section 4.1 have been performed and strengthened with results from an electric utility survey performed by LUT (May, 2010) in the field of network operation. These results have not been presented in any previous publications. The web-based survey with 17 questions was sent to 93 electric utilities in Finland and the response rate was 39%.

Electric utilities were asked questions in areas related to their a) operational environment of NO, b) NO business- and capability-related development strategies and c) DMS utilization and experienced benefits. Figure 4.3 presents the division of utility working environments.

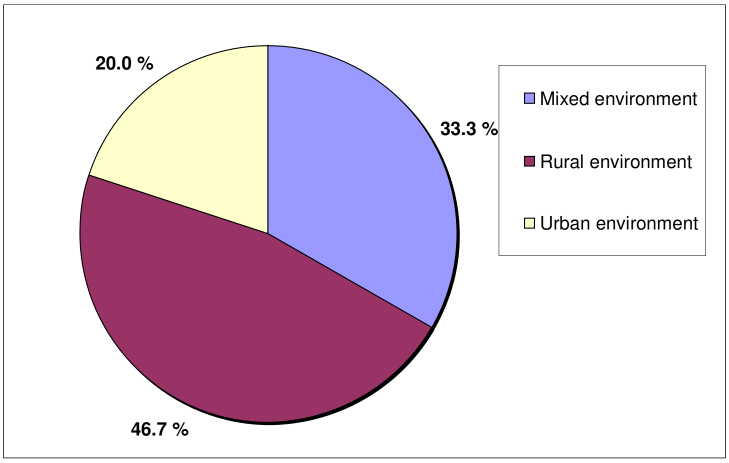

Figure 4.3. Results of the electric utility web survey, operative environment division between responding utilities.

Out of the responding utilities roughly 81% used the DMS within network operation. Among several utilities that used the DMS, the system was viewed as a strategically important tool with large-scale influences on continuous development of efficiency and customer service. Some of these utilities that identified the DMS as an important management tool were about to/had increased the use of new communication channels towards end-customers such as web, sms messages and e-mails within fault management. Furthermore, some results were reported related to the utilization of AMR data from alarms and query data within operation of low-voltage networks.

The DMS was further viewed as an important knot of information to both external and internal interest groups. One specially important internal connection point was that towards network maintenance, as network operation informs the maintenance function of faulty sections by connecting these to the supervised network.

When asked which functionality/functionalities have been found most beneficial within the utility, the one DMS function that was mentioned to some extent in all 27 answers was fault management. More specifically, the fault location and restoration application was interpreted by several utilities as particularly useful. Those DMS users who found DMS beneficial were further asked whether they currently measured the DMS benefits in any way (financially or by other meters). The status of the current DMS benefit measurement within utilities is presented below in Figure 4.4. Hence, the majority of utilities did not currently measure/quantify the

DMS benefits. Other than financial DMS benefit meters were mentioned as measured improved process functionalities (faster fault clearing process, minimized stand-by costs and improved occupational safety).

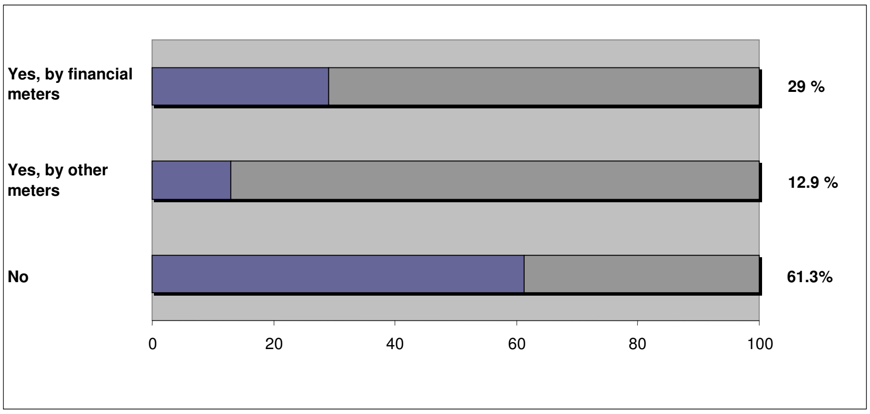

Figure 4.4. Results of the electric utility web survey, measuring of the DMS benefits within utilities.

