# Architectural Innovation, Functional Emergence and Diversification in Engineering Systems

by

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## Abstract

The evolution of the architecture of long-lived complex socio-technical systems have important consequences and can happen in unexpected ways. This dissertation explores this question through the study of the architectural evolution of Municipal Electric Utilities (MEUs) and their diversification into broadband services in the United States. Our research seeks answers to questions of process (*why and how did this happen?*), impact (*what was the economic effect of this evolution?*), theory (*what is the phenomenon that explains this evolution?*) and method (*how can we study such changes?*).

The number of MEUs offering broadband services increased by more than 200% between 2000 and 2005, which made MEUs one of the most important providers of fiber-based broadband services in the nation. As a result, the entry of MEUs into broadband became a heavily debated policy issue at local, state, and national levels, and many laws were proposed for restricting or broadening their role in broadband. Our research provides the first evidence about the economic impact of this phenomenon for better-informed policy making.

The analysis of the architectural evolution of MEUs required appropriate methods. We integrated the Representation Stage of the Complex Large Interconnected Open Socio-Technical (CLIOS) Process and Object Process Methodology (OPM) under a framework for system architecture analysis, and developed the CLIOS-OPM Integrated Representation Method (COIReM). COIReM's objective is to study the architectural evolution of socio-technical systems. We applied it to the evolution of MEUs using data from case study research, documentation, field research and interviews. We find that the evolution of MEUs and their entry into broadband services resulted from a process we define as Functional Emergence (FE): the process by which a *new externally delivered function* emerges triggered by the combined effect of technical and contextual changes affecting *internal functions* of a complex socio-technical system.

The diversification of MEUs into broadband shows that small technological changes related to the *internal functions* of the system in the presence of regulatory and organizational adaptation, can stimulate the emergence of new *externally delivered* *functions*. Especially in organizations with high absorptive capacity and dynamic capabilities, these new functions can become sources of strategic diversification. The inability to understand these dynamics can create dramatic competitive disadvantages. For example, in this case technical changes created significant resources that, while not being perceived as valuable by the system itself, were greatly valued and demanded by an active local customer base.

The impact of this evolution was studied quantitatively using Matched Sample Estimators. Results showed that: (i) the adoption of IP-enabled services had a positive impact on the internal efficiency of MEUs, (ii) there is no evidence to support the contention advanced in some policy discussions that MEUs are subsidizing their broadband business with funds from their electric power operations, and (iii) MEU-based broadband is associated with higher growth rates in the number of local business establishments, even after adjusting for the presence of private broadband providers.

These qualitative and quantitative results have important implications for policy making. We argue that the entry of MEU into broadband owes more to their nature as an electric utility than as a municipal agency. We suggest that, as result of the economies of scope between electric power and broadband services, MEUs represent a case of sustainable broadband facilities-based providers and that, given the effects in internal efficiency and local economic development, they should be exempted from state legislation preventing local governments from offering telecommunication services.

This research makes four main contributions. First, it uncovers a new behavior of complex technological systems: small technological and contextual changes affecting internal components and functions can produce the emergence of new external functions. Second, we propose a new framework to study the architectural evolution of socio-technical systems. Third, it provided evidence that, in the case of MEUs, this behavior is observable and measurable. Finally, the thesis provides a framework with which to formulate intervening policy measures.

**Thesis Committee Chair: Professor Joseph M. Sussman**

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*To Magdalena,*

*for your love, endurance and unconditional support*

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# Table of Contents

# Glossary of Terms:

| | | |
|---|---|---|
| ACGE | : | Administration Costs and General Expenditures |
| AMR | : | Automatic Meter Reading |
| APPA | : | American Public Power Association |
| ATM | : | Asynchronous Transfer Mode |
| CLIOS | : | Complex Large Interconnected Open Socio-Technical |
| COIReM | : | CLIOS-OPM Integrated Representation Method |
| CPE | : | Customer Premise Equipment |
| CSSI | : | Customer Service, Support and Information |
| DOE | : | U.S. Department of Energy |
| DSL | : | Digital Subscriber Line |
| D-EDF | : | Designed Externally Delivered Function |
| EDF | : | Externally Delivered Function |
| E-EDF | : | Emerged Externally Delivered Function |
| EIA | : | Energy Information Administration |
| EPRI | : | Electric Power Research Institute |
| FCC | : | U.S. Federal Communications Commission |
| FERC | : | U.S. Federal Energy Regulatory Commission |
| FTTP | : | Fiber-To-The-Premises |

HFC : Hybrid-Fiber Coaxial

IOU : Investor-Owned Utility

MEU : Municipal Electric Utility

MSE : Matched Sample Estimators

NARUC : National Association of Regulatory Utility Commissioners

NATOA : National Association of Telecommunications Officers and Advisors

NERC : North American Electric Reliability Council

OLT : Optical Line Terminals

ONT : Optical Network Terminal

OPN : Outside Plant Network

OPM : Object Process Methodology

PSTN : Public Switched Telephone Network

PUC : Public Utility Commission

RCT : Randomized Control Trial

SCADA : Supervisory Control and Data Acquisition

TCP/IP : Transmission Control Protocol/Internet Protocol

USPS : U.S. Postal Service

USTA : United States Telecom Association

WDM : Wavelength Division Multiplexing

ZCTA : Zip Code Tabulation Area

# Chapter 1: Introduction

The availability of broadband is a vital component of national competitiveness in a globalizing economy. The relative scarcity of this resource is an increasing problem for the United States as it continues to fall behind other developed countries. In this context, an increasing number of electric utilities owned by local governments have become broadband providers, bringing affordable broadband to suburban and rural areas. This trend has brought immediate market, legal, and public relations responses from telecommunications providers and prohibitions from state legislatures.

This dissertation studies the causes, processes, and effects of the architectural evolution of Municipal Electric Utilities (MEUs) and their diversification into providing external broadband services. In this context, this research answers two substantive questions: (i) why and how did this happen? and (ii) what has been the economic effect on localities?

In addition to describing this process and illuminating the impacts of this evolution, the search for answers to these questions reveals two counterintuitive trends, one regarding the technology choices within the utilities and response of other entities, and one regarding the entry and leadership of local governments in increasingly market-driven services. The implications of the data analysis developed in this project are significant in thinking about the future of telecommunications.

In addition, the dissertation makes two theoretical contributions: First, it demonstrates the effectiveness of a new approach to thinking about such systems that brings together robust qualitative and quantitative analytic methods. The research undertaken here required the integration of two pre-existing research methodologies, the Complex Large Interconnected Open Socio-Technical (CLIOS) Process and Object

Process Methodology (OPM), into a third approach, which we are calling the CLIOS-OPM Integrated Representation Method (COIReM).

Second, this study extends the definition of "Functional Emergence" and proposes it as a property of socio-technical systems, borrowing a term from neurosciences and artificial intelligence. Here, functional emergence refers to the way in which new externally delivered functions are forged from internal functions in the crucible of the technical, social, and regulatory changes affecting a socio-technical system. In the case of MEUs, regulatory changes induced the replacement and upgrade of components required to control and monitor electric power systems. The technical changes in the new generations of these components enabled organizational learning and adaptation within MEUs triggering the emergence of their broadband services.

## *1.1 The entry of municipal electric utilities into telecommunications*

Experts predicted that large investor-owned utilities (IOUs) would become the third entrant into telecommunications, after telephone companies and cable television providers. Contrary to expectations, the major entrants were small municipally-owned utilities which stepped in to fill the void in localities lacking sufficient services. Furthermore, the forecast was that, if this happened, electric utilities would deploy communications services over their existing power line networks, using Power Line Communications (PLC) technology. However, the MEUs who first entered the broadband market did so using newly adopted fiber-optic networks. This technology option, common among telecommunications providers, is known for being expensive and highly complicated to deploy, requiring very sophisticated technical knowledge. This study explains the reasons MEUs chose this technology, and demonstrates the factors in their successful deployment of wired and wireless services over local fiber optic backbones.

### 1.1.1 Historical Background

Municipal electric utilities were created early in the development of the electric power industry as local governments responded to the increasing need for electricity. Demand for public lighting outside large urban areas had begun to exceed supply, at that time controlled by the private sector.

In 1882 there were only four municipal electric systems in the United States (Vennard 1968). Meanwhile, in the following decade the number of privately owned central electric stations increased to more than 2000; by 1902, there were more than 3,600 private utilities. The number of municipal electrics also grew, reaching 847 the same year (Vennard 1968; Chung 1997; Granovetter and McGuire 1998).

Despite this growth, by 1930 less than 12% of rural areas had access to electric power. MEUs were developed to fill this vacuum; by 1932 1,863 MEUs--a large proportion of those currently in operation—had been established. In 1935, President Franklin Delano Roosevelt established the Rural Electrification Administration, a pillar of the New Deal, which brought power to 1.5 million farms in its first two years.

Since then, the evolution of electric utilities has been driven first, by current and future expectations for load demand, and second, by limitations imposed by policies and previous decisions about each electric utility (Rustebakke 1983), which is known as the "legacy of the architecture" (Crawley and Weigel 2004). These expectations and limitations, plus the technical evolution of electric utilities, provided the basis for the architecture and components of current grids. Built between 1950 and 1970 (CIGRE 2000), these grids represent the dominant design of today's utilities (Hughes 1983).

As electric power gained importance and became a general purpose technology, the demand and operating context of private and public electric utilities also broadened, and command and control functions became critical. One of the latest changes in the architecture of electric utilities was the adoption of Supervisory Control and Data Acquisition (SCADA) and Automatic Meter Reading (AMR). These technologies enhanced a system's command and control capabilities, and increased the robustness and reliability of the grid. MEUs first implemented SCADA and AMR using twisted-pair telephone lines during the late 1970s and early 1980s (Tamarkin 1992).

For MEUs, these investments became an important architectural basis for the deployment of external broadband services during the late 1990s. As the infrastructure used by many electric utilities for operating SCADA and AMR began to decay (around 1995), many municipal electric utilities began to consider options for replacing it with assets that would last for the next 20 to 40 years.

By the end of 2005, 446 MEUs had deployed SCADA, 305 had AMR, and 272 had deployed communications within their respective municipal governments. Interestingly, by the same time, 665 MEUs were also offering some type of external advanced telecommunication services, and 260 of them were offering external high-speed Internet access.

This dissertation studies why and how this happened, and outlines the economic effect of this evolution on the efficiency of the internal operations of MEUs, and on the economic development of the markets they serve.

### 1.1.2 Why is this Relevant?

As they are electric power agencies, the entry of MEUs into broadband services by using fiber optic networks was unexpected. Experts anticipated that large investor-owned electric utilities (IOUs) would become the third facilities-based telecommunications provider. Contrary to those expectations, we see an extensive number of small municipally-owned utilities entering telecommunications and a relative absence of IOUs. Experts also predicted that electric utilities would enter telecommunications by leveraging the economies of scope of their already available power line networks through the use of Power Line Communications (PLC) technology. Instead they deployed new fiber optic network backbones.

The policy debate has become highly polarized, and it has been based on limited or anecdotal evidence about the positive or negative effects of broadband services deployed by MEUs. No empirical study has been conducted to test the hypothesis that IP-enabled solutions for command and control is associated with positive effects on the internal efficiency of MEUs. No empirical analysis has tested whether broadband deployed by MEUs is associated with positive effect on the local economy. Finally, there has been no empirical examination of the hypothesis that MEUs cross-subsidize their broadband operations with revenues from their electric power services, allowing them to underprice private broadband providers.

Since the enactment of the Telecommunications Act of 1996, the telecommunications sector has become increasingly market-driven. However, the deployment of broadband services by municipalities in general, and MEUs in particular, is an example of local government action. More specifically, the entry of MEUs in broadband services is relevant from the perspective of local government involvement in private business in general, and broadband Internet access in particular, for two reasons: (i) it presents a case of increasing public ownership of telecommunications infrastructure, in times when the tendency is towards privatization and market-orientation, and (ii) it illustrates a case in which an important fraction of the innovators in deployment of next generation broadband access technology is comprised of public agencies instead of private companies.

The involvement of MEUs in broadband shows that local government agencies are capable of being innovators in deploying new-generation telecommunications infrastructure: Broadband delivered by municipalities represent 32% of all homes served by fiber-to-the-home in the United States, and MEUs represent most of this share (Gillett 2004).

MEU-based broadband is a special case of municipal broadband, in which new high speed Internet services are deployed by the electric utility owned by the local government, instead of by a new department.

Recent research has linked the deployment of external telecommunication services by MEUs to their adoption of new technologies for Supervisory Control and Data Acquisition (SCADA) and Automatic Meter Reading (AMR) (Osorio 2004; Gillett, Lehr et al. 2006). This research established the existence of a relationship, but did not explain its nature. Our research fills this gap.

The positive relationship between the deployment of broadband by municipal electric utilities and economic development may appear intuitively true, but it has its subtleties. The existence of this relationship is being heavily contested in policy forums, largely in discussions based on anecdotal evidence or limited analysis[1]. This study is the first investigation that studies this relationship using econometric methods and place-level data from MEUs from the continental United States.

This research contributes to the understanding of an additional policy controversy. Besides the economic effects of the entry of MEU into broadband, its opponents have argued that MEUs undercut private competition by supporting broadband operations with revenue generated from their electric business. Our research provides the first empirical analysis testing this hypothesis.

### *1.2 Approach: research questions, hypotheses, and methods*

The entry of electric utilities into the broadband business provides a case study of the evolution of socio-technical systems. It is a special case of a more general phenomenon: the architectural evolution of socio-technical systems that can lead to diversification into new types of services. This research is relevant from the perspective of socio-technical systems in general, and engineering systems in particular, because it is a case of gradual and unforeseen evolution and adaptation in one sector (electric power) created by technical changes in another (telecommunications).

There are two complementary approaches to studying the process and effects of the architectural evolution of MEUs and their diversification into advanced telecommunication services. The first research question is about the process of architectural evolution. To answer it, we develop and use a qualitative approach to

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[1] Ford and Koutsky (2005) presented a more limited study focused on the effect of municipal broadband on sales across ten counties in the state of Florida, and Burton and Hicks (2005) analyze its benefits in Central Appalachia.

explore why and how MEUs became broadband providers. The second question focuses on the economic effects of this evolution. To explore this issue, we use a quantitative approach to assess the impact of deploying new generation SCADA and AMR on MEUs' internal efficiency, and the impact on local economies when MEUs become broadband providers. The methods are summarized below and addressed more comprehensively in Chapter 3.

### 1.2.1 Methods for Qualitative Research: analyzing the process of evolution

There are two underlying questions for qualitative research: (i) why did MEUs became broadband providers?, and (ii) how did this happened? We present three hypotheses:

1. Changes in technology and regulatory context triggered the adoption of IP-enabled solutions for controlling and monitoring electric power systems, which created important endowments of data transmission capacity that exhibited economies of scope for advanced communication services,
2. The adoption, and later operation and deployment of the new technology allowed organizational learning and adaptation within MEUs that created capacities for offering communication services, and
3. As MEU managers identified the need for local provision of broadband services in rural and suburban areas, they decided to take advantage of the community-owned surplus of the new resource (bandwidth) and start offering broadband services.

We test these hypotheses by studying the evolution of the architecture of MEUs. Our qualitative research is based on the theory of system architecture. The information analyzed was derived from case studies of three MEUs selected. To compare and find common elements among them, we developed a hybrid methodology, COIReM mentioned above, based on an integration of the CLIOS Process and OPM.

#### 1.2.1.1 Theory of System Architecture

We define a system's architecture as the way in which a "concept" maps a systems' "form" onto its "function", a definition proposed by Crawley and Weigel (2004). "Function" refers to the visible external function of a system, also called its externally delivered function (EDF). In the case of MEUs, their "designed" EDF is the provision of electric power.

The evolution of MEUs and their diversification into telecommunication services is a case of architectural evolution, but most of all, of architectural innovation. Architectural evolution results from changes to the form, function and/or concept of a system's architecture. Architectural innovation is defined as "*the reconfiguration of a new system to link together existing components in a new way*" that are often "*triggered by changes in a component*", while the overall concept of the system remains unchanged (Henderson and Clark 1990). Architectural innovations are created by a special type of architectural evolution that, by its nature, can have important competitive effects such as, in our case, the entry of MEU's into telecommunications. Building on Henderson and Clark, we suggest here that architectural innovations can be triggered not only by technical, but also by social, organizational, or contextual changes.

The theory of system architecture provides a general framework for understanding several influences on the concept, form, and function of MEUs.

#### 1.2.1.2 Case Studies

Data that would reveal the critical factors in the architecture of MEUs were derived from detailed case studies of three MEUs. Case study research provides a way to examine and collect data and information about the evolution of the technology and organizations by direct observation in the field and by examining data from interviews, documentation, and archival records. As a method, it is a especially relevant for understanding the *why* and *how* of a phenomenon (Yin 1984). In this dissertation, the case studies of three municipal electric utilities: Braintree Electric & Light Department (BELD), in Braintree, MA; Hometown Utilicom, in Kutztown, PA; and Owensboro Municipal Utility (OMU) in Owensboro, KY. They were chosen based on (i) when they deployed new generation technology for their internal operations, (ii) the type of technology chosen for offering external broadband services, (iii) when they deployed external broadband services, and (iv) their overall socio-economic context.

#### 1.2.1.3 COIReM: a new qualitative method for studying architectural evolution

In this dissertation we examine the architectural evolution of MEUs by applying a new method, the CLIOSP-OPM Integrated Representation Method (COIReM)--to the case-study data. This approach integrates two methods: The Representation Stage of the Complex Large Interconnected Open Socio-Technical (CLIOS) Process (Dodder, Sussman et al. 2005) and Object Process Methodology (OPM) (Dori 2002).

The CLIOS Process was developed to study "a system's underlying structure and behavior, identifying strategic options for improving the system's performance, and deploying and monitoring those strategic options."(Dodder, Sussman et al. 2005). OPM was developed to study and design product and system engineering.

Chapter 3 details the way in which the strong points of these two approaches were combined to produce COIReM, explains the rationale behind COIReM, and presents its application to our research problem.

COIReM enables us to understand the architectural evolution of MEUs as a CLIOS System. The objective is to discover how the concept, form, and externally delivered function of its subsystems were affected from three perspectives: (i) the physical infrastructure, (ii) the organization, and (iii) the institutional context.

Understanding why and how MEUs became broadband providers still leaves the question about the economic effects of such evolution.

### 1.2.2 Methods for Quantitative Research: studying the effects of architectural innovation

The overall research question here is: What has been the economic effect of the evolution of MEUs into broadband providers? More specifically: How has it affected the MEUs internally, and how has it affected the communities they serve? The answers to these questions might seem intuitive, but there are various reasons why they are not. We discuss them in the literature review in Chapter 2 and on our econometric results in Chapter 5. A derivative question of particular interest to policy makers whether MEUs cross-subsidize their broadband operations with revenues from their electric power services. This is relevant because, by doing it, MEUs could underprice private broadband providers driving them out of business.

We hypothesize that the adoption of IP-enabled SCADA and AMR solutions enhances the internal efficiency of the electrical operations provided by MEUs. We test this "Internal Efficiency Hypothesis" by examining the effects of these IT solutions on (i) price; (ii) consumer service, sales, and information cost; and (iii) administrative costs and general expenses per MWh. Each MEU analyzed had the systems in place by 2000; the effects are measured for 2003. MEU officials claim that fiber optic network infrastructure was first deployed to operate IP-enabled SCADA and AMR. This analysis examines whether such investments have had any effect on the electric power systems. We also test the hypothesis that MEUs do cross-subsidize their broadband operations using revenues from their electric power services. This is the Cross-Subsidy Hypothesis.