The electric utilities were further asked how they interpreted their current DMS utilization rate. Results are shown in Figure 4.5. In the responses included in the alternative “Other”, it was evaluated that the current DMS utilization rate was good; however, potential for development still existed. Especially the full-scale utilization of AMR and some challenges with up-to-date information in the low-voltage network were seen as some factors behind the utilization potential.

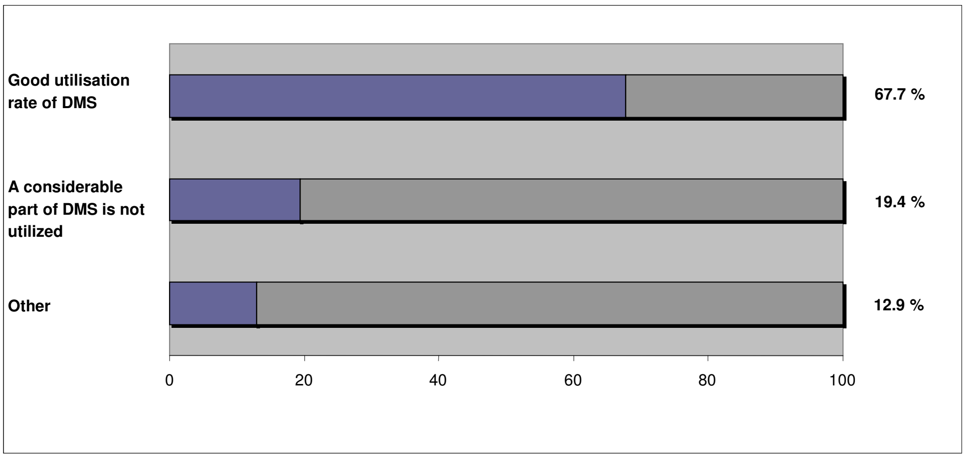

Figure 4.5. Results of the electric utility web survey, DMS utilization rate in utilities.

In utilities where potential still existed for increased DMS utilization, the following main reasons behind the current utilization were that the level of education of the DMS users could be increased, and on the other hand that technical problems existed in the system. Other reasons included challenges with integration towards other systems, DA techniques from many tens of years (compatibility) and the lack of integration between old substations to the customer information system (CIS).

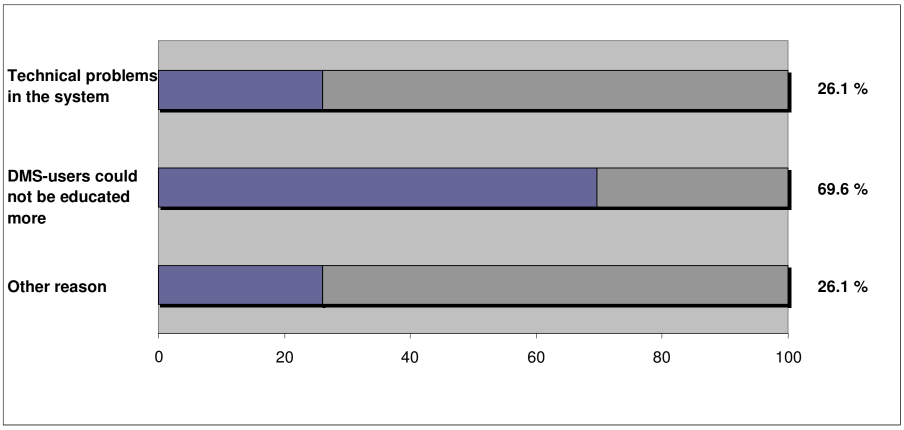

Figure 4.6. Results of the electric utility web survey, reasons behind limited utilization of DMS.

All in all, the empirical results received from the electric utilities seem to be generally in line with those of the theory. However, differences in empirical opinions are considerable among those using the DMS and utilities which do not (yet) apply the DMS.