The last hypothesis is that towns in which MEUs have deployed external broadband services will exhibit higher levels of local economic development than similar towns with no MEU-based broadband. As explained in section 1.4, this relationship has not been confirmed in prior research; we test this "Local Economic Development

Hypothesis"[2] by analyzing the (i) growth rate of local business establishments, (ii) growth rate of employment, (iii) growth rate of average salaries between 2000 and 2002, and (iv) share of local business establishments in IT-intensive sector by 2002.

In a perfect world, these questions could be answered by selecting a population, or a representative sample, and randomly assigning a "treatment" to a part of it (the *treatment group*). This method, common in medicine and biological science, is known as randomized control trial (RCT). In the case of this dissertation, the "treatments" are (i) the deployment of IP-enabled SCADA and AMR (to test the Internal Efficiency Hypothesis) and (ii) the deployment of external broadband (to test the Local Economic Development Hypothesis).

The test groups would be probabilistically similar with one exception: The *treatment grou*p would adopt or deploy the technologies. The *control group* would not. We could ascertain the average effect of the treatments by analyzing the difference in a defined outcome variable between the treatment and control groups. For the Internal Efficiency Hypothesis, the outcome variables are measures of internal efficiency (e.g. price per MWh[3]), while for the Local Economic Development Hypothesis are measures for economic growth (e.g. rate of growth of local business establishments).

This type of experiment is impossible to implement when the units of observations are large engineering systems and the treatments are expensive technology deployments. The reason is simple. Carrying out such experiments would require for MEUs in the treatment group (i) to adopt IP-enabled SCADA and AMR to test the Internal Efficiency Hypothesis, and (ii) to deploy external broadband networks to test the Local Economic Development Hypothesis. The time and costs associated with the implementation and possible effects of either experiment would be prohibitive.

However, another method is available. Matched Sample Estimators (MSE), developed by Abadie, Drukker, Herr and Imbens (2001) emulates randomized control trial in everything except the randomly assigned treatments. In a population or sample, MSE takes every treatment observation and pairs it with an observation of a case most closely matched in all other variables from the untreated group (control observation). Then, MSE calculates the difference in the outcome variable between treatment and control groups to reveal the average effect of the treatment.

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[2] The econometric analysis of the relationship between deploying internal services and becoming a provider of external telecommunication services, and the effect of the presence of private telecommunication providers, is studied in Gillett, Lehr and Osorio (2006).

[3] MWh is the abbreviation for Megawatt hour.

## *1.3 Results from Qualitative Research: why and how did this happen?*

This dissertation answers the qualitative questions of why and how municipal electric utilities became broadband providers by (i) stating our hypotheses for why and how this happened (stated in Section 1.2.1), and (ii) iteratively applying COIReM to test these hypotheses. Four explanations for these phenomena emerged:

i. *Internal technical needs caused MEUs to adopt fiber optic technology.*

Municipal electric utilities reached the beginning of the 21st century with infrastructure for monitoring and control that either needed replacement or did not exist. In the cases where MEUs had traditional SCADA and AMR, their infrastructure had reached the end of its design life or was plagued by reliability problems. Competitive pressures created by new regulatory settings, the liberalization of the electric power industry, and the reliability problems of the National Grid further stimulated the need for SCADA and AMR. It was time to replace the existing infrastructure.

However, technical changes in the information technology sector had greatly advanced the critical components of SCADA and AMR solutions the electric power networks required for their operations. In the late nineties, MEUs made the transition from traditional solutions working over dedicated communication channels to new IP-enabled control and monitoring systems working over fiber optic networks. By adopting this infrastructure MEUs acquired a new resource --bandwidth-- in excess of their needs, and valuable for telecommunication services. The upgraded infrastructure created possibilities for MEUs beyond the electric power business. Interviews and examination of meeting minutes reveal that among first-adopters, MEU executives were not aware ex-ante that the internal technical changes would open the way to a new business for MEUs in telecommunication services.

ii. *The culture of MEUs included long-range financial perspectives and a major concern with efficiency.*

At first, MEUs did not adopt new technology with the intent to become broadband providers, but to enhance both the reliability of their electric operations and, as shown in Section 1.5 and chapters 4 and 5, their internal efficiency. While some might question the decision to deploy complex and costly fiber optic networks merely to operate SCADA and AMR, the choice can be easily understood by considering the *electric utility mentality*.

Reliability has always been a major driver in the electric power industry, and IP-enabled SCADA and AMR and fiber optics can deliver it. These IP-enabled solutions provide the real-time and remote control, monitoring, and response needed to prevent failures in network elements including those on customer premises. The old systems, however, focused mainly on failure alert. Furthermore, fiber optic cables are not affected by electromagnetic and radio frequency interference and are now as durable as copper wires.

Fiber optic cables are also the kind of long-lived assets, lasting 20-40 years, in which electric utilities traditional invest and amortize accordingly. This is a far different investment horizon and rationale than those of private telecommunication firms, which require higher discount rates and nearer investment horizons.

*iii. MEU personnel had the capacity to absorb knowledge and learn about fiber optic technology and see its possibilities.*

MEU employees had the basic knowledge to learn how to operate these new technologies not only for their own benefit but for third parties as well. They were able to absorb the new knowledge, understand its implications, and adapt their capabilities accordingly. In some cases, their linemen became proficient in splicing and deploying fiber optic cables, while in others some technology-savvy members of their labor force got engaged in the deployment and operation of the new systems. As time passed by, MEUs realized the range of possibilities available through the new infrastructure, and began to deploy services to other local government agencies. At that point, the MEUs became de facto broadband providers.

*iv. Communities in which some MEUs operated had demand for broadband services that could be supplied by excess capacity of the new fiber optic systems.*

The decision to diversify into telecommunications arose from a two- or three-year process in which local people and businesses, elected officials, and MEU management and personnel continually discussed the funding, opportunities, and limitations of such investments. In the beginning they focused on investments in new infrastructure needed for electric utility operations. Later, the focus broadened to include other potential applications of such investments. They recognized that the infrastructure had spare bandwidth capacity that could be used to meet the growing demand of residents and businesses for high-speed Internet access.

### *1.4 Results from Quantitative Research: what difference does it make?*

The three hypotheses about the effects of the evolutionary process described in Section 1.2.2 can be addressed through quantitative means: (i) What difference does the adoption of IP-enabled solutions for systems control make for the internal efficiency of MEUs? (ii) Do MEUs cross-subsidize between their electric power and business operations, getting an unfair competitive advantage as compared to private broadband providers? And (iii) What difference does it make for a local economy if an MEU becomes a broadband provider? Chapter 5 presents detailed answers to these questions, which are summarized below.

Assessing the effect of the new system on internal efficiency requires comparing groups of MEUs that are similar in many dimensions, with the exception of the adoption of the new IP-enabled SCADA and AMR. By the same token, assessing the effect of MEU-based broadband on the local economy requires comparison among towns that are similar in many dimensions, with exception of the availability of MEU-based broadband.

We answer these questions by using Matched Sample Estimator (MSE), which was summarized in section 1.2.2 and is described in detail in Section 5.1. MSE is a quasi-experimental method developed by Abadie, Drukker, Herr and Imbens (2001). It emulates randomized control trial in everything, except the random assignation of treatments. It takes every treatment observation and pairs it with the observation of the control groups that most closely matches it across a group of observed variables. Then, MSE calculates the difference in the outcome variable between treatment and control groups to reveal the average effect of the treatment. MSE is the closest option to performing randomized control trial, which is known as the optimal approach to be used in cases like ours.

i. *Internal Efficiency Hypothesis: adopting IP-enabled solutions enhances MEU efficiency*

The analysis of the Internal Efficiency Hypothesis evaluates the merits of the initial motivations for deploying IP-enabled communication networks in MEUs. This research is the first work assessing the impact of such deployments on the efficiency of the provision of electric power by municipally-owned electric utilities.

Our findings support the fact that the adoption of IP-enabled SCADA and AMR enhances the efficiency of MEUs. We found that MEUs adopting the new technology exhibit lower customer service, sales information costs, and are able to offer lower electric power prices than non-adopter MEUs. We conclude, in brief that in regard to the internal efficiency hypotheses, MEUs that adopted the new IT-bases systems for internal control and monitoring exhibit higher efficiency than non-adopters. Chapter 5 presents and discusses these results in more detail.

ii. *Cross-Subsidies Hypothesis: no evidence of subsidies from electric power to broadband*

As a subsidiary point, we also examined the hypothesis that MEU subsidize their broadband operations with funds from their electric power operations. This is important because, if MEUs were subsidizing their broadband operations with funds from their electric power business, then they would be able to offer prices that would be artificially lower and thus drive private providers out of the market.

We tested whether deploying external broadband by MEUs with IP-enabled command and control systems was associated with effects on the price or cost of their electric power services. Everything else being equal, an increase in the price per unit of electric power following deployment of broadband services would indicate that MEUs were subsidizing their communication services with resources from their electric power businesses.

Based on our results, we found no evidence to support this hypothesis. Analysis of the cross-subsidy hypothesis demonstrated no statistically significant evidence of cross-subsidies, refuting the idea that about cross-subsidies from electric power to communication services in MEUs.

*iii. Local Economic Development Hypothesis:*

The relationship between the deployment of broadband by MEUs and local economic development is far from obvious. Discussion has been based mostly on anecdotal evidence and limited regional analysis. This research presents the first empirical analysis of the hypothesis that broadband deployed by municipal electric utilities *positively* affects local economic development using nation-wide data.

Some have argued that "*the connection between municipal broadband and economic growth has never been demonstrated and probably never will be*" (Bast 2005). Others have argued that municipal broadband systems can create "*a dramatic increase in economic growth*" (Ford and Koutsky 2005). These arguments are discussed in Chapter 5.

In relation to the hypothesis regarding local economic development, our research showed that MEU deployment of broadband was associated with an increase in the growth rate of local businesses, whether or not broadband was also available from private providers. However, we found no statistically significant effect from broadband deployment of MEUs on the growth rate in average salaries and employment or on growth in the share of business establishments in IT-intensive sectors.

## *1.5 Policy Implications*

The importance of broadband for US competitiveness and economic development has been a topic of increasingly active debates in policy, industry, and academic forums. A number of critics have pointed out that the United States has ceded its leadership on the deployment, innovation, quality of service of broadband to Asian nations (Bleha 2005; Forbes 2005; Weiser and Bleha 2005). In his 2004 presidential campaign, President George W. Bush declared universal broadband access to be a major national goal (Squeo 2004; Trembly 2004; Fein 2005):

> *"[t]his country needs a national goal for…universal, affordable access for broadband technology by 2007" (Squeo 2004)*

In this context, the opportunities created by the architectural evolution of MEUs appear to be promising and oriented in the right direction.

Reality shows, however, that these opportunities are at risk. The number of states prohibiting municipal entry into telecommunications is increasing. Fourteen states have adopted barriers to the entry of municipal entities into some, or all, types of telecommunication services by 2006[4]. These laws appear to emanate from pressure on legislators from existing telecommunications companies rather than from carefully planned state-level telecommunication policy for increasing competition or innovation.

For instance, Hometown Utilicom (HU) of Kutztown, PA, was awarded the 2003 Governor's Award for Local Economic Excellence in the category of Information Technology in recognition for their deployment of local broadband services[5]. The award sent a message to other local governments that Kutztown was an example to be emulated.

About a year later, however, the state sent a totally contrary message, passing a law prohibiting any local government or other political subdivision of the state from providing advanced telecommunication services unless no private company was currently or had the intention of providing services for the following 14 months. This legislation followed a negotiated settlement between Verizon and the Wireless Philadelphia Project, according to Dianah Neff, Chief Information Officer for the City of Philadelphia (Fisher 2005).

The opportunities created by the architectural evolution of MEUs are also at risk because of the underlying assumption that MEUs cross-subsidize their broadband services with electric power operations. This assumption is used to create public policy that would eliminate the opportunity for electric utilities in general, and MEUs in

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[4] Arkansas, Florida, Missouri, Minnesota, Nebraska, Nevada, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, Washington, and Wisconsin.

[5] Letter from Dennis Yablonsky, Secretary Designee, Department of Community and Economic Development, Commonwealth of Pennsylvania, to Frank Caruso, Director of Information Technology, Hometown Utilicom, dated February 14, 2003.

particular, to cross-subsidize. This can be done in by requiring them to comply with financial and accounting regulatory procedures that would ensure that no cross-subsidy is done. Also, legislation can simply prohibit MEUs from entering the broadband market.

Our analysis shows no evidence of cross-subsidies from electric power rates, or costs, to telecommunications services. It also demonstrates that the electric power prices of IP-enabled MEUs that provide external broadband are statistically the same as those of MEUs not providing broadband.

This research underscores the position that regulatory approaches to telecommunications and electric power are limiting the application of technology-based economies of scope that could increase local government efficiency, enhance economic growth, and foster competition in the telecommunications market. A stated national goal for the United States is to build much-needed broadband infrastructure and provide affordable broadband access by 2007. Public policy in regard to MEU-provided broadband, however, has focused excessively on issues of telecommunication competition. The future for municipal broadband thus remains unclear.

Information and communication technologies (ICT) have reached a point where the convergence between telephony, cable television and data transmission is just another example of convergence among network services. The course of these convergences seems to predict an even more drastic convergence among different types of network services.

As ICT becomes ubiquitous, the cost and difficulty of deployment and operation are decreasing and their data transmission capacity is increasing. As the use of ICT for general purposes increase, knowledge that once belonged only to experts is becoming basic technical knowledge in all organizations that deploy and manage their own network infrastructures.

The implications of this research show how important is to (a) understand how technical changes needs to be reflected in new public policy; (b) recognize when these policies need to be changed and updated, and (c) design public policies with an understanding of how technical change could affect them in the future. If these issues are not addressed, the opportunities created by the architectural evolution of MEUs will not be the only ones at risk, because similar arguments could be used to prevent other players from entering broadband services.

## *1.6 Contributions to Theory*

Two contributions to theory have emerged through the research process of this dissertation: (i) the development of the CLIOSP-OPM Integrated Representation Method (COIReM) for representing socio-technical systems, and (ii) the identification and definition of Functional Emergence.

### 1.6.1 CLIOSP-OPM Integrated Representation Method (COIReM)

The qualitative research tool COIReM illuminated the various dimensions of the technical system, and its relationship with its organizational setting and outer institutional sphere. The Representation Phase of the CLIOS Process and OPM were, in the judgment of the author, the two most appropriate existing options for representing the systems. They provided a basis for a new process, COIReM, which took advantage of their complementary strengths and offset their individual limitations. The new derivative combination allowed better outcomes than could be obtained by using either separately.

COIReM is a method to achieve deep understanding of a system's architecture and the many influences affecting its physical and functional components. It dissects the system and its institutional sphere, revealing its structure and the relationships among elements and functions at a specific hierarchical level of disaggregation. The level of disaggregation described through COIReM provides information sufficient to meet a researcher's needs. More analytical depth could obscure the picture; too little would not provide enough insight about critical issues.

In this dissertation, COIReM has been used only to represent and study one complex system. The method has not been tested for system design or the implementation of changes. The extent to which COIReM could expand to include the remaining stages of CLIOS Process is left for further research.

CLIOS and OPM: Strengths and Limitations

CLIOS System Representation is the first stage of the CLIOS Process developed by Dodder, McConnell, Mostashari, Sgouridis, and Sussman (2006) of the Massachusetts Institute of Technology.

For the purpose of this research, the major strengths of the Representation Stage of the CLIOS Process (CLIOSP-RS) are (i) its explicit consideration of the physical and institutional domains of socio-technical systems, (ii) the fact that the physical domain includes, besides the technical subsystem of the CLIOS System, other subsystems that explain the broader context in which technology is embedded (e.g. economic activity subsystem, and municipal subsystem), and (iii) different types of links and definitions of common drivers[6] that make it possible to identify the relationships among physical components and between each of them and the organizations on the institutional sphere.

For studying the architectural evolution of MEUs, CLIOS System Representation had two main limitations. First, CLIOS-SR has no way to represent functions or processes and, second, provides no explicit way to define the hierarchy of components.

The second approach, OPM, is a methodology used in product design and engineering developed by Dov Dori (2002) of Technion. In OPM, a system is defined as an object that exhibits function, where the function is "the main intent for which was built, the purpose for which it exists, the goal it serves" (Dori 2002: 251). Under OPM, both the object and function can be decomposed hierarchically in a well defined manner into several hierarchical levels, integrating relationships between objects, functions, operators, and operands.

This method, however, has two major limitations. First, it does not recognize, mention, or include any consideration of the broader institutional context in which the system is supposed to be operated, designed, or developed. Because it fails to do this, OPM's representation of the system is biased against any contextual influence on its performance, behavior, or form. Second, OPM does not include any explicit consideration of the social dimension beyond the possible interaction of a system with its operators and customers.

The CLIOS Process can serve as basis for derivative work, as suggested by its authors who recognize it as a modular process that can be "customized and expanded as needed" (Dodder, McConnell et al. 2006). COIReM is such an adaptation, developed to meet the need for a method that could help answer the qualitative research questions in this dissertation by integrating the strengths of CLIOS-SR and OPM. Chapter 4 presents this integration in greater detail, and demonstrates its application for the study of MEUs evolution and diversification into broadband services.

### 1.6.2 Functional Emergence

This dissertation analyzes how the rapid technical changes in information and communications technologies of the last decades affected the design and performance of components used for an internal function in electric power systems: supervisory control, data acquisition, and automatic meter reading. The adoption of new IP-based solutions triggered by regulatory changes and the upgrade of components led to

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[6] The authors define common drivers as "components that are shared across multiple…subsystems of the physical domain"

architectural innovations that gave new capacity and performance to the internal function. In this transition, an overstock of resources was created. These resources; organizational adaptation and learning in the deployment and use of these resources; and increasing external demand led to changes in the internal function that emerged as a new externally delivered function. We define this process as "Functional Emergence", borrowing the term from other fields[7].

We define Functional Emergence as the process by which a system's internal function emerges as a new externally delivered function as the system's architecture evolves. This process is triggered by innovation and technical changes in the components performing the internal function; the externally delivered function emerges as a result of dynamics between the physical system and its social, organizational, and institutional context. This process does not affect or change the system's original concept and primary externally delivered functions.

We propose that functional emergence is not just a particular characteristic of municipal electric utilities, but an emergent response of complex socio-technical systems to changes in technical, social, organizational and contextual changes, especially when such systems rely on general purpose technologies. The type of IT-based evolution studied in this research for the case of MEUs has also been perceived in other CLIOS Systems such as Intelligent Transportation Systems (Dodder 2006).

Here we differentiate between emergent and designed externally delivered functions. A Designed Externally Delivered Function (D-EDF) is a function that, quoting Dori (2002), is "the main intent for which [the system] was built, the purpose for which it exists, [and] the goal it serves". An Emergent Externally Delivered Function (E-EDF) is a new externally delivered function that emerges from one or more internal functions of the original system that, due to technical, organizational, or contextual changes in its related components, have increased their capacity and performance. The enhancement in their capacity and performance, have triggered organizational learning and adaptation giving the system the capabilities, practices, and capacity to deliver services found in other areas.

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[7] The term functional emergence has been used with other meanings in various areas. It is used referring to special types of emergent *behavior* in sociobiology (Barash 1982) and neurosciences (Luciana and Nelson 1996). Also in neurosciences and artificial intelligence, Cariani (1992, 1992b) identifies it as a special case of self-organizing systems and defines as "the deviation of the behavior of a physical system from an observer's model of it" (Cariani 1992). Also in artificial intelligence in design, Brown (1998) defines a function to be emergent "during the design process" as "an identifiable function in a design which has not been explicitly anticipated or explicitly represented in the current…design".

We argue that functional emergence is a property of many socio-technical systems with potentially broad implications for public and private policy making.

Every system has components that are designed, engineered, and built by firms in other industries. For this reason, it has *blind spots* of knowledge about the basics of such components that sometimes extend to what is necessary to know for operating and maintaining them. The quality, price, and capacity of such components evolve as result of technical change; the production learning curve; and increasing demand and innovation enabling more and new types of use. We argue that two major triggers of functional emergence are the changes in the context and technology in components of a system, especially changes that dramatically affect the capacity and performance of such components.

## *1.7 Organization of this Dissertation*

This chapter has presented a summarized overview of our research objectives, questions, methods, and findings.

Chapter 2 includes an analysis of the relevant literature in five areas: (i) theory of system architecture, (ii) organizational theory, learning and the development of architectural innovations, (iii) public management and the creation of public value, (iv) complex socio-technical systems, and (v) economic impact of information technology.

Chapter 3 presents the research objectives, questions, and methods for qualitative research. We start by discussing our qualitative research questions: (i) why and how did MEUs become broadband providers?, (ii) how can we explain the underlying phenomenon behind this architectural evolution and their diversification into broadband? and (iii) how can we use CLIOS Process and OPM to study the architectural evolution of socio-technical systems? We then discuss the development of the CLIOSP-OPM Integrated Representation Method (COIReM), with special focus on the steps in its application and use for testing our hypotheses about the architectural evolution of MEUs.

The results from qualitative analysis are presented in Chapter 4. We apply the twelve steps of COIReM, present our observations about the evolution of MEUs, and our conclusions about the use of COIReM as a method for studying the architectural evolution of socio-technical systems.

Chapter 5 is quantitative in nature; it presents and discusses the answers to the questions about economic effect of IP-enabled SCADA and AMR on the efficiency of electric power operations, cross-subsidies between MEUs' electric power and broadband services, and economic effect of MEU-based broadband on local economic development.

Chapter 6 defines and describes the Theory of Functional Emergence. The development of the theory is based on the analysis and identification of the underlying phenomenon behind the architectural evolution of MEUs. We discuss the implications of functional emergence for policy making and technology management, and propose how it should be included in the analysis of investment in engineering systems.

Finally, chapter 7 concludes by presenting the contributions of this dissertation at three levels: (i) answers about long-standing policy questions and their implications for telecommunication policy at state and federal level, (ii) the usefulness of a new method for representing and studying the architectural evolution of socio-technical systems, (iii) the theory of functional emergence, and (iv) a view of further directions for research that can be drawn from this dissertation.

# Chapter 2: Review of the Literature and Contributions to Theory

The previous chapter presented an overview of this dissertation and its major research questions: (i) Why and how did municipal electric utilities become broadband providers, and (ii) What has been the economic effect of this? This chapter presents a review of the literature and past contributions to theory that are relevant to our research.

From a theoretical perspective, the entry of MEUs into broadband presents an interesting case of architectural evolution that can be studied building on the convergence of previous work in five areas:

(i) theory of system architecture;

(ii) organizational theory, learning, and the development of architectural innovations;

(iii) public management and the creation of public value,

(iv) complex socio-technical systems; and

(v) economic impact of information technology.

A review of the literature in these areas contextualizes the contributions of our research to theory, which include:

(i) the creation of a new method for studying the evolution of the architecture of socio-technical systems;

(ii) a first case study about the evolution of the architecture of a *class* of long-lived engineering systems that integrates qualitative and quantitative analysis;

(iii) extension of the integrated approach to the causes and concept of architectural innovation;

(iv) a proposed modification to the notion that added structural complexity hinders innovation, and

(v) the identification of a new type of "functional emergence" as property of some complex socio-technical systems

These contributions are detailed in following chapters. The following sections review the theoretical and methodological underpinnings of the study.

## *2.1 Theory of System Architecture*

System architecting is currently under development (Whitney, Crawley et al. 2004), and increasingly gaining the characteristics of a science, building up from what some have called an "art" (Rechtin and Maier 2000). Necessary steps in our research are to understand (i) what do we mean by system architecture, (ii) what causes its evolution, and (iii) what frameworks could be used for studying architectural evolution.

### 2.1.1 What is System Architecture?

Computer science has been an important source of contributions to the study of the architecture of complex systems. Blaaw (1997) defines computer architecture as "*the minimal set of properties that determine what programs will run and what results they will produce*" and, thus, is concerned with the "*functional appearance*" of the computer, or "what should it do". In his view, the structure is not part of the architecture but correspond to different domains of computer *design*: implementation (logical structure) and realization (physical structure).

In Blaaw's perspective, the nature of computer architecture is no different from that of language, or software architecture, which he explains by presenting the recursive nature of languages ranging from microcode to application. Consequently, he defines computer architecture as the outcome of the design of a "programming language when expressions are costly" (Blaaw 1997).

Also from the field of computer science, Black (1989) presents a view for analyzing network architectures and protocols. He defines network architecture as the definition of "*what things exist*" in a network, "*how they operate*" (protocols) and "*what form they take*" (topology).

A common feature of the different network architectures analyzed by Black is the decoupling (Suh 1998) or orthogonality (Blaaw 1997) between mayor functions in "layers". These layers provide (i) a decomposition in logical subsystems, (ii) standard interfaces among them, (iii) functional symmetry across nodes (or peer elements), and (iv) command and control (Black 1989).

The idea behind this view of layered architecture is that each layer operates independently and interacts with others using a set of protocols. This idea is behind each of the network architectures that Black studies in his work: (i) Open Systems Interconnection (OSI), (ii) U.S. Government Open Systems Interconnection Profile (GOSIP), (iii) Systems Network Architecture (SNA), (iv) Digital Network Architecture (DECnet), and (v) the Defense Data Network (DDN). Interestingly enough, all these networks present the same underlying concept of layered architecture described by Black (1989).

Hans van Vliet (2001) presents the role of architecture in software development by identifying and characterizing different architectural *styles* and different *forces* affecting architecture. His focus is on how to identify and describe different software architectures (shared data, abstract data type, implicit evocation, and pipe-and-filter). Thus, he proposes that software architecture has three major objectives: (i) serving a vehicle of communication among stakeholders, (ii) capturing early design decisions (legacy and compatibility with early versions), and (iii) providing a basis for transferring and reusing the system, creating the basis for a *product family* (Meyer and Utterback 1993) by providing access to common code.

Karl Ulrich (1995) defines architecture as the *scheme by which function* is *allocated to physical components*, and argues about its importance in manufacturing; he states that it is a *key driver of performance* and managerial decision making in general. More importantly, however, he argues that architecture is specifically relevant for product change, variety, and performance, component standardization and in the management of the product development process.

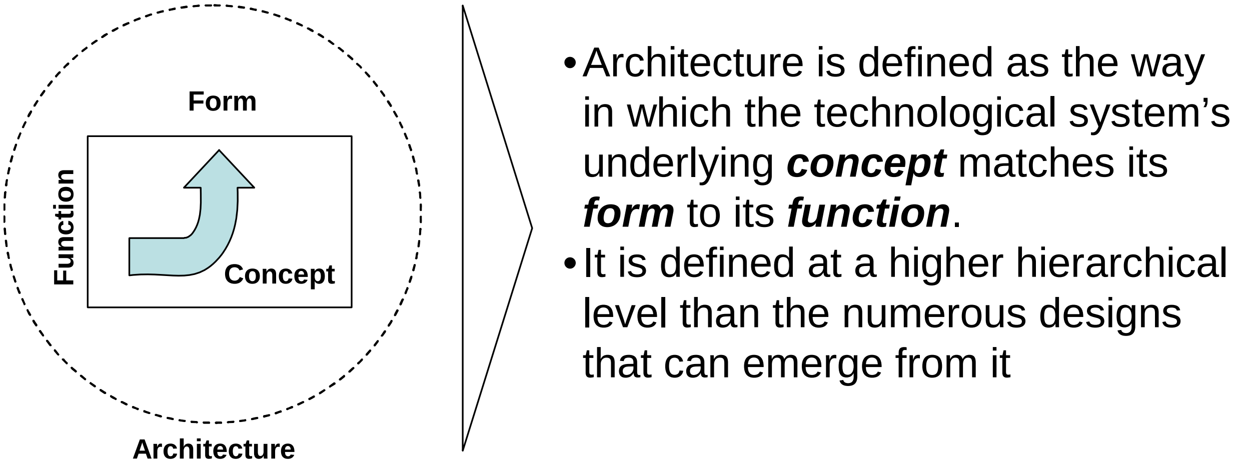
Ulrich argues that the architecture is central to the change of products along their lifetime, across generations, and within a company's variety of products. The author suggests that product variety results from flexibility in architecture rather than core capabilities (a factory's equipment). Ulrich proposes product variety as a function of the flexibility in both product architecture, and component processes and standardization.

Finally, similarly to Ulrich (1995), Edward Crawley and Annalisa Weigel propose that the "architecture" of a technical system is defined as the way in which its concept matches its form to its function[8] (Ulrich 1995; Crawley and Weigel 2004).

We can find parallels among many of the works discussed in this section by defining architecture in terms of form, function and concept (Crawley and Weigel 2004). From the perspective of Black (1989), the protocols, topology and "*what things exist*" can be parallel to function, form, and concept. We can also draw a parallel between these ideas and Karl Ulrich's (1995) terms *scheme* (concept), *function* (function) and *physical components* (form).

**Figure 2.1** represents the relationship between form, function and concept and defines systems architecture.

**Figure 2.1**: System Architecture



- Architecture is defined as the way in which the technological system's underlying ***concept*** matches its ***form*** to its ***function***.
- It is defined at a higher hierarchical level than the numerous designs that can emerge from it

Source: Adapted from Crawley and Weigel (2004).

We now turn to two complementary issues: the evolution and representation of system architecture.

### 2.1.2 Evolution of System Architecture

System architecture theory is in its early stages of development as a discipline. However, it provides a useful framework for analyzing complex socio-technical systems and, especially, for studying their evolution. This requires an understanding of a given

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[8] The base of this definition was first proposed by Karl Ulrich from the University of Pennsylvania, and later perfected by Edward Crawley and Annalisa Weigel from MIT

system’s building blocks; and understanding of how its architecture evolves, and finding a way to represent these factors.

Herbert Simon’s (1997) discussion about the existence of a science of complex systems presents four principles for their design that could help us: (i) homeostasis, (ii) membranes, (iii) specialization, and (iv) near-decomposability.

- Homeostasis is a systems’ capacity to attenuate the internal effects of contextual and environmental changes (by having *balancing loops* in the system dynamics jargon) and thus reducing dynamic complexity.
- Membranes insulate the system and its subsystems, and serve as mechanisms for transporting information, material and energy. This is the basis of later work proposing strategies for product architecture and decomposition (Pimmler and Eppinger 1994).
- Specialization refers to the specialization of complex functions, which has been used in methods such as Axiomatic Design (Suh 1998), decomposition strategies for products (Koopman 1995), and decomposition of the design process (Eppinger, Whitney et al. 1994).
- Finally, near-decomposability means the system can be decomposed into structural and dynamically stable subsystems or subunits.

These principles are based on the flexibility of complex systems which enables them to perform adaptive functions. From the perspective of our research, this implies the capacity for evolution and flexibility in architecture and of the architecting process.

From the perspective of Hans von Vliet, the evolution of architecture is affected by the development organization and has a cyclical relationship with its environment (van Vliet 2001). He focuses on the architecture of software, which is an interesting contrast to Blaaw’s approach to computer architecture, mentioned above.

A problem with Blaaw’s (1997) approach is that all the cases of computer architecture discussed on his paper occurred prior to 1985. Once computer and software architecture shifted towards the personal computer, and Microsoft MS-DOS took over the operating system (OS) and was separated from the computer, his vision of architectural evolution is not longer applicable. Now, computer and OS architecture are distinctive and their evolution is marked by different, but interrelated, clockspeeds. Computer architecture evolves about every other year guided by increases in processing capacity, but software architecture evolves continually due to the benefits of Internet-based distribution of updates and patches.

The case of computer and OS architecture is an interesting example of architectural evolution that initially comprises one distinctive system (the computer) and evolves into two (the hardware=computer and the software=OS).

This problem is somewhat similar to the one we are studying. It can help us understand how a second line of business might emerge from what had been the internal activities of an organization by studying the relationships between the form and functions of the components of the infrastructure supporting both services.

Here, a key concept is the system's Externally Delivered Function (EDF) (Crawley and Weigel 2004), which is defined as the system's function at its highest hierarchical level. EDF is understood by decomposing and disaggregating it into several internal functions that are mutually exclusive, but comprehensively exhaustive (Pimmler and Eppinger 1994).

The deployment of a new EDF is a consequence of the many external and internal influences affecting the system (Crawley and Weigel 2004; Whitney, Crawley et al. 2004). Investigators need to focus on the engineering system as a technical system embedded in a defined policy, social, and economic context (Dodder, Sussman et al. 2005). In the policy context, several actors can affect the form, function, or concept of the system by various regulatory means. In the social and economic contexts, residents and businesses exhibit certain needs and demand services.

The existence of such regulatory effects and social and economic needs, and their effect on decision making are central to the evolution of an organization. Analysis of these factors can help explain why the architecture of systems evolve, in particular the architecture of long-lived systems. These systems are of special interest because their evolution has not been planned by one architect throughout the system's life. It has resulted from a series of small and consecutive changes planned and executed by different actors. In these cases, possible paths for evolution are constrained by the legacy of the pre-existing architecture, and limited by each architect's bounded rationality and lack of information about the evolutionary possibilities.

The question how is how to study representation of system architecture and its evolution.

### 2.1.3 Decomposition and Representation of System Architecture

The final representation of a system's architecture will result from the chosen decomposition strategy that will be used for structure, processes and concepts.

Phillip Koopman (1995) proposes a framework for decomposing and representing system architecture based on structures (form), behaviors (functions) and goals ("desired emergent properties" or need), creating a taxonomy that allows for comparison across different strategies. Some features of his framework are that (i) it considers both technical and non-technical criteria, and (ii) it is explicit in *not* considering technical, regulatory, political or business influences. From the perspective of our research, this is a major limitation that will be discussed on Chapter 3.

Koopman's framework is based on decomposing the design according to the three previous dimensions, which range from "pure" (when performed only according one of them), "split" (separating dimensions into decoupled sub-designs and using pure decomposition in each), and "combined" (which considers two or all dimensions at the same time). The approach departs from ad-hoc decomposition by allowing options for greater modularity. It does not, however, differentiate between *design process* and *final design*.

Suh (1998) presents his Axiomatic Design, a method for designing systems in terms of minimizing the complexity arising from the interaction between functional requirements (FRs), design parameters (DPs) and process variables (PVs) for systems of fixed functional requirements. This objective is similar to the one followed by Koopman (1995), and Pimmler and Eppinger (1994).

Axiomatic Design (AD) is based on two axioms: independence among functions (Independence Axiom) and achieving the least possible information content on the design (Information Axiom). The Independence Axiom is equivalent to Simon's (1997) *Specialization*. The method has the following steps: (i) defining the FRs for the system, which requires finding the customers' attributes and needs, (ii) mapping FRs with physical elements in order to create DPs and identify PVs, (iii) test the independence axiom between functions, and (iv) verifying the information content of the system.

Besides the axioms, AD is based on the hierarchies among FRs, DPs, and PVs, and the zigzagging between the functional and physical domains (FRs and DPs). Hierarchy provides a policy and supervisory function that start at highest system level, and progress to the smallest level of detail tracking up and down from the beginning point (which is important for the zigzag design decisions between FRs and DPs).

Pimmler and Eppinger (1994) present a method for analyzing product design decompositions and understanding and evaluating the requirements of system engineering. The method follows a three-steps process (i) decomposing the system into elements, (ii) documenting their interactions (whether they are of proximity, energy transfer, information, or of material interchange), and (iii) clustering them into "chunks". Each type of interaction is ranged from -2 (interaction must be prevented to achieve functionality) to 2 (interaction is necessary for functionality). Thus clustering is achieved by reordering elements around the diagonal in order to reduce interaction complexity.

These authors present decomposition strategies. They, however, do not present representation methods. Dov Dory (2002) presents a representation method - Object-Process Methodology (OPM)- that has been used by Edward Crawley to incorporate some of these strategies and represent a system architecture based on form, functions and concept. We describe OPM in more detail in chapter 3.

Little study has been devoted to the architectural evolution of long-lived engineering systems, especially among those designed to perform one function but that have evolved to perform many. This research fosters the advancement of the theory of system architecture in general, and of architectural evolution in particular. We also extend the study of architecture by integrating it with research in the management sciences about architectural innovations (Henderson and Clark 1990), which will be discussed on the next section. We applied this to the study of the evolution in the architecture of municipal electric utilities as they moved from the provision of electric power to the deployment of broadband operations.

## *2.2 Organizational Theory, Learning, and the Development of Architectural Innovations*

Previous research on organizational theory, learning, and innovation is helpful in understanding the process of evolution by which MEUs became broadband providers. This dissertation contributes to this literature by considering two issues that have not been considered before.

First, most research on architectural innovations has referred to competition within the *same* industry and among actors assumed to be private and actively entrepreneurial. Our research extends the idea to cross-industry competition by studying how architectural innovations allowed electric power utilities to enter into telecommunications. Furthermore, in this case the innovators are bureaucracies (public organizations) that are threatening entrepreneurs (private firms).

Second, scholars of architectural innovation have studied how technical changes affected a system. Our work, however, argues that architectural innovations can also be triggered by changes in social, organizational, and external context changes.

### 2.2.1 What do we mean by "architectural innovation"?

Many scholars (Nelson and Winter 1977; Clark 1985; Utterback 1994) include cross-industry technology transfer and adaptation in the absence of previous knowledge or experience as innovation. Theory provides four classifications of innovations: (i) radical, (ii) incremental, (iii) modular, and (iv) architectural innovation (Henderson and Clark 1990).

Henderson and Clark define radical innovations as those in which a core concept is overturned or introduced completely anew, presenting a new relationship between the core concept and components. Incremental innovations are those in which core concepts are reinforced, and present no or little change in the relationship between core concept and components. Modular innovations are those in which the core concept changed, but the relationship between components and concept remained unchanged. Finally, architectural innovations are those changes affecting how the system's components are connected, but with no change in the system's core design concepts.

For the purpose of our research we are interested in architectural innovations. Henderson and Clark (1990) proposed that architectural innovations are triggered by technical changes in critical components. We expand this definition to suggest they can also be triggered by social, organizational, and contextual, including regulatory, changes. While their focus is on the impact of architectural innovations on established firms *within an industry,* we are also extending their analysis to consider the impact of architectural innovations *across industries*.

Following these authors, the adoption of broadband technologies for monitoring and controlling electric power systems represents an architectural innovation, and their later diversification into broadband a case of cross-industry diversification.

### 2.2.2 Organizational knowledge and learning as factors for architectural innovation

Erik von Hippel identifies various sources of innovation: (i) demand (users), (ii) manufacturing, (iii) suppliers, and (iv) others (von Hippel 1988). These distinctions are significant because an important part of the innovation process is to realize whether a new idea has a market, whether an old idea can be used to solve a new problem (Sutton 2002). In the case of our research, we are interested in the process for figuring out the latter.

Abernathy and Clark note that the significance of an innovation depends on the ways it can influence a firm's established competencies in terms of its resources, skills, and knowledge about its market, and production systems[9] (Abernathy and Clark 1985). The extent of these influences, however, depends on the amount and quality of prior "related knowledge" and access to more and new knowledge (Ruef 2002).

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[9] They call it "transilience."

Prior related knowledge creates the basis for an organization's "absorptive capacity" (Cohen and Levinthal 1990), which is defined as the "ability to exploit external knowledge" that seems to be critical for development of new capabilities.