4.6. Generalizability

The main contributions of the doctoral thesis are well generalizable in supporting developed regulative electricity markets such as in Great Britain and the Nordic countries. Upon the development of regulation to include outage management indices on top of the current OPEX and CAPEX dimensions, the results will be available for the development purposes. However, as available literature is scarce in the area of DA and DMS benefit evaluation, the results of this study will also support development in unregulated utilities. The study will thus be useful for both regulated and unregulated utilities and regulators when decisions regarding investments in DMS and DA need to be made.

As the amount of network intelligence such as remote-controlled disconnectors and switchgear as well as end-customer-based automatically read meters is increasing with a fast pace in the electricity distribution networks, there is a remarkably growing amount of new opportunities how to operate these intelligent distribution networks. New operative working models are required by the management that support the capitalization of the DA investments made, while network operation capability development shall be conscious and long-term in order for electric utilities to benefit from the usage of DMS. Hence, in all electric utilities where electricity distribution networks are strategically modernized, also the chosen network operation model should be revised in order to ensure the fit between realizable quality and cost benefits with the current operative model. This thesis provides a business hierarchy framework for the design and revision of network operation models and should thus prove its place when electricity distribution networks are modernized.

One case electric utility frequently appearing in the validation of practical theoretical results presented in the study was Suur-Savon Sähkö Oy. Suur-Savon Sähkö Oy has a working history experience with LUT, which allows discussion and analysis of sensitive business challenges also. The authors believe that the SSS utility represents a pro-active and market-conscious case of utility reorganization, the empirical results and experiences of which can be widely exploited, because the unbundling process with its challenges is similar inside the distribution business regardless of the country in which the outsourcing is carried out. Nevertheless, experiences from utilities active outside the North European market area can bring different and complementary results.

4.7. Originality

The results of this thesis are founded on the previous scientific grounding and shed new light especially on the operative usability of the method based on extended transaction cost theory in electricity distribution networks. Within the scope of the research presented in this doctoral thesis, four papers have been published in international scientific journals and have thus been subjected to peer review.

Anonymous reviewers in *the International Journal of Energy Sector Management* state that regarding **Publication VI** (Tanskanen et al., 2010), there are very few studies in the area of cost-benefit analysis in rural electricity distribution on the investments incurred on DMS and DA. The reviewer further states the specific study is written in an area where literature needs to be built.

Regarding **Publication III** (Tanskanen et al., 2007) and the study on extended TCE analysis, the study brings not only the transaction costs but also the benefit-side and the dynamic aspects of boundary choices under assessment for evaluation within electricity distribution networks.

4.7.1. Future work

As the preliminary extended TCE results indicate market-related benefits for control room functions, also case practices of external control room models such as BOOT-, external alliances and external outsourcing followed by a theoretical analysis could bring new insight into generalizable processes, and from the theoretical perspective, add to scientific literature. Moreover, the usability evaluation of ongoing electricity distribution network data system integration standardization project TIEKE could be investigated as part of piloting of the control room BOOT model.

In addition, as the research in this doctoral thesis has focused more or less purely on business-to-business-related development challenges driving the changes in network operation models, an end-user friendly approach would in the next phase help to prioritize the identified NO areas of development. Nevertheless, new dimensions and possibilities how to effectively operate the low-voltage distribution network are coming from the end-user perspective as old meters are being changed to automatically read meters giving way to new service concepts for electric utilities. As the amount and use of DA in electricity distribution network continues to grow also in other areas such as remote-controlled disconnectors and circuit breakers, it could be beneficial from the long-term capability development perspective to compare the estimated life cycles of new strategic DA components and their functionalities and match these requirements with competences at hand within network operation.

5. Conclusions

The doctoral thesis addresses alternative network operation models from the DSO's and service provider's perspective within electricity distribution networks in the regulated Nordic electricity market. The research drills down to a techno-economical analysis of the critical application functions within the distribution management system for capitalization of benefits identified in the alternative network operation models. In this thesis, network operation markets are considered to include network operation management, control room application services and blue collar activities in the field. Highly cost- and efficiency-driven network business functions such as network construction and maintenance are today natural service offerings within competitive markets. On the contrary, network operation functions are, due to their unique asset-specific capability-based nature, typically quality-driven.