Organizational knowledge and learning are important for understanding why and how a second externally delivered function can be created from an engineering system with an originally different EDF. This is especially relevant if the two EDFs would require knowledge that at first glance would appear to be different. Here, we need to consider mechanisms for learning. The literature shows us at least two basic learning mechanisms that lead to innovation: first and second order learning (Adler and Clark 1991).

First-order learning is "*experiential learning by doing*". In the case of MEUs, this would be equivalent to sending MEU employees to work at a telecommunications company in order to learn how to operate broadband services. Second-order learning, however, is defined by Adler and Clark as "*learning that transforms the goals of the process by explicit managerial or engineering action to change the technology, the equipment, the processes of the human capital in ways that augment capabilities*".

As result of organizational learning to absorb new knowledge, some of them exhibit what is known as "dynamic capabilities" (Teece, Pisano et al. 1997). These dynamic capabilities represent an organization's "ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments" and its "ability to achieve new and innovative forms of competitive advantage given path dependencies and market positions". Path dependence is of extreme importance, because it can partially explain the dynamic of succession among technologies (Sterman and Wittenberg 1999) and of architectural legacy in technical systems (Crawley and Weigel 2004).

These streams of literature are relevant to our work in two ways:

1. In the case of our research, the structural complexity of our system increased when MEUs adopt IP-enabled SCADA and AMR. Theory says that innovation and complexity are negatively correlated most of the time (Gottfredson and Aspinall 2005). However, we argue that increase in complexity increases the likelihood of a special type of innovation: architectural innovation. We present evidence about this in Chapter 4 and propose a theory in Chapter 6.

2. Learning, however, is a critical enabling process. This theory will help us understand how the learning process occurred in MEUs, helping them to become broadband providers.

## *2.3 Public Management and the Creation of Public Value*

Two streams of research in public management can help explain and analyze the hotly debated issues around municipal broadband more effectively. First, theory on the creation of public value addresses the reasons why public organizations might decide to extend the reach of their action. Second, theory on privatization and public-private partnerships provides a framework to analyze the reasons for public activity in traditionally private business.

Good public management calls for the creation of public value (Moore 1995); this is relevant for municipal broadband. To measure the public value created, public management requires a measurable impact from public initiatives. This is why it is important to understand if the municipal broadband phenomenon is related to local economic development and if the adoption of IP-based technologies is related to increased efficiency in MEU's internal operations. Public value can be found in both the impact or effectiveness of a public initiative and the efficient use of public resources (Osborne and Gaebler 1992; Libecap 1996; Osborne and Plastrik 1997). This is, of course, true in the case of information technology (Heeks 1999).

From this perspective, a study of the effects of broadband deployed by MEUs should focus on local economic impact and internal efficiency. The internal efficiency argument calls for analyzing the presence of economies of scope between MEUs' electric power and broadband businesses. If such economies exist, then one should perceive an effect on the cost structure of the electric power business in cases where the MEU has deployed broadband. From the perspective of good public management, if an MEU deployed broadband infrastructure primarily for running internal services, and then decided to use its overcapacity to offer external broadband services, a prohibition on selling this resource to residential and business customers would be contrary to the efficiency goal.

Our research also assesses the extent to which providing municipal broadband has had a positive or negative effect on the efficiency of the electric power business.

The privatization literature is also relevant. Various authors have studied the reasons for competition between public and private initiatives (Donahue 1989; Vickers and Yarrow 1991; Savas 2000) in general, and telecommunications in particular (Newbury 1999; Stiglitz, Orszag et al. 2000). Savas (2000) states that government should identify people's needs, and promote private enterprise to satisfy those needs, and leave to businesses the implementation of the solutions. This position, however, does not consider that private investment will satisfy those needs only to the extent to which the investor can appropriate private benefits in the form of returns.

Donahue (1989) proposes another perspective. He takes into account (i) the public/private nature of the service, and (ii) whether the service is individually or collectively paid for. He argues that it is necessary to have some public and private competition. Roseau (1999) offers the additional perspective that public-private partnerships would be a feasible solution for municipal broadband, but that in many cases they could lead to inferior results in terms of efficiency, equity, access, and democracy.

Donahue's (1989) framework considers the dimensions of financing and performance of initiatives. In terms of financing, the question is whether the service should be paid for through individual customer billing or taxes. In terms of performance, the question is who should produce or deliver the service. This is presented by the delivery-payment matrix presented in **Figure 2.2**.

**Figure 2.2**: Municipal Telecommunication Services in the Matrix of Public/Private Choice

| | **Collective Payment** | **Individual Payment** |
|---|---|---|
| **Public Sector Delivery** | **Homeland Security,<br>FBI,<br>Public Schools,<br>police departments, etc.** | **US Postal Service,<br>National Park Service system,<br>NASA (launching satellites)<br>Census Bureau (data), etc.<br>Municipal Electric Utilities<br>*Municipal Telecommunication Services*** |
| **Private Sector Delivery** | **Government procurement,<br>Consulting services to public agencies,** | **Purely private products** |

Source: Osorio (2004)

In the context of this research, the most interesting quadrant is the one in which goods and services could be produced either by the public or private sectors, and paid for–at least in part—by individual customers.

There are three general reasons for supporting at least partial public spending: (i) the presence of a market failure; (ii) moral or philosophical reasons for collective action or support for "non-market goals"; and (iii) an "opportunistic" view of the possible effects of such public spending[10].

Donahue's framework offers an advanced version of "managed competition" in which public agencies compete with private firms without bidding (United States. General Accounting Office. 1997). A public initiative could openly compete with private firms in providing services, and justify doing so by offering the greatest value at the same cost, or the same value at lowest cost.

Most research has focused on the rivalry between public and private organizations, and the existence of economies of scope or sub-additive production efficiency (Parker 1999). These are characteristics of natural monopoly, which is especially relevant in network-based investments. In this research however, we are proposing the convergence between different types of non-telecommunications utility networks. We will argue that utilities' adoption of IP-enabled communications to produce greater efficiency allows them to converge and become telecommunication providers (Viscusi, Vernon et al. 1997; Newbury 1999).

Public management theory could be used to test first, whether the entry of MEUs into broadband creates public value and internal efficiency, and second, whether MEUs are cross-subsidizing their broadband businesses from their electric power revenues. Answers to these questions would help clarify both the policy debate and the decision-making process for those MEUs that have not yet deployed broadband networks.

### *2.4 Complex Socio-Technical Systems*

In this research, our units of analysis are Municipal Electric Utilities. From an organizational perspective, MEUs fit Charles Perrow's "*neo-Weberian*" model (Perrow 1986). They follow the typical Weberian bureaucratic model found in public organizations, and incorporate Perrow's additions: (i) decision making, (ii) conflict, and (iii) technology. His model incorporates the developments of bounded rationality and behavioral theory of the firm; multiple conflicting goals, expectations, and choices that, partially based on March's garbage-can model (March 1991), are sources of ongoing bargaining processes and of organizational learning and change; and contingency theory, which construes "technology" as the knowledge required to carry out tasks. Perrow's (1986) model is built on understanding interactive complexity and system coupling.

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[10] Quotes in original version. Donahue (1989), p.17.

There are, however, other types of complexity, which include structural, behavioral, internal, and combinatorial (Sussman 2003). Structural complexity is of special interest in this research because, as mentioned before, it has been suggested that it might negatively affect innovation (Gottfredson and Aspinall 2005).

According to the theory of technology enactment this increase in technology-driven structural complexity is not isolated from its related organization-driven structural complexity (Fountain 2001). DeSanctis and Poole's Adaptive Structuration Theory proposes that the impact of technology on behavior is buffered by organizational social practices. Thus, the final effects depend on the management of the organizational change process of adopting the technology (DeSanctis and Poole 1994).

The relationships between organization, institutions, and technology, however, are also shaped by interactions with other contextual elements.

These relationships are partially considered in the theory of system architecture and the work of Dodder, Sussman, McConnell, Sgouridis and Mostashari (2005). They propose a process for studying complex, large, interconnected, open socio-technical (CLIOS) Systems that focuses on identifying the structure of relationships between subsystems in a physical domain, and the various organizations affecting them through a policy context (in which the CLIOS System is embedded.)

The first stage of this process, Representation, is especially relevant for this research for two reasons: (i) It facilitates analysis of the overall structure of a socio-technical system, and to make inferences about its behavior, and (ii) It can be used in parallel with other frameworks to study system architecture. An especially relevant framework is Object Process Methodology (OPM) (Dori 2002). OPM is developed to design new products and to study systems engineering. It is based on high-detail representation of a system's structure, and it has been used to study a system's technical architecture.

This study extends previous knowledge about the effects of complexity by identifying how increases in the structural complexity of a system might be associated with sources of architectural innovation. Researchers in management sciences have argued that complexity limits innovation (Fleming and Sorenson 2001; Gottfredson and Aspinall 2005) and complexity theory offers various examples of behavioral emergence by complex systems.

Thus, according to the literature, more complexity would decrease the possibility of innovation and increase behavioral emergence. This dissertation proposes that adding structural complexity to an already complex socio-technical system could actually trigger architectural innovation under certain social, organizational, and contextual circumstances. We discuss this and provide evidence on chapters 4, 6 and 7.

Additionally, we propose a new type of emergence in which an externally delivered function emerges from a system's pre-existing internal functions. We call this a "functional emergence".

Finally, this work also offers a new methodological approach to understanding socio-technical systems, and study functional emergence by proposing a new method based on the integration the Representation Stage of the CLIOS Process with Object Process Methodology.

### *2.5 The Economic Impact of Information and Communication Technologies*

Studying the local economic effect of municipal broadband requires an examination of relevant work on the economics of information technology, and of methods for hypothesis testing. The study of information technology and productivity has been a focus of interest ever since the proposal of the Solow Productivity Paradox. In 1987, Robert Solow stated that computers could be seen everywhere but in the productivity statistics (Triplett 1999). Others questioned the relevance of the so-called New Economy, comparing it to the impact of previous technologies such as electricity, running water, or refrigeration (Gordon 2000). They found that only a few sectors had benefited from information technology (manufacturing, information technologies themselves, and finance).

Dale Jorgenson, from Harvard University, presented the first and most influential work about the impact of information technology on the American economy on his 2001 Presidential Address to the American Economic Association (Jorgenson 2001; Jorgenson 2004). Since then, a number of scholars have presented their assessment about the magnitude of the productive impact of IT at the industry level (Litan and Rivlin 2001; Stiroh 2002), on the market value of firms (Brynjolfsson, Hitt et al. 2002) and on labor productivity and skill-biased technical change (Bresnahan, Brynjolfsson et al. 2002; Wolff 2002; Autor, Levy et al. 2003), and job growth (Pociask 2002).

Brynjolfsson, Hitt, and Yang (2002) analyze how the effect of investments in IT is complemented by investments in organizational capital: new organizational forms, norms, and practices. According to their view, pure investment in IT could produce no change, or even have a negative impact, if not accompanied by adequate organizational change. This view is supported by varied research in organizational theory and information technology on the enactment of technology (Fountain 2001) and impact of IT on organizational structure (DeSanctis and Poole 1994; Orlikowski 2000).

Bresnahan, Brynjolfsson, and Hitt (2002) and Autor, Levy, and Murnane (2003) study how IT can both have a positive and negative effect on labor. According to their research, digital technologies can enhance labor productivity by complementing the non-routine labor of high-skilled workers. However, IT investments can also replace low-skilled labor with more efficient digital technologies, or by creative destruction rendering the core competencies of some activities or sectors obsolete (Abernathy and Clark 1985). Furthermore, the availability of high-speed Internet access could open local markets to large retail companies with no physical presence in suburban or rural places. Internet-based commerce could erode local sales and, thus, salaries or jobs. As result, at the aggregate level, these effects could offset each other.

Kevin Stiroh analyzed 20 studies relevant to the impact of information technologies on productivity according to sample period, level of aggregation, measure of IT, production function specification, and estimation techniques (Stiroh 2002). He reached three conclusions.

i. He discovered that these impacts are both positive *and* negative depending on (i) econometric techniques, (ii) definitions of capital (computer, telecom, non-IT capital) and (iii) ways to measure output (gross output, value added, no. firms, etc.) lead to very different results. Out of 41 estimates for IT-productivity/growth elasticity the median was is 4.6% in a [-6%, 24%] range (Stiroh 2002b).

ii. Stiroh makes a strong methodological point: research on the productivity effects of IT needs to address *endogeneity* problems of inputs. It is necessary to find variables that correlate with inputs but not with productivity shocks. The effect of unobservable variables has been a critical problem on measuring the impact of IT (Haltiwanger and Jarmin 2000).

iii. Finally, he points out the importance of separating the effects of *computers* and *telecommunications.* (See also Jorgenson (2004.) This is especially relevant for the purpose of this research because we are trying to measure both things: the effect of the deployment of a technology that incorporate high-speed data transmission capacity and the use of computers.

Only a few researchers have addressed the question of the economic impact of telecommunications or broadband. Some have focused on the economic effects of competition in local telephony (Economides, Seim et al. 2005), while others have analyzed the impact of telecommunications on regional economic development (Lentz and Oden 2000; Yilmaz and Dinc 2002), but without a formal analysis on local impact.

More particularly, there have been not many studies about the economic impact of broadband alone. Most have proposed broad estimations of its aggregated future impact (Crandall and Jackson 2001; Brough 2003; Criterion Economics 2003; The Allen Consulting Group 2003; Ford and Koutsky 2005), and a few have recently analyzed broadband's effect on firm localization based on its adoption patterns (Forman, Goldfarb et al. 2003; Forman, Goldfarb et al. 2003b; Forman, Goldfarb et al. 2005).

Only one attempt has been made to measure the nation-wide productive impact of broadband at the zip code level (Lehr, Gillett et al. 2005), and no previous econometric work has tried to assess the relationship between broadband deployed by municipal electric utilities and economic development, growth or productivity at the national level.

### 2.5.1 Measuring the Economic Impact of MEU-Based Broadband

Some opponents of MEU-broadband refer to important research on location theory indicating that places near large metropolitan areas would have access to more and better opportunities than places located farther away (Markusen 1999; Polenske 2001). If this were the case, towns close to large metropolitan areas would have better access to high-speed Internet access and, thus, could enhance business opportunities. The same theories would support that towns further away from large cities would see only increase fixed costs from the new developments and little, if any, positive economic effect.

Deployment of broadband by municipal electric utilities is justified by advocates who assume that it would help attract knowledge-based firms or retain new businesses in a locality. While econometric work has shown that broadband availability is associated with an increase in the rate of growth of business establishments (Osorio, Lehr et al. 2005), other work has shown that the availability of broadband does not affect the location decision of firms intensive in the use of IT (Forman, Goldfarb et al. 2003). There is no empirical analysis of the economic effect of broadband deployed by municipal electric utilities.

The measurement of the economic impact of municipal broadband is necessary and a complicated task. It is important because, as said before, the policy debate has been mostly based on anecdotal evidence. It is complicated because there are various methodological issues that need to be considered. We discuss them in detail as follow.

### 2.5.2 Positions about the Economic Impact of Municipal Broadband

A position often cited is that broadband deployed by MEUs can create "*a dramatic increase in economic growth*" (Ford and Koutsky 2005). The arguments supporting this position are:

(i) The deployment of reliable broadband in a low-cost real estate market could attract information technology intensive firms with highly paid workers, thus enhancing the local economy.

(ii) Because broadband has a positive effect on the local economy, broadband deployed by MEUs in the absence of a private provider should have a positive effect on the local economy.

(iii) As two thirds of the benefits created by broadband are externalities that cannot be appropriated by the investor in the infrastructure, private providers tend to underinvest in the deployment of broadband networks leaving room for additional economic growth triggered by municipal electric utilities (BEA 1999, Ford and Koutsky 2005).

(iv) Broadband competition between MEUs and incumbent private providers increases the quality and decreases the prices of available broadband alternatives, thus creating a positive effect on the local economy.

Opponents to municipal broadband in general, and broadband by MEUs in particular, adhere to the position of Joseph Bast, from Heartland Institute, which states "*the connection between municipal broadband and economic growth has never been demonstrated and probably never will be*" (Bast 2005). The most common arguments for this position are four:

(i) The deployment of municipal broadband crowds out private initiative, thus reducing investment, eliminating jobs, and producing no, or little, positive effect on the economy (Ford 2005, Burton and Hicks 2005).

(ii) Any likely benefit directly from broadband provided by MEU is offset by the tax burden imposed on local residents and business to pay for the risky investments in broadband infrastructure (Lenard 2005, Thierer 2005).

(iii) The deployment of broadband services by MEUs is unlikely to create any positive effect on the local economy because broadband affects economic growth by increasing productivity in finance, manufacturing, and information services, which are sectors with little representation of firms in rural areas (Gordon 2000, Stiroh 2002b, Burton and Hicks 2005).

(iv) The adoption of broadband in rural areas is slow and unlikely to have a positive effect, because broadband's economic impact results from its use, not just its deployment (Burton and Hicks 2005).

A few case studies have compared the benefits of municipal broadband in towns in Florida (Ford and Koutsky 2005) and local civic networks in three Italian regions (Berra 2003). Various individual cities (Scott and Wellings 2005) like Cedar Falls, IO, (Kelley 2003) have been also investigated. However, no nation-wide empirical study has been done so far.

In terms of the economic effect that adopting IP-enabled Supervisory Control and Data Acquisition (SCADA) and Automatic Meter Reading (AMR) on the internal efficiency of MEUs, recent work has proposed that SCADA and AMR systems contribute to the efficiency of electric utility operations (Black 2006, IBM Business Consulting Services 2004). No empirical analysis has tested these hypotheses. Some argue, however, that new-generation fiber optic networks are too complex for MEUs and increase their costs, add unnecessarily risks, and push them to increase prices for electricity in order to finance such investments (Bast 2002, IBM Business Consulting Services 2004).

The lack of empirical analysis of these issues opens the opportunity for our research, but also presents the methodological problem of measuring the economic impact of broadband.

### 2.5.3 Methodological Considerations

The theories and previous research described above can help us to examine the phenomenon of MEUs deployment of broadband services, and will be incorporated into the methodology.

Measuring the economic effect of deploying infrastructure raises several difficulties. The deployment is only the beginning. What really makes the difference is its use. Previous work has found investment in general infrastructure to have a statistically significant, but negligible, effect on economic growth (Holtz-Eaking and Schwartz 1994). More over, the authors found *"little support for claims of a dramatic productivity boost from increased infrastructure outlays"*.

The problem in our study, however, is not only to measure the effect of deployment of infrastructure, but also of public spending in infrastructure. Previous examinations about the economic effect of public spending in general (Aschauer 1989) and of spending on infrastructure in particular (Duffy-Deno and Eberts 1989; Eberts 1990; Holtz-Eakin 1994; Pereira 2001). This research joins work that have examined the competition and complementarities between public and private investment in infrastructure (Marglin 1963; Rieinikka and Svensson 1999). This line of work informs our analysis about the need to measure the economic effect of MEUs in presence of private provision of broadband.

Besides the previous issues, there is a more methodological consideration. We have noted that results from previous studies about the effect of information and communication technologies vary depending on the method used by the researcher (Stiroh 2002b).

In order to claim causality between a treatment and dependent variable, we need a treatment variable that is not related to any other observed and unobserved variable (Kennedy 1998; Wooldridge 2003). Any study of the economics of deploying infrastructure requires accommodating the problems of endogeneity and the availability of data because many other factors could be affecting the measurements.

A usual method for dealing with this problem is by using instrumental variables (IV) in two-stage regression analysis. In order to address this issue, the IV must (i) be correlated with the treatment (in a first-stage regression), (ii) cannot be correlated with the error term (in the second-stage model), and (iii) the IV can only have be related to the outcome or dependent variable through the instrument (Kennedy 1998; Wooldridge 2003). However, it is often impossible to find good instrumental variables. This is the case in most attempts to measure the effect of infrastructure on economic growth.

Another option is to use randomized controlled trials (RCT). RCT are the best option from an experimental perspective (Campbell and Stanley 1963; Shadish, Cook et al. 2002), but cannot be used in large infrastructure projects (this is explained in more detail in Chapter 5). There is, however, a close alternative: Matched Sample Estimators (Abadie, Drukker et al. 2004; Abadie and Imbens 2006), which is the method chosen for our econometric analysis in chapter 5.

This completes the review of the relevant literature. We now take these streams of research and build frameworks for our qualitative and quantitative analysis.

Chapter 3 presents a framework that integrates the various dimensions for qualitative analysis into a coherent methodology for testing the hypotheses about why and how MEUs became broadband providers. Chapter 4 applies this methodology. Chapter 5 presents the results of testing the hypotheses about the impact of municipal broadband on the local economy and on the internal efficiency of MEUs' electric power operations. Chapter 6 introduces our concept of functional emergence, presents its definition and discusses its relevance.

# Chapter 3: Qualitative Research: Motivation for and Development of COIReM

To understand the phenomena underlying the evolution of MEUs into broadband providers and to illuminate some policy questions about the deployment of these services we begin with a qualitative approach. In developing the right tools to answer this question, we suggest that this research also contributes to the study and representation of socio-technical systems.

## *3.1 Research Objectives*

We have two objectives for our qualitative research: (i) understanding the evolution of MEUs and their diversification into broadband services, and (ii) understanding the underlying phenomenon and sources of such architectural evolution. These are discussed below.

### 3.1.1 Understanding the transition of MEUs into broadband

We base our analysis on the theory of system architecture (TSA). TSA provides a useful overarching framework for understanding the various factors influencing the overall form, function, and concept of a system's architecture.

The data for the analysis comes from documentation, interviews, and other elements of case studies of the evolution of three MEUs into broadband: Braintree Electric Light Department (BELD) in Braintree, MA; Hometown Utilicom (HU) in Kutztown, PA; and

Owensboro Municipal Utility (OMU) in Owensboro, KY. The reasons and process by which MEUs diversified into broadband have significant policy implications. Here, we are interested in studying the factors that led to these changes among innovator MEUs, i.e., those first deploying advanced communication networks. Our research does not consider MEUs that have diversified as result of the active role of the American Public Power Association in fostering what is known as "Community Broadband".

To study the evolutionary process implicit in the data we develop a qualitative research method which we call CLIOSP-OPM Integrated Representation Method (COIReM). COIReM integrates the Representation Stage of the Complex, Large-Scale, Inter-Connected, Socio-Technical (CLIOS) Process (Dodder, Sussman et al. 2005) and Object Process Methodology (OPM) (Dori 2002).

In this study we use COIReM to

i. build a general model of the architecture (form, functions, and general concept) of MEUs that diversify into broadband, including the relationships of organizational actors;

ii. dissect the most important subsystems linking components and functions at a hierarchical level of decomposition "adequate" for meaningful analysis; and

iii. identify the relationships between components and functions that explain the emergence of broadband services.

### 3.1.2 Understanding the sources of architectural evolution

The second objective of this study is to better understand the evolution of long-lived engineering systems and the ways in which technical, social, organizational, and contextual changes affect the architecture of socio-technical systems. Most studies of engineering systems addressing similar questions have been in-depth analyses of a *single* case. Our research seeks the existence of general rules governing architectural evolution by studying the process in a specific *class* of cases--MEUs involved in telecommunications.

A generalized description of the phenomena underlying the evolution and diversification of MEUs into broadband requires the combined insights of qualitative and quantitative reasoning. Heretofore, researchers have suggested that such evolution could result from the interaction between increased structural complexity and technical, social, organizational, and contextual changes. By positing this notion as a hypothesis, we can test this idea about complex socio-technical systems for a specific, bounded set of similar systems (three MEUs that have deployed external broadband). Furthermore, this study of the impacts of increasing structural complexity reveals the existence of a new property of such systems: Functional Emergence. We define this as the emergence of a new externally delivered function from pre-existing internal functions.

While no single approach could serve all purposes, a combination of methods under a guiding theory could facilitate the study of the architecture of socio-technical systems. Here, we create such a method by integrating the Representation Stage of the CLIOS Process (CLIOSP) and OPM into COIReM, which could help us identify and understand the sources of architectural evolution of MEUs.

The next section explains the underlying theory and methods used in the analysis: (i) the theory of system architecture, (ii) Object-Process Methodology, and (iii) the CLIOS Process.

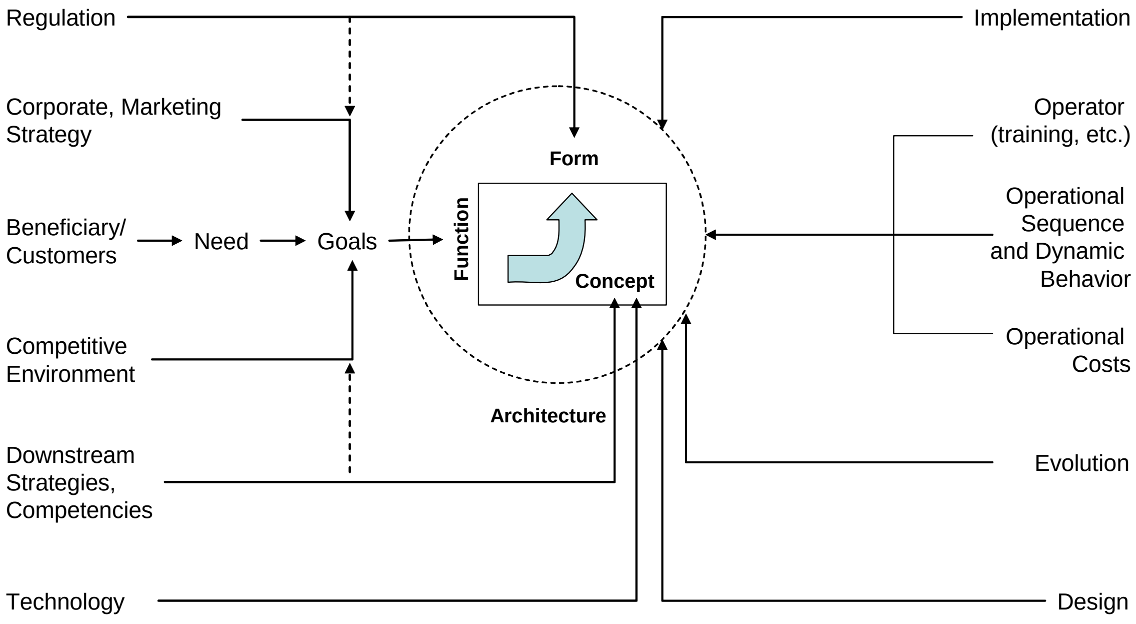
### *3.2 The Theory of System Architecture: A General Theoretical Framework*

The theory of system architecture provides a guiding framework for the analysis of the form, function, and overall concept of the CLIOS system and its subsystems. It also provides guidelines about the dominant influences in system architecture, which serve as complements to those offered by the CLIOS Process.

The working definition of a system's architecture, as presented in **Figure 2.1** in the previous chapter, is the way in which a *concept* matches its *form* and to its *function*. A first step in the analysis of the architecture of a socio-technical system is to identify the dominant influences that affect these three major dimensions of the architecture at the highest hierarchical level.

Dominant Upstream Influences (DUI) include the regulatory and legal environment that affect form and function, corporate and marketing strategy, the influences imposed by customers and beneficiaries through their needs, the effects of the competitive environment, the evolution and availability of technology, and other strategies and internal competences. Dominant Downstream Influences (DDI) include those arising from the design, implementation, operation, and evolution of the system (See **Figure 3.1**).

**Figure 3.1**: Dominant Influences on System Architecture



Source: Adapted from Crawley and Weigel (2004)

This figure shows that a system's architecture can be affected by various influences not only during its design, construction, and first implementation, but also through its operational life through changes affecting its form, function, or concept. In our research, we focus on the architectural evolution of a system during its operational life. Here, we want to understand how the architecture of MEUs has evolved, and how important the legacy aspects of its architecture have been.

However, from the literature review we know that theory of system architecture is not enough to achieve these goals because: (i) it is still not yet sufficiently developed, (ii) while it provides some guidelines for system decomposition, system architecture does not offer methods for system representation.

For this reason, we complement this discussion in the next section with the introduction and explanation of Object Process Methodology.

### *3.3 Object Process Methodology*

Traditionally, the study of a system's architecture has focused on the technical system, and has been supported by the use of Object Process Methodology (OPM)[11]. OPM offers a consistent method for the study of the architecture of a system, provides operators for hierarchical decomposition, and helps identify the underlying processes that link functions and form. The result is a picture of the behavior of the system under scrutiny. However, OPM has important limitations for our study: (i) it does not recognize the relevance of social, organizational, and contextual dimensions, and (ii) does not provide a way to include them in the analysis.

OPM is a methodology used in product design and engineering; it was developed by Dov Dori (2002). In OPM, a system is defined as an object that exhibits a function, where the function is "the main intent for which [the system] was built, the purpose for which it exists, [and] the goal it serves" (Dori 2002: 251).

The major features of OPM allow for a hierarchical decomposition of the system into objects, or physical elements, and functions in a well-defined manner at various hierarchical levels. This is done by integrating relationships between objects, functions, operators, and operands. The operators are individuals that make the system work; and the operands are the most important inputs used by the system to carry out its externally delivered function.

OPM specifies certain symbols to represent the elements (form) and processes (functions) of a system's architecture (Dori 2002). OPM includes notation for representing states (e.g. an alarm can be on or off), and can also be used to study a system's life cycle and evolution (Dori 2002: 289). The operators used to represent relationships among objects and processes are shown in **Figure 3.2**.

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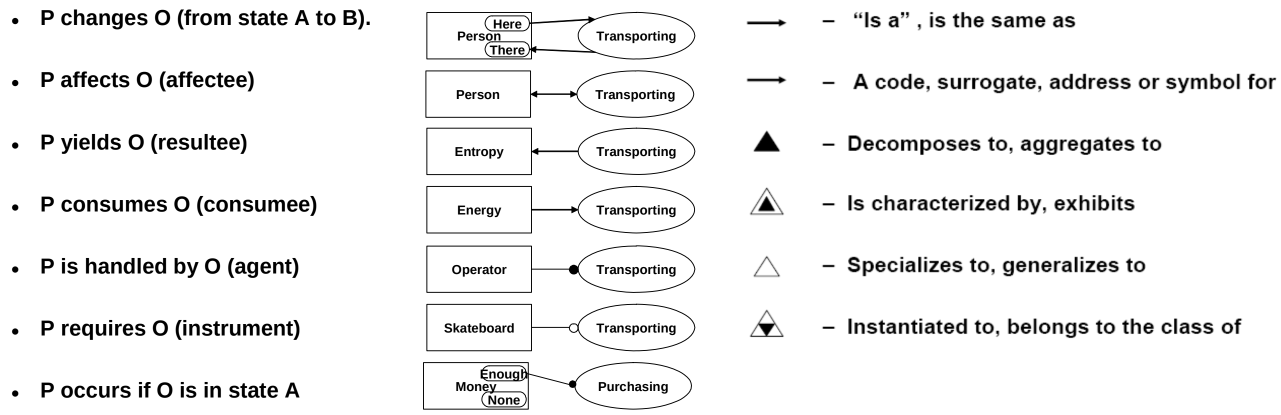
[11] For this reason, this section is complemented with the description of Object Process Methodology in section 3.3.1.

**Figure 3.2**: Links and Operators in OPM.



Source: Crawley and Weigel (2004)

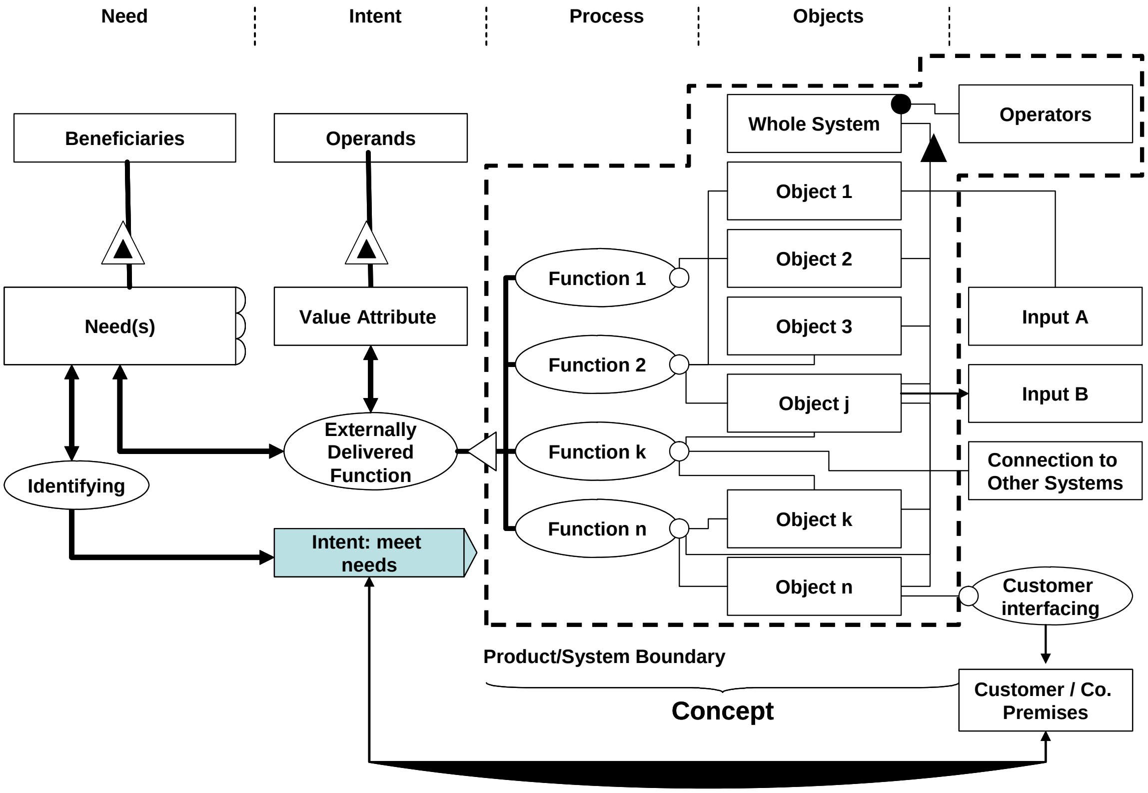
OPM has been combined with theory of system architecture for design and new product development, but it presents limitations for the analysis of complex socio-technical systems: OPM does not include the representation of direct effects of organizations on the architecture of a system.

We borrow the focus on form, function, and concept from system architecture, along with identification of needs, intent, processes and objects. OPM process starts with the examination of the concept, and the way in which (i) the *externally delivered function* (EDF) is associated with the needs of beneficiaries from using the technical system, (ii) the intent to fulfill their needs, (iii) the operands and value attributes associated to the EDF, (iv) operators of the system, and (v) first-level decomposition of the technical system among functions and objects.

We focus on the representation process to understand the extent to which the system meets the needs of beneficiaries through its EDF. An important way to achieve this is through hierarchical decomposition: OPM requires the decomposition of the system's function and form (components) from high to low hierarchical levels.

Form decomposition includes linkages only among units of form in the same way that functional decomposition includes linkages among only functional elements. Then, the analysis combines the form and functional decompositions into a single object-process diagram. This is normally done up to the third or fourth hierarchical level, which is possibly relevant for system design and development but not necessarily for our research. **Figure 3.3** shows a typical example of how OPM is used for object-process representation of technical systems.

**Figure 3.3**: Object-Process Representation of a System's Architecture



Source: the author based on Crawley and Weigel (2004)

Here, we want to understand why and how MEUs deployed broadband services, and how this deployment is related with legacy of MEUs' architecture. For this reason, we need to find the "adequate" level of disaggregation in form and function that allows us to understand the underlying evolution process. Therefore, the decision about level of analysis is based on the complexity of the system, the need for deeper understanding about the system's behavior, and the criteria of the analyst.

From this perspective, OPM has many characteristics one might want to use for studying a system's architecture. However, it has two major limitations:

i. It does not include any consideration of the broader context under which the system operates, is designed, or is developed. OPM would consider the electric utility as a system in and of itself; it would not include any type of formal consideration of a broader organizational and institutional context (e.g. relationship with the local government, economic activity system, and actors in the institutional sphere). This is an important shortcoming because the system's representation is biased against outside influences on concept, function, or form.

ii. OPM does not include any explicit consideration of social dimensions affecting form, function, or concept beyond the interactions of the system with its operators and consumers. The social dimensions are, like institutional factors, critical influences on a system's architecture (DeSanctis and Poole 1994; Crawley and Weigel 2004); its organization (Orlikowski 2000), especially if it is public (Fountain 2001); and the overall strategy that governs it (Arcelus and Schaefer 1982).

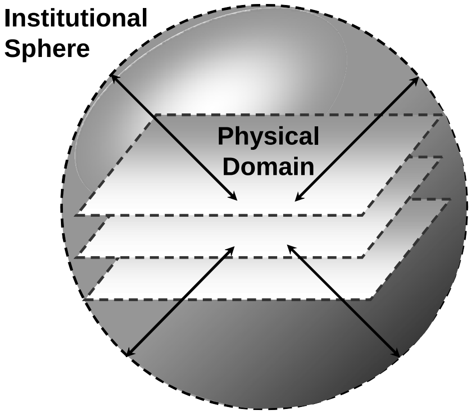
Thus, we need to complement the strengths of OPM with a method that could offset its limitations. In our opinion, Complex, Large Interconnected Open Socio-Technical (CLIOS) Process is such a method.

### *3.4 The CLIOS Process*

The CLIOS Process is an iterative process for analyzing Complex, Large Interconnected Open Socio-Technical (CLIOS) systems by an iterative process. The CLIOS Process consists of three stages: (i) Representation, (ii) Design, Evaluation and Selection of policy alternatives, and (iii) Implementation of the chosen alternatives (Dodder, Sussman et al. 2005).

In our research, we focus on the Representation Stage, the objective of which is to "convey the structural relationships between the components of the CLIOS system" (Dodder, McConnell, at al. (2006). According to these authors, CLIOS Systems are composed of a complex Physical Domain (PD) that is nested into an also complex Institutional Sphere (IS). This is represented in **Figure 3.4**. The institutional sphere is formed by formal and informal organizational actors that interact with the Physical Domain. The interactions between the PD and IS create what the authors define as "Nested Complexity".

**Figure 3.4**: Illustration of Nested Complexity



Source: Dodder, Sussman et al. (2005)

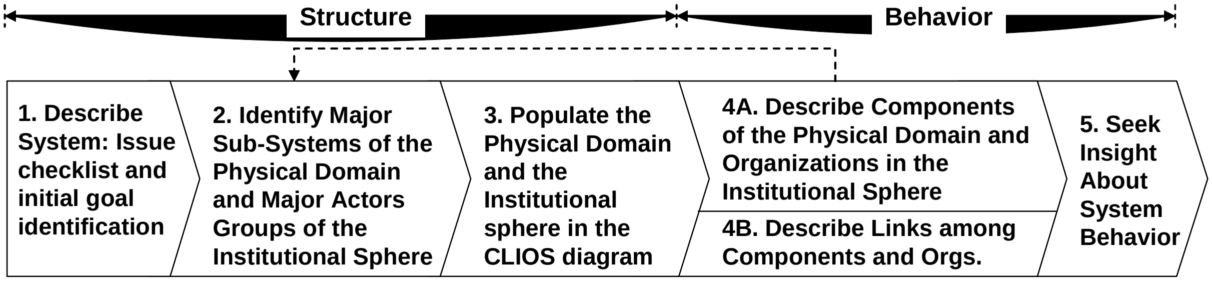
The Representation Stage of the CLIOS Process provides an excellent framework for the analysis of socio-technical systems, separating them into a physical domain nested in an institutional sphere. This distinction complements the analysis of dominant influences in a system's architecture. Additionally, the distinction of common drivers helps us identify objectives and elements that can affect system evolution by being common to two or more subsystems. The CLIOS Process by itself, however, has limitations: (i) it does not provide a system to represent hierarchical relationships among elements, and (ii) it does not provide a way to represent functions or processes and differentiate them from elements of form in a CLIOS system.