Unbundling models in the natural monopoly business of network asset management in segmented electric utilities have been evaluated with a special reference to markets for control room application activities. A SWOT analysis from the electric utility and service provider perspectives is performed for the control room application activity.

Within the research structure of the thesis, the fundamental research viewpoints address a) whether there are conditions and qualifications for competitive markets within electricity distribution network operation and b) if so, what are the identified mechanisms, limitations and actions needed for creation of such markets. In the light of literature reviews, benchmarks from resembling industries, empirical surveys and network expert interviews performed according to the methodologies presented in the doctoral thesis, there appears to exist a market demand, primitive market conditions and supporting regulative framework (CAPEX, OPEX, outage costs) for network operation markets within electricity distribution. However, limitations currently challenging the creation of such markets include; a) legislative restrictions as the operating manager has to be in service of the network owner, b) lack of long-term SLA agreements and c) contradictions in pricing of cost and quality factors amongst electric utilities and service providers and d) long-term asset-specific capability development requirement of network operation prior to implementation.

The addressed network operation models include; a) internal centralizing of control room functions, b) external outsourcing of control room functions (incl. SCADA), c) external utility alliances of control room functions and d) external implementation of the DMS BOOT model for control room functions (Build-Own-Operate-Transfer), while the focus in the thesis has been on the external models of c) and d). The identified factors within the research supporting progress in the addressed models include: quality-based target-setting of control room services, risk minimizing for new business models through implementation of a neutral financing model (for example BOOT) and piloting activities primarily with electric utilities operating currently without DMS. According to the DMS benefit evaluations in the thesis, the outage cost calculations propose theoretical maximum benefits of DMS applications equalling roughly 25% of the annual outage costs and 10% of the respective operative costs in the case electric utility. However, such benefits are hard to capitalize without necessary dynamic capability development within the DMS functions. Hence, the results in the thesis suggest that full-scale capitalizing of DMS in the chosen network operation model benefits requires dynamic capability development (market, hierarchy) in the outage-cost related DMS applications. The results further suggest strong process, data system and communication interdependencies among network operation and other network functions such as long-term network development, where unbundling considerations are made. Recommendations are given within the thesis for handling of such strategic interdependencies in internal unbundling activities. Finally, Table 5.1 below summarizes the research outputs for electric utilities.

Table 5.1. Summary of the research outputs for electric utilities.

<table>
<tr><td rowspan="5">Strategy Design of NO</td><td>NO business model hierarchies</td><td>Output</td></tr>
<tr><td>1) External drivers and market analysis</td><td>- identification and prioritizing of the main impacts of external forces on the network's NO strategy</td></tr>
<tr><td>2) Internal capability development within core competences</td><td>-analysis and update of the internal knowledge base strategy for dynamic capability development</td></tr>
<tr><td>3) NO model governance decisions (extended TCE)</td><td>-design and selection of the NO governance model</td></tr>
<tr><td>4) Implications of service provider SWOT</td><td>- partnering considerations including DMS utilization</td></tr>
<tr><td rowspan="2">Strategy implementation of NO</td><td>5) Unbundling of network business activities</td><td>- internal set-up, management and performance KPIs of unbundled NO-related functions</td></tr>
<tr><td>6) Capitalization of DMS functions</td><td>- evaluation of utility-specific magnitudes of DMS for the decision basis of purchase and/or development focuses.</td></tr>
</table>

To conclude, the main contributions of the thesis include

- recommendations for network operation governance models in regulated electricity distribution business, where
  - the results suggest positive indications towards market governance within control room activities for small- and medium-size utilities where dynamic transaction benefits are greater than alternative dynamic management benefits supported by cases where dynamic management costs are higher than transaction costs
  - the analysis is based on an extended transaction cost economics (TCE) analysis, including a proposal for networking-based distribution management system (DMS) Build-Own-Operate-Transfer (BOOT) concept for a control room model
- validation of the usability of the extended TCE theory for the governance analysis of electricity distribution networks
- application of outage-cost- and reliability-indices-based calculation for evaluation and capitalization of the selected DMS applications
- empirical validation of theoretical results both from the electric utility and service provider perspective in the areas of unbundling network activities, performance measurement and DMS benefits.

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