From the perspective of organizational theory, the concept of Nested Complexity could explain some of the dynamics, and problems in performance and integration among the technical and organizational dimensions of systems. The CLIOS Process approach to studying nested complexity through the representation of the PD and IS is the major reason why the process is useful to our research.

To identify the dominant influences affecting the form, function, and overall concept of the architecture we will modify the concept of the institutional sphere proposed by Dodder, Sussman et al. (2005), and separate it into an external and internal institutional sphere. This modification is discussed later in section 3.4, and represented in **Figure 3.10**.

The Representation Stage of the CLIOS Process (CLIOSP-RS) follows five iterative steps, which are described below and represented in **Figure 3.5**.

**Figure 3.5**: CLIOS System Representation Stage



Source: the author, based on Dodder, Sussman et al. (2005)

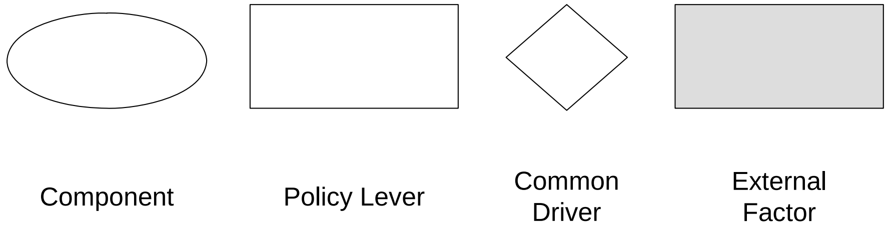
1. *System Description***.** The objective of this step is to describe the system, its major characteristics, goals, and the main issues at stake. The description should highlight the reasons why this is an interesting system.

2. *Identification of Major Subsystems of the Physical Domain and Major Actors of the Institutional Sphere*. In this step, we identify the major subsystems of the CLIOS System, their nature, and relationships among them. An important aspect is the definition of the Institutional Sphere, and identification of actors within this sphere. Dodder, Sussman, McConnell and Mostashari (2005) propose one institutional sphere for their concept of "nested complexity" which is created when the physical system is affected by policy or organizational systems.

3. *Populate the Physical Domain and the Institutional Sphere*. In this step (4a in **Figure 3.5**), the functions and elements of each subsystem are described in greater detail. This is done by *nesting* the physical systems into the institutional sphere; *layering* the physical system into different subsystems and, if more detail is necessary, exploring some subsystems in more detail by *expanding* the analysis of some subsystems at a higher level of granularity. It should be noted that there is no defined way to express hierarchical decomposition of components, and that shapes for representing components do not formally define functions.

   Dodder, Sussman et al. (2006) define four types of system components: (i) physical components, which are represented by an oval, (ii) policy levers, which are the elements of the technical system most easily affected by actors in the IS, represented by a rectangle, (iii) common drivers, which are elements found in many if not all subsystems, represented by a diamond, and (iv) external factors, represented by a gray rectangle, which are components that greatly affect the system but, for practical purposes, are not affected by the system. Subsystems components are called elements. (See **Figure 3.6**).

**Figure 3.6**: Shapes for Representation of Components in the CLIOS Process



Source: Dodder, Sussman et al. (2006)

The population of the physical domain and institutional sphere is parallel to the description of links among components of the physical domain and organizations in the institutional sphere. This constitutes step 4.b in **Figure 3.5**.

4. *Identifying Links among Components and Organizations*. In this step, we identify the types of relationships between components, subsystems, and the various actors in IIS and EIS by using links. According to the needs of our research, this step requires modification in ideas and notation to adequately represent the phenomena we seek to understand.

   Dodder, Sussman et al. (2005) offer general guidelines for defining the properties of such links in terms of their strength, timing of influence, activity/inactivity, and the directionality and magnitude (when possible) of influence, among others. In their paper, the authors define three classes of links:

   (i) among elements of the physical system (Class 1 links),

   (ii) between the physical system and institutional sphere (Class 2 links), and

   (iii) among components of the institutional sphere (Class 3 links).

   We will later differentiate between internal institutional sphere (IIS) and external institutional sphere (EIS), Class 2 and Class 3 links would be of two types: internal and external.

   Considering the issues discussed in previous sections and the needs for our research, we need to include the possibility for representing: (i) functions, and (ii) hierarchical decomposition. We need to identify functions in order to describe the relationship between existing and new functions of an MEU. The capacity to represent hierarchical relations among functions is important because it could allow us to recognize when a new function is emerging, and where it is emerging from.

   This limitation of the CLIOS Process can be solved by adopting ideas and notations from Object Process Methodology (OPM).

5. *Insight about System Behavior*. A major objective of CLIOS system representation is to understand a system's behavior. Understanding overall system behavior is achieved by understanding its subsystems, components, relationships among them, and with components if IIS and EIS. System architecture analysis will be especially helpful to achieve this goal.

In summary, for the purpose of this research, the major strengths of CLIOSP-RS are the following:

i. CLIOSP-RS is explicit in considering the physical and institutional domains of socio-technical systems, which allows for analyzing relationships and possible behavioral interactions among them. This is relevant for two reasons: (i) The definition of the institutional sphere is a major contribution to studying the effect of external institution-based influences in architecture. (ii) This is especially relevant because we want to analyze how the various dominant influences on system architecture – explained above and represented in **Figure 3.1** -affect form, concept, and function of MEUs in their electric power and broadband businesses.

ii. The physical domain in CLIOSP-RS considers not only the technical subsystem of interest--here the electric power infrastructure of the MEU--but also other subsystems that explain the broader context in which a technology is embedded (e.g. economic activity subsystem and municipal subsystem). These subsystems can have important effects on the evolution of the architecture of MEUs, which are dependent on the local government and active in local economic development. Additionally, by definition, the CLIOS Process pays special attention to social influences.

iii. CLIOSP-RS includes the category of "common drivers", defined as "components that are shared across multiple…subsystems of the physical domain". These identify relationships among physical components and between them and organizations in the institutional sphere. This distinction is very important because it is related to the underlying concept behind each subsystem and, thus, can affect its form and/or function.

CLIOSP-RS has two main limitations in achieving the objectives of our research by itself: (i) It does not have operators that represent functions or processes as different types of elements. This is important because functions are one of the three main components of a system's architecture that need to be represented. (ii) CLIOSP-RS does not include an explicit way to define the hierarchy of elements or functions.

For this reason, we have created a derivative method that builds on the strengths of OPM and the CLIOS Process and offsets their limitations: the CLIOSP-OPM Integrated Representation Method.

### *3.5 CLIOSP-OPM Integrated Representation Method*

The previous sections presented a brief summary of system architecture, OPM and the Representation Stage of the CLIOS Process. System architecture provides the theoretical framework, and the combination of the CLIOS Process and OPM provide the base for building our analytical framework. This section discusses how CLIOS Process and OPM are integrated into a single analytical framework, which gains from aggregating their individual strengths while offsetting their limitations.

The Representation Stage of the CLIOS Process and OPM are combined into the CLIOSP-OPM Integrated Representation Method (COIReM), which creates an analytical framework that is more robust overall, and offsets the limitations of using them separately. The resulting framework aggregates the simplicity of CLIOS Process for the study of large scale socio-technical systems with the rigor and orientation to details of the OPM. An important outcome of the integration of OPM with the CLIOS Process is that it makes the analysis of upstream influences[12] on system architecture implicit in the system representation process. Without this change, because of the limitations of OPM, the analysis of social, organizational, and contextual factors was separated from the OPM representation of systems.

Below, we detail how COIReM is constructed.

### 3.5.1 COIReM Terminology and Representation Operators

An important aspect of system representation is the extent to which it can give insight into a system's behavior (Sterman 2000; Dori 2002; Dodder, Sussman et al. 2005). In this research, we wanted to understand the reasons for the evolution of MEU architecture. To do so, we have adopted the distinction in the CLIOS Process between a physical domain and its institutional sphere, and performed the analysis inspired by the steps of the Representation Stage of the CLIOS Process. We have also adopted OPM's distinction between elements of form and function.

We have given a brief introduction to the CLIOS Process and OPM. However, if the reader would like to have a deeper understanding of the following discussion, we suggest becoming more familiar with both methods. We have not reproduced all information about the CLIOS Process and OPM, because we think the best sources are the scholars that created them.

The operators used for representation in COIReM evolve from the originals proposed in CLIOSP-RS, adding the differentiation between elements, or components, of form and function (See **Figure 3.7**). These components are defined as follows.

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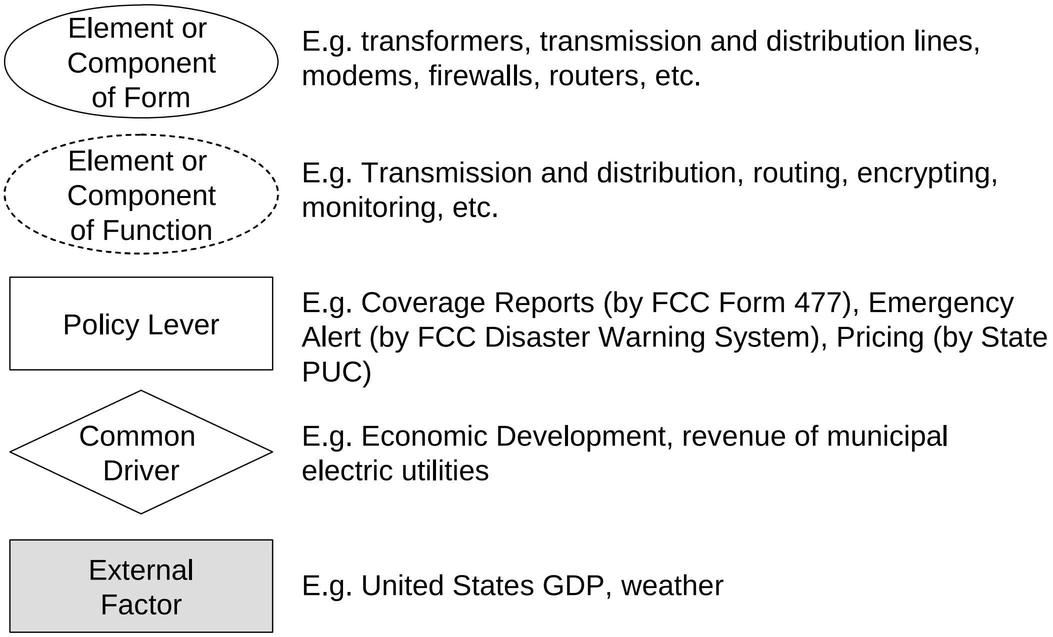
[12] According to Crawley and Weigel (2004), *Upstream Influences* in system architecture include regulation; the organization's strategy; needs and goals of customers and beneficiaries; competitive environment; and technologies. There are also *Downstream Influences*, which include the design, evolution, operation and implementation. These could be matched to the latter stages of the CLIOS Process with further development of COIReM.

**Figure 3.7**: Components Shapes



E.g. transformers, transmission and distribution lines, modems, firewalls, routers, etc.

E.g. Transmission and distribution, routing, encrypting, monitoring, etc.

E.g. Coverage Reports (by FCC Form 477), Emergency Alert (by FCC Disaster Warning System), Pricing (by State PUC)

E.g. Economic Development, revenue of municipal electric utilities

E.g. United States GDP, weather

Source: the author, based on Dodder, McConnell et al. 2006

- *Components of form*, indicated by a solid-line oval, are defined as the physical elements that create a system. Some examples in the case of an electric utility would be transmission and distribution lines, transformers, etc.

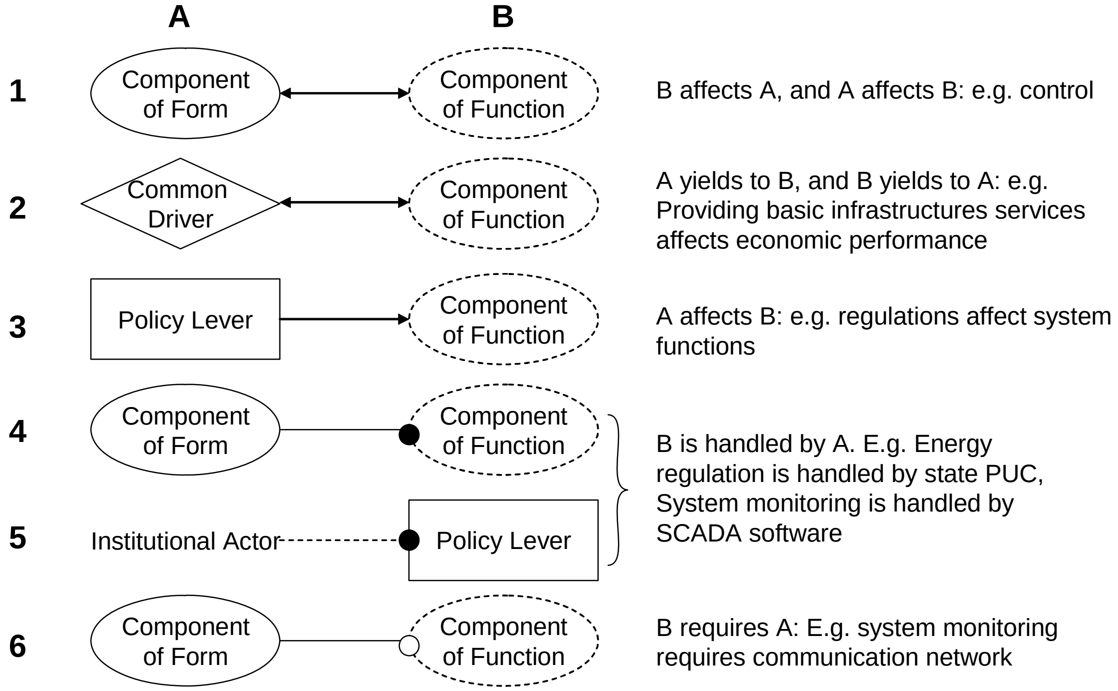
- *Components of function*, represented by a dotted-line oval, are used to characterize the purposes and goals of the physical elements of a system and to represent the functions associated with elements of form. In the case of a distribution line, for instance, its associated function would be distribution of electric power from the distribution transformer to the customer premises.

- *Policy levers*, indicated by a white rectangle, are "components within the physical domain that are most directly controlled or influenced by decisions of actors…on the institutional sphere" (Dodder, McConnell et al. 2006 b). Thus, policy levers are a way by which institutional actors can affect form or functional components of a subsystem in the physical domain (See **Figure 3.8**, case 3 for example).

- *Common drivers*, represented by a diamond, are "components that are shared across multiple and possibly all subsystems of the physical domain" (Dodder, McConnell et al. 2006). Common drivers are important influences on architecture, especially due to their influence across subsystems of the physical domain.

- *External factors*, represented by a shaded rectangle, are exogenous parameters that cannot be affected by the system, but do affect the system.

**Figure 3.8**: Links for COIReM Diagrams



Source: the author based on Dodder, McConnell et al. 2006 and Dori (2002)

As shown in **Figure 3.8**, COIReM proposes a set of links based on those from the CLIOS Process and OPM. These links are used to represent:

1. *Relationships of effect between components of form and function*: These links are used to represent the way in which a function affects an element of form, or illustrate that one or more components perform a function.
2. *Relationships between functions and common drivers:* The performance of functions can affect a common driver, in the same way that a common driver can affect a function.
3. *Effect of policy levers on functions:* These are used to represent the way in which functions are affected by specific components in the physical domain that are controlled by actors in the institutional sphere.

4. *Control of a function by a component of form:* This type of relationship is used to reflect the control of functions by specific elements of form, and is represented by a solid line and black dot.
5. *Control of a policy lever by an institutional actor:* This is represented by a dotted line and black dot.
6. *Functional requirement of a component of form:* A solid line ending in a white dot represents the infrastructure requirements for performing a function. For example, performing IP-enabled system monitoring and control requires an IP-based communication network.

In summary, we might have a function affecting a component of form, or a component of form affecting a function. Also, a function can affect a common driver, for instance the provision of broadband services affects economic development[13]. In the same way, a common driver can affect a function or element of form, for instance, adoption of new information technologies can affect SCADA and AMR systems, and lead to the adoption of IP-enabled solutions. In the same way, functions sometimes require a component of form, but are controlled by another element. For instance, system monitoring requires a communication network, but is controlled by the SCADA system.

Institutional actors can affect functions directly or indirectly by regulating the policy levers affecting the function. These relationships between the institutional sphere and physical domain, called "projections", are represented with dotted lines. Functions and policy levers are controlled by components of form and actors in the institutional sphere, respectively.

The symbols described above can be used to represent the relationships among components of form, function, common drivers, policy levers, institutional actors, and external factors. We can use them to represent relationships of cause and effect (A affects B), control, or requirement among components.

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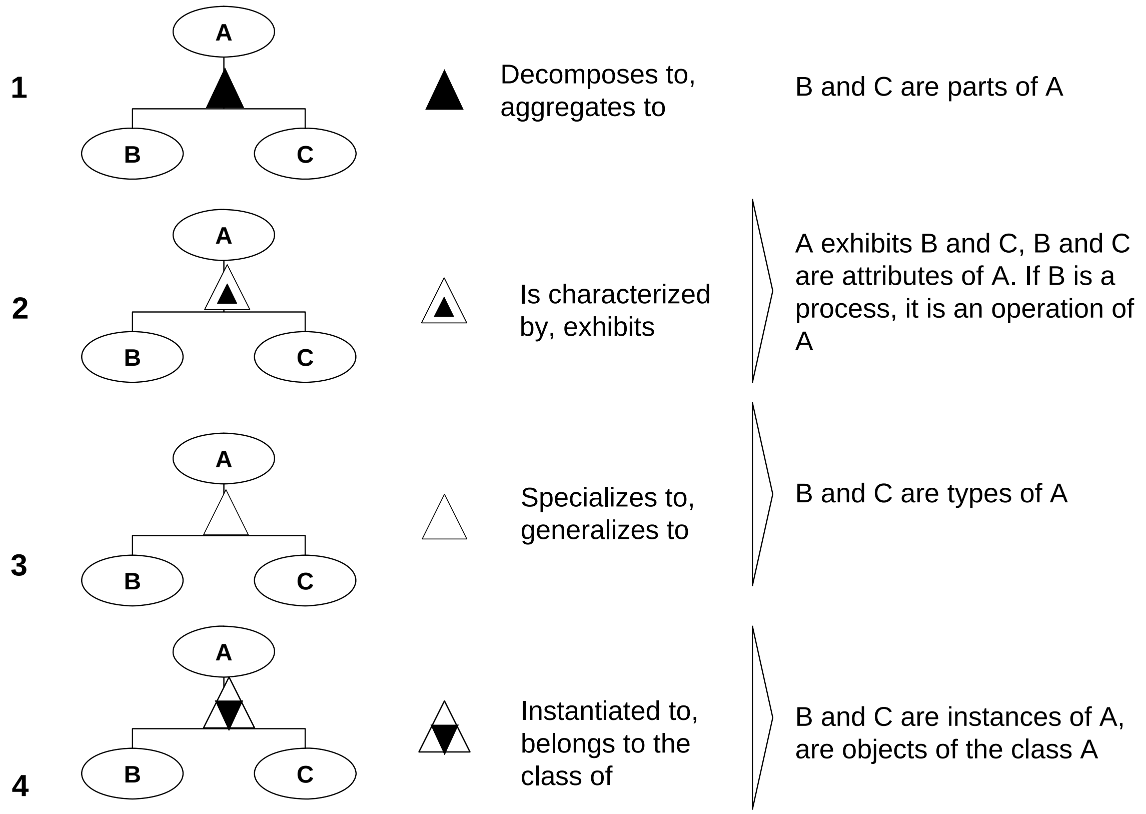
[13] We are using actual common drivers of our analysis with the purpose to illustrate these relationships. Chapter 4 presents a complete analysis applying COIReM.

**Figure 3.9**: Hierarchical Operators



Source: Dori (2002)

Finally, we borrow a third group of operators from OPM that are especially useful for representing hierarchical relationships and characterizing specialization, generalization, or information about system behavior related to elements and functions. (See **Figure 3.9**, above) As numbered in the diagram above these are:

1. *Representation of hierarchies:* A black triangle signals the decomposition of a system into subsystems that are "mutually exclusive and comprehensively exhaustive" (MECE). The hierarchical decomposition can be performed at as many hierarchical levels as the researcher considers appropriate for the purpose of the research.

2. *Representation of attributes*: A black triangle inside a white triangle signals the attributes of a system, common drivers, components of form, or functions.

3. *Specialization of components:* A white triangle signals the characteristics of elements in terms of their specialization.

4. *Class of components:* An inverted black triangle inside a white triangle signals inclusion into types of classes.

### 3.5.2 Differentiating the External and Internal Institutional Spheres

This analysis builds on the CLIOS Process definition of Nested Complexity, which is the complexity created by the embeddedness of the physical system into its surrounding organizational and institutional domain (the institutional sphere). All technical systems are directly affected by their immediate organizational environment, culture, practices, and structural embeddedness.

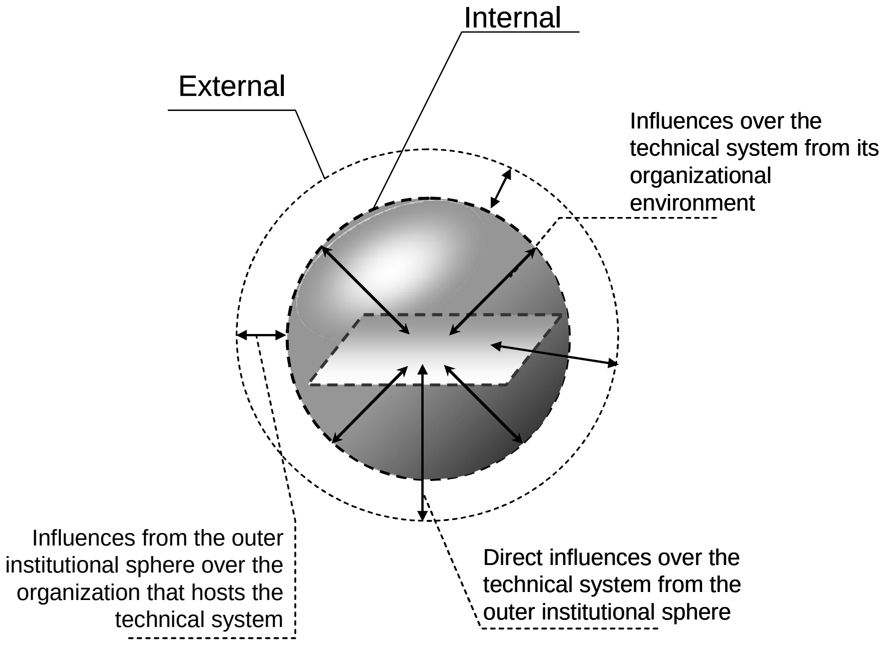
We will examine the physical system as it is affected by organizations at two levels: *Internal* and *External*. By doing this, we are proposing an important extension of the CLIOS Process by separating the institutional sphere according to the types of organizational actors and their relationships. This distinction is relevant because, from the perspective of system architecture, the *nature* of the influences in architecture do matter (See sections 2.1 and 3.2). This is further discussed below:

- The *internal* level of the institutional sphere is formed by the organizations in which the technical system is physically located (i.e. the Local government and Municipal Electric Utility in the case of the electric power and broadband infrastructure). Thus, we define the Internal Institutional Sphere (IIS) as the one formed by the immediate organizational environment of a technical system. Interaction between the internal institutional sphere and the physical system has been studied by many scholars in organizational theory and behavioral policy sciences (Perrow 1986; Orlikowski and Baroudi 1991; DeSanctis and Poole 1994; Orlikowski 2000; Fountain 2001).
- The *external* level of the institutional sphere is formed by the several formal and informal actors, a group we will call the External Institutional Sphere (EIS). Components of the EIS can directly or indirectly affect the technical system under study through federal or state regulation, local government rules, the practices of suppliers, or national changes in customer needs. Scholars of the history of technology, privatization, and regulation have analyzed various ways in which public policies have affected the architecture, design, or operation of technical systems in areas such as emissions control and pollution, car safety, and electric power and telecommunications, among others (Hughes 1983; Donahue 1989; Viscusi, Vernon et al. 1997; Newbury 1999; Laffont and Tirole 2000; Savas 2000). Theories about system architecture and product development have explained how technical systems are shaped by changes in customer needs and preferences (Rechtin and Maier 2000; Crawley and Weigel 2004; Ulrich and Eppinger 2004).

- Finally, relationships between the actors in the IIS and actors in the EIS generate a third type of relationship that can have an indirect effect on the technical system. Several scholars have analyzed the different ways in which organizations relate and interact in different economic and regulatory settings (Powell 1990; Powell and Smith-Doerr 1994; Podolny and Page 1998; Polenske Forthcoming), and how this happened during the birth of the electric power industry in the United States (Chung 1997; Granovetter and McGuire 1998). In such an interaction, the effect of the institutional sphere on the organization might affect a system's performance in ways other than a direct effect on the technical system.

**Figure 3.10** shows the differentiation of the internal and external institutional spheres in our modified model.

**Figure 3.10**: Illustration of Extended Notion of Nested Complexity



Source: the author, based on Dodder, Sussman et al. (2005)

Of special interest are the influences from within and outside the organization on the technical system. For the purpose of this research, it is necessary to show how actors from the institutional sphere are related to components of each subsystem, the organization "Municipal Electric Utility", and how the organization is related to the main components of the physical system.

For this reason, COIReM includes two distinctive features for the representation of a subsystem and the representation of the institutional sphere. First, the representation of the subsystems in the physical domain includes projections from the actors on the institutional sphere affecting the subsystems. Second, the representation of the institutional sphere differentiates between IIS and EIS, and will also include projections from the EIS and IIS to a summarized representation of the physical domain that includes the components most salient to this research.

### 3.5.3 Combining Research Approaches to Create COIReM

The previous sections highlighted the strengths and limitations of the Representation Stage of the CLIOS Process and OPM, discussed the most relevant aspects of system architecture and defined shapes and connectors for COIReM. System Architecture and OPM have been used together for the design, engineering, and analysis of products. OPM provides a useful method for representing a system's technical architecture. Form and functional decomposition allows for learning about a system, and identifying sources of architectural legacy. Object-process representation allows for relating the most important functions of a system with its critical components.

The study of the evolution of system architecture, however, requires two other activities that are be included into OPM: (i) historical analysis and (ii) analysis of dominant influences in system architecture:

- The historical analysis allows for identifying how path dependence can affect a system's organization (structural embeddedness and culture) and technical system (legacy of its architecture). Path dependence and legacy in architecture are especially important when studying the evolution of a system's architecture. In our case, they are even more relevant because some architectural legacy on the electric power infrastructure could explain the emergence of broadband services. For this reason, we analyze the physical domain looking for components of the technical infrastructure that are likely to exhibit legacy influences and can affect the evolution of the architecture of our system.

- The analysis of dominant influences allows us to identify and understand the sources and effects of regulatory, social, organizational and contextual changes on system architecture The analysis of dominant influences helps us understand the various technical, regulatory, institutional, and organizational factors affecting a system. The dominant influences in system architecture and the CLIOS Process can be matched as follow:

  i. *Internal Institutional Sphere (IIS)*: An organization's corporate and marketing strategy can affect the functions or forms of its technical infrastructure. In addition, new organizational competencies can be generated by decision making at operational and tactical levels. Other dominant influences in the IIS include internal policies or decisions about operation of the technical system, and strategies based on the identification of needs in the user base.

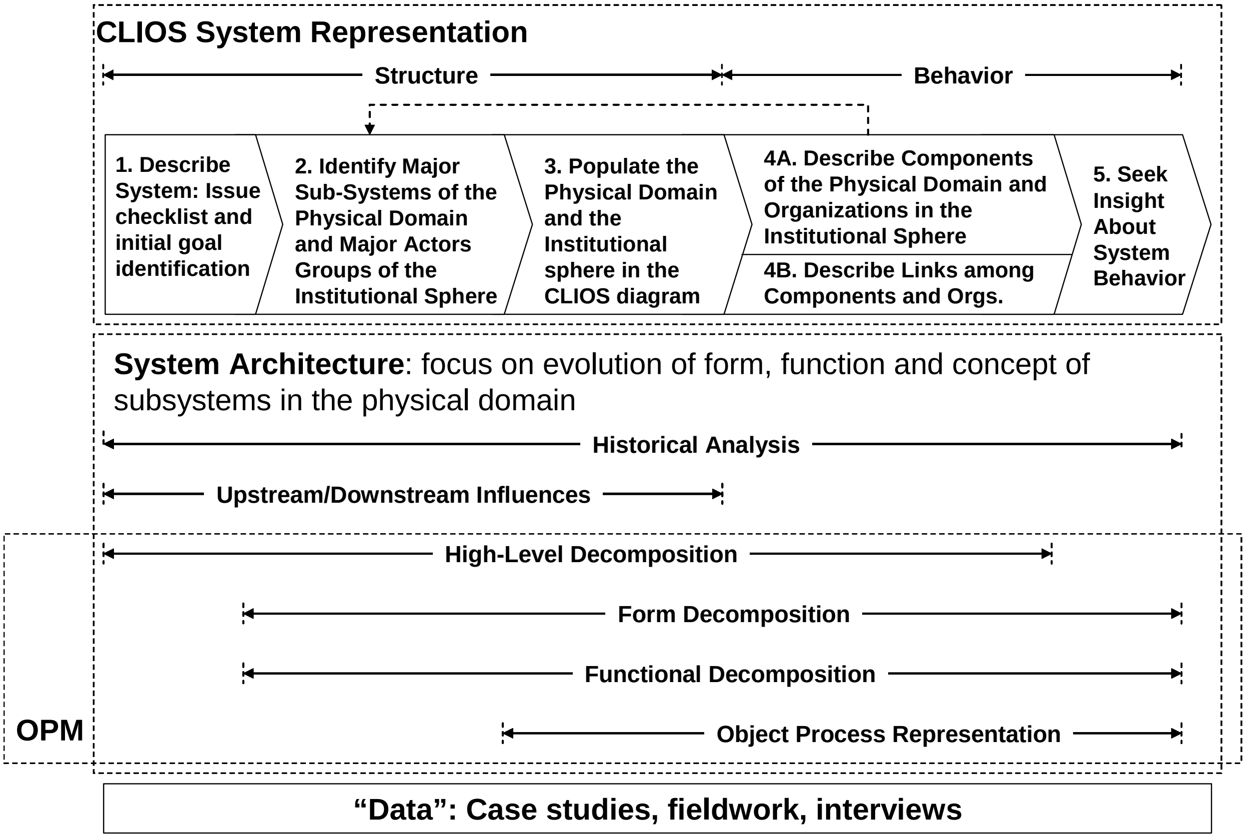
ii. *External Institutional Sphere (EIS)*: Organizations in the EIS exert three of the most important types of dominant influence in a system's architecture: (a) regulation, (b) changes driven by competitive environment, and (c) changes to the needs to be satisfied by the system. From the perspective of system architecture, the institutional actors can be divided into public and regulatory organizations, private companies providing competitive services, and other formal or informal organizations concerned about the direct or indirect effect of the system on customer needs, regulatory aspects, or other issues such as environment, labor, etc.

iii. *Existence of Common Drivers*: The dominant influences include two major drivers of the evolution of a system's architecture: new technology and operational costs (here defined as efficiency). In our research, we consider the technical architecture of a CLIOS System as a major component of its physical domain. This technical architecture can be represented as one or more subsystems. If there is more than one, then new technology and efficiency will be drivers common to all subsystems including parts of the technical infrastructure of the system.

Historical analysis and analysis of dominant influences are included in the analysis of system architecture, which can also be performed using OPM. We can draw a parallel, however, between analysis of dominant influences and the CLIOS Process. Thus, by integrating system architecture with OPM and the CLIOS Process, we make it possible to integrate historical analysis and dominant influences into the representation process. The resulting integration among system architecture, OPM and the Representation Stage of the CLIOS Process is illustrated in **Figure 3.11**.

The objective of this integration is to complement the benefits from (i) historical analysis, (ii) the study of dominant influences, and a process of detailed system analysis that results from combining (iii) the analysis of the Internal and External Institutional Spheres from the Representation Stage of the CLIOS Process with (iv) the detail and rigor from the object-process decomposition of OPM analysis. We do this with the purpose of creating a *research* method for studying the architectural evolution of a system where most of the *learning* comes from (i) understanding the system's setting, (ii) understanding and identifying its sources of legacy, influences and path-dependence, and (iii) learning about the system's evolution through the process of detailed representation of the system.

**Figure 3.11**: Combined Activities of CLIOS Process and OPM for System Architecture Analysis



Source: the author

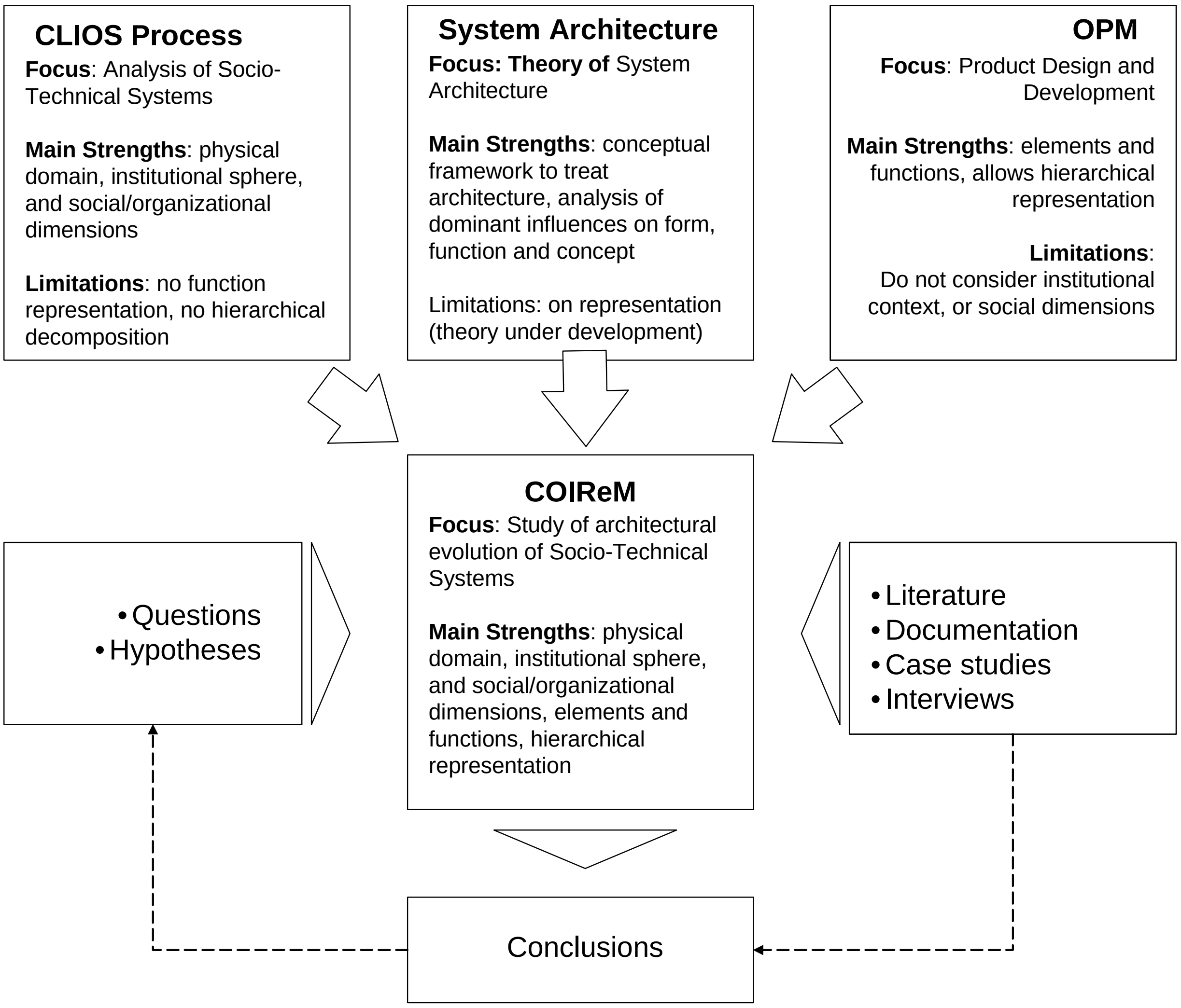
### 3.5.4 Focus on System Evolution

There are three other relevant dominant influences: (i) evolution of the architecture, (ii) implementation of the architectural changes, and (iii) design. These are especially relevant to our research, and are a major reason why COIReM is designed to focus on the process of system evolution, and on identifying possible path dependence and architectural legacy. We are not as interested in characterizing the behavior of the system as we are in explaining the reasons for the evolution of its architecture.

We test the hypotheses by comparing how a COIReM representation of the system based on the hypotheses compares to the information gleaned from case studies, interviews, review of documentation, etc. from the field. We can revise our research questions and hypotheses accordingly. COIReM-based research is, thus, iterative; we refine the representation based on other data and gain deeper understanding about the research questions. The process reveals information about the factors affecting the evolution of the system's architecture.

**Figure 3.12** illustrates this general approach. The figure includes a summary of the difference in focus, strengths and weaknesses between CLIOS Process and OPM, and the value of integrating them into one representation method.

**Figure 3.12**: CLIOS Process, OPM and COIReM: Integration and Application



Source: the author

The input for COIReM is the set of hypotheses about the architectural evolution of a socio-technical system. We start by studying the overall technical and contextual setting of the system, as well as analyzing its history. We use data from the literature, and documentation on social, regulatory, technical and organizational dimensions in order to identify path dependence, legacy and influences on architecture.

We then use detailed representation of the system's architecture (physical domain) and sources of influence (internal and external institutional sphere, and general context) as a method to learn about the evolution process. We do this iteratively, and constructing our representation from lower to higher complexity. Along the process of analysis, we take note about how each step helps us to validate or reject our initial hypotheses. The representation process results from combining the Representation Stage of the CLIOS Process and OPM.

After a certain point, the researcher will find that his or her learning about the system has stalled or stopped due to the decreasing marginal productivity of a more detailed historical analysis or a more detailed representation. Then, we will turn into fieldwork research by using case studies and interviews in order to validate or reject our previous findings, and get information that would allow further learning about the reasons and process of architectural evolution.

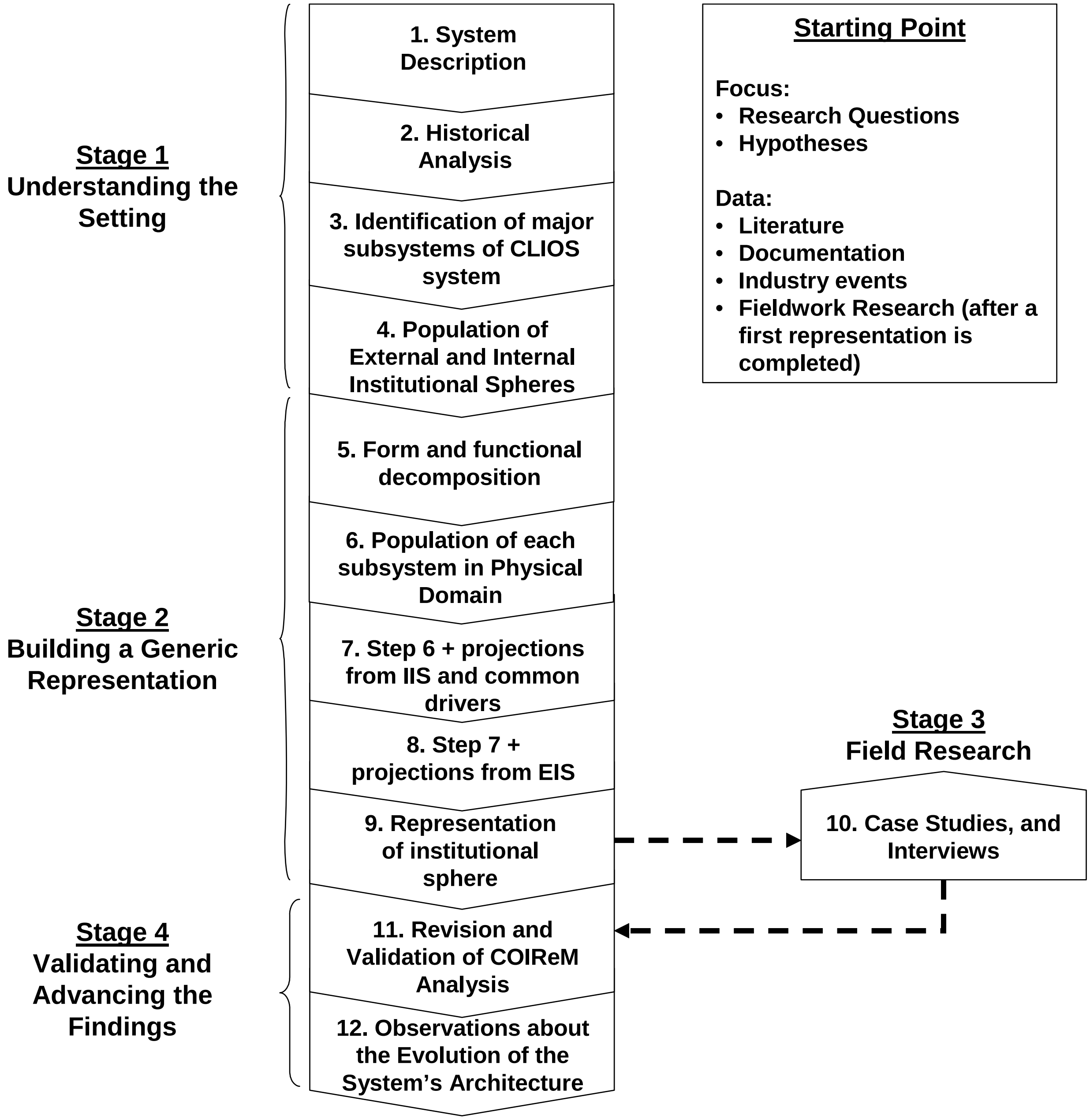
This iterative process would allow us to conclude (i) which where the most relevant sources of influence for architectural evolution, (ii) how relevant was the system's architectural legacy and what role did it play on its evolution, (iii) how do the various subsystems of a system interacted to foster or hinder its architectural evolution, and (iv) why did the system's architecture evolved.

In some cases, the process will end with no changes to the original research questions and hypotheses, while in others the researcher would have to revisit them, maybe discovering a research path that was overlooked. The next section presents a formalization of this process.

### 3.5.5 Using COIReM: Steps in the Research Process

COIReM analysis proceeds in four stages: (i) understanding the setting, (ii) building a generic model of the system based on our hypotheses, (iii) obtaining data through field research in order to validate the model and hypotheses, and (iv) validating the generic model and confirming findings. Fi**gure 3.13** shows the steps in each stage.

**Figure 3.13**: The Steps of COIReM-based Analysis



Source: the author

*Starting Point*: Before starting COIReM analysis, the researcher needs to set up the research questions and hypotheses that will be tested by qualitative analysis. This also requires collecting documentation and information, and securing the interviews and making arrangements for field research in order to assemble enough data to test the hypotheses. The researcher has to state the research questions and hypotheses at the beginning of the analysis.

*Stage 1 - Understanding the Setting:* Our first aim is to understand the setting of the problem under study, identify sources of path dependence and architectural legacy, and identify the major subsystems and actors in the external and internal institutional spheres. This is done in four steps.

Step 1 – System Description: COIReM analysis starts by presenting a summarized view of the CLIOS System under study, its goals, and major regulatory factors affecting its most relevant subsystems (electric power and broadband division). The objective is to highlight why the system is interesting and why the problem under study is relevant.

Step 2 – Historical Analysis: We need to understand how the historical evolution of the system has affected its present architecture and culture. We are studying evolution in the architecture of a *class* of systems, rather than a system in particular. The objective of historical analysis is to identify path dependence on various fronts: (i) regulatory, (ii) entrepreneurial activity, (iii) role in local economic development, and (iv) technology. We also need to understand how this history, which created path dependence, also created a legacy shaping the current state of the system's architecture.

Step 3 – Identification of Major Subsystems of the CLIOS System: In this step we identify and define the subsystems of the institutional sphere that are relevant for the purpose of our research.

Step 4 – Population of Internal and External Institutional Sphere: We identify the organizations in both spheres, explaining their relevance and ways in which they affect the physical domain directly and indirectly. We want to understand how institutional actors are affecting the physical domain of our CLIOS system.

As it becomes integrated into the CLIOS Process, the traditional system architecture analysis of dominant influences becomes part of the representation process. This makes it possible to see more clearly how various actors influence the functions and forms of the different subsystems.

*Stage 2 - Building a Generic Representation*: In this stage we build a generic representation based on our initial understanding of the problem and hypotheses. Representing the system allows us to build understanding about it, the relationships about technical components, and among them and actors in the internal and external institutional spheres. In this stage, the "data" for representing the system is found in publicly available information and literature. In essence, we use the representation process as a research method that will allows us to learn about the architectural evolution of the system, and test our research hypotheses. The result of this stage will be a graphic representation and of our hypotheses and assumptions. We build the model in five steps:

> Step 5 – Form and Functional Decomposition: We start by creating a form and functional decomposition of the subsystems in the physical domain with two objectives in mind, to identify: (i) sources of architectural legacy that could explain the architectural evolution of the system, and (ii) the "appropriate" hierarchical level at which we would make the object-process representation of the subsystems[14].
>
> The researcher is responsible for defining and justifying the "appropriate" level of hierarchical decomposition. Traditional OPM form and function decomposition can reach four or more hierarchical levels, but this might not be necessary for all subsystems. In our case, we are interested in understanding how the legacy of the architecture of the Main Subsystem creates conditions for deployment of a new external function.
>
> Step 6 – Population of Each Subsystem in the Physical Domain: We create a representation for each subsystem in the Physical Domain by combining our hypotheses and information from industry documents and literature. The objective is to build a generalized model that we will build up, by identifying common drivers among subsystems, and identifying dominant influences from organizations in the internal and external institutional spheres. These models will be later validated with data from fieldwork.
>
> Step 7 –Add projections from the Internal Institutional Sphere and Identify Common Drivers: Building on Step 6, we identify drivers common to the subsystems, and projections from organizations in the IIS. We continually test our hypotheses as we observe the phenomenon.
>
> Step 8 – Add projections from External Institutional Sphere: To the representations created in Step 7, we add projections from organizations in the EIS. As in the

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[14] Object-process OPM representation is illustrated in **Figure 3.3**.

previous step, we want to represent the way in which different institutional actors affect the various subsystems in the Physical Domain.

Step 9 – Representation of Institutional Sphere: In this step we build a representation of the internal and external institutional spheres, which includes relationships among actors in the Internal and External Institutional Spheres.

*Stage 3 - Field Research*: An important outcome of the previous stage is the identification of information and questions that are still needed to complete testing our initial hypotheses. These data and information requirements will be included on the creation of a quasi-structured interview protocol to be applied during field research. Data from interviews and site visits will be used to test the hypotheses.

Step 10 – Case Studies and Interviews: The objective of this stage is to obtain the data to test the validity of the representation made in Stage 2. In the case of our research, we will apply quasi-structured interviews and case study research, with special focus on why and how the MEUs' architecture evolved. We transcribe the interviews and write the case studies in terms of the architectural evolution of the individual systems. At this point, there is no analysis of the case—the information is descriptive only.

As stated in Section 3.5.4, the objective of field research is to advance the learning about the system and help validating or rejecting the research hypotheses about the architectural evolution of our system. Thus, COIReM is designed to be used with case studies and interviews.

In addition to providing important parts of the data used in COIReM, case studies have further uses. Case study research makes it possible to link the theory behind the problem to the interaction between context and processes around the question of *why* and *how* things happen (Yin 1984; Hartley 2004; Silverman 2005).

*Stage 4 - Validation and Advancement of the Findings*: In this stage, we validate the generic model using data from fieldwork, and make observations about the evolution of the architecture of our system.

Step 11 – Revision and Validation of COIReM Representation: Once we have finished field research, we proceed to revisit our understanding of the setting and representation (Step 3 through Step 9). The main objective of Step 11 is to test our generic model against data from the case studies, interviews, and other documentation. Again, our main focus is on the reasons for and processes of change.

Step 12 – Observations about the Evolution of the System's Architecture: Finally, we conclude by detailing the reasons and process of the evolution of the system's architecture. We do this by aggregating our findings from the study of the context, historical analysis, the learning that comes from the process of representing our CLIOS System, and fieldwork. Here, our focus is to explain the architectural evolution as a process, and determine whether our hypotheses hold.

The next chapter presents an application of COIReM to the hypothesis that the innovator MEUs diversified into broadband services in this order of events and decisions:

i. Regulatory and technical changes triggered the adoption of IP-enabled components for monitoring and controlling electric power systems by MEUs, thus creating an endowment of resources that exhibit important economies of scope[15].

ii. The adoption of such technologies enabled learning and adaptation within MEUs through the operation and deployment of the communication network for operating Supervisory Control and Data Acquisition (SCADA) and Automatic Meter Reading (AMR).

iii. As managers of a resource surplus belonging to the community, MEU executives decided to take advantage of their economies of scope and create public value by offering broadband Internet access, which is scarce in rural and suburban areas.

This concludes the development of COIReM. The next chapter presents the application of COIReM for testing these hypotheses, and the conclusions of this analysis.

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[15] This first hypothesis builds on the findings of Osorio (2004) and Gillett, Lehr and Osorio (2004) about the relationship between deploying internal command and control systems and deploying external telecommunication services.

# Chapter 4: Qualitative Analysis: Why and How MEUs Became Broadband Providers

The previous chapter presented the integration of the Representation Stage of the Complex Large Interconnected Open Socio-Technical (CLIOS) Process and Object Process Methodology (OPM) into a new approach, called CLIOSP-OPM Integrated Representation Method (COIReM). Here, we apply COIReM to test our hypotheses about the architectural evolution of MEUs using data and information from interviews, documentation, and fieldwork for three cases.

These hypotheses, presented in the last page of Chapter 3, represent a preliminary suggestion about why and how municipal electric utilities (MEUs) became broadband providers and propose how the changes in their architecture led to their diversification. The results extend our knowledge and understanding about previous empirical findings of a statistical relationship between the deployment of IP-enabled solutions for system command and control by MEUs, and their entry into telecommunication services (Osorio 2004; Gillett, Lehr et al. 2006).

This chapter starts by stating our research questions and hypotheses, and is later organized along the stages of the COIReM analysis developed in Chapter 3: (i), Understanding the Setting, (ii) Building a Generic Representation, (iii) Field Research, and (iv) Validating and Advancing the Findings (See **Figure 3.13**). It is important to highlight that the overall results from qualitative analysis result from the complete COIReM analysis, and not simply from the representation of the CLIOS System.

## *4.1 Research Questions and Hypotheses:*

The starting point for applying COIReM is marked by our initial research questions and hypotheses. We will apply COIReM in order to test the hypotheses below, and to meet our research objectives.

In Chapter 3, we presented our research objectives for qualitative research: (i) to answer pending questions about the deployment of broadband services by municipal electric utilities, (ii) to better understand the underlying phenomenon behind this evolution, and (iii) to contribute to the study and representation of socio-technical systems. We presented the rationale for integrating CLIOS Process and OPM into the CLIOSP-OPM Integrated Representation Method to approach these questions.

This chapter addresses two related questions: (i) Why and how did MEUs become broadband providers? (ii) What phenomena underlie the architectural evolution of MEUs?

Our initial hypotheses were that:

i. Regulatory and technical changes triggered the adoption of IP-enabled components for monitoring and controlling electric power systems by MEUs, thus creating endowment of resources that exhibit important economies of scope.

ii. The adoption of such technologies enabled learning and adaptation within MEUs through the operation and deployment of the communication network for operating Supervisory Control and Data Acquisition (SCADA) and Automatic Meter Reading (AMR).

iii. As good public management should see the opportunity for taking advantage of unused valuable resources, MEUs decided to open their networks to take advantage of their economies of scope and create public value by offering broadband Internet access, which is scarce in rural and suburban areas.

This chapter uses COIReM to test these hypotheses. We begin with Stage 1 of the COIReM Process, in order to understand the setting, discover path dependence, and identify the major subsystems and institutional actors.

## *4.2 Stage 1 - Understanding the Setting*

The objectives of the first stage of our research are to understand the setting of the problem under study, identify sources of path dependence and architectural legacy by historical analysis, and identify the major subsystems and organizations in the external and internal institutional spheres. This first stage of COIReM is composed by four steps:

(i) System Description, (ii) Historical Analysis, (iii) Identification of Major Subsystems of the CLIOS System and (iv) Population of Internal and External Institutional Spheres. These steps are presented in in sections 4.2.1 through 4.2.4, respectively, which include commentaries and observations on how the analysis evolved as field research helped refine our original hypotheses.

### 4.2.1 Step 1 – System Description

The CLIOS System of interest is defined as the class of municipal electric utility that deployed broadband services before or by 2001. Analysis shows slightly different situations before and after that year in terms of goals, opportunities, challenges, threats, and weaknesses (See **Table 4.1**).

**Table 4.1**: CLIOS System Goals, Issues, Opportunities, Threats and Weaknesses

| CLIOS System Goals | Issues and Opportunities | Threats and Weaknesses |
|---|---|---|
| | 1990 - 2001 | |
| • Generating, transmitting and distributing electric power over a reliable system | Issues:<br>• System reliability and control: need to update infrastructure of SCADA and AMR<br>• Industry de-regulation<br>• Responding to constituencies and political agendas<br>• Increasing revenue<br><br>Opportunities:<br>• New technology allows for more reliable deployment of SCADA and AMR solutions<br>• Demands from community leading users allow for expanding action to telecommunications<br>• Ambiguity of TA96, Section 253(a) | Threats<br>• Telecommunications and Cable TV operators (incumbents and entrants)<br><br>Weaknesses<br>• Lack of experience, expertise, knowledge and in-house know-how in telecommunications |
| | 2002 - Present | |
| • Generating, transmitting and distributing electric power over a reliable system<br><br>• Providing High-Speed Internet Access | Issues:<br>• Increasing revenue<br>• System reliability and control: need to update infrastructure of SCADA and AMR, and become a local broadband provider<br>• System Control<br>• Responding to constituencies and political agendas<br><br>Opportunities:<br>• There are new and more proven options for deploying broadband<br>• Several MEUs are doing broadband, which helps to identify model to follow<br>• New technology allows for more reliable deployment of SCADA and AMR solutions<br>• Demands from community leading users allow for expanding action to telecommunications<br>• Ambiguity of TA96, Section 253(a) | Threats<br>• Telecommunications and Cable TV operators (incumbents and entrants)<br>• States are enacting laws prohibiting municipal broadband<br>• Proposals for new telecommunications act include language constraining municipal telecommunications<br>• Law suits by telecommunication operators<br><br>Weaknesses<br>• Lack of experience, expertise, knowledge and in-house know-how in telecommunications |

Source: the author

*Definition of the System*. The systems of interest are Municipal Electric Utilities that have deployed broadband networks for internal use by 2001, and subsequently offered broadband networks. MEUs are usually located in suburban and rural areas, with income per capita slightly below the United States average. These systems can be separated into two groups: (i) those deploying external broadband services before or by 2001 (innovators), and (ii) those deploying external broadband services starting in 2002 (followers).

Evidence from our fieldwork research supports the statement that the two groups had inherently different underlying reasons for deploying new technology communication networks. While innovators were first motivated to renew old infrastructure in order to run SCADA and AMR, followers were primarily motivated by the prospect of offering broadband services. In this research, we are interested in the process followed by the first group.

*System Goal*. The overarching objective of an electric utility (EU) is to provide electric power to meet load requirements. This means generating, transmitting, and distributing electric power to meet the demands of residential, commercial, and industrial customers. The nature and objectives of EUs have not changed during the last half century. As presented by Powell (1955), today's main subsidiary objectives of EUs are still to: (i) provide service to all who apply for it, (ii) avoid customer discrimination, and (iii) provide those services at a reasonable price, with quality and reliability.

*History and Path Dependence*. Currently, there are 2,006 MEUs in the United States. Half of them were in operation 100 years ago. They were established by local governments to accelerate the adoption of electric power, which, at the time, was believed to be an engine of local economic development, interestingly, as broadband is now. Since then, MEUs have been actively involved in local economic development beyond the electric power business, and many of them have diversified into gas, sewer, water, and wastewater services.

*Internal Technical Factors*. Electric power and telecommunications networks in MEUs began to converge during the 1970s with the first tests for implementing AMR through the telephone lines. Since then, the *clockspeed*[16] in the information and communication technologies has been much faster than in the electric power sector.

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[16] Fine (1998) defines clockspeed as the rate of evolution of a sector, or industry. The clockspeed of the telecommunications and information technology sectors is given by Moore's Law, which states that the density of transistors (per square inch) has doubled every 18 months. The clockspeed of the electric power industry is much lower, and could be approximated by the average year of its assets, which vary between 24 and 30 years, depending of the type of asset (CIGRE 2000).

Over the years, changes in cost and capacity of components of communications network infrastructure have allowed MEUs to invest in networks that not only cost less, but exhibit capacity in excess of their needs. This overcapacity, the pressing demand for broadband in their communities, social and organizational dynamics, and the MEU role in local economic development have been important factors in their deployment of external broadband services.

*External Economic Factors*. Two external factors have stimulated local governments in general, and MEUs in particular, to enter the telecommunication industry. First, the slow deployment of broadband networks by the private sector has left many places without access to high-speed Internet access. Second, there have been concerns about undersupply, pricing, and quality problems in broadband markets lacking competition.

*Policy and Regulatory Factors – Electric Power Sector.* Two factors have stimulated the adoption of IP-based SCADA and AMR among MEUs: (i) deregulation of the electric power markets, and (ii) increasing concerns about the fragility of the U.S. National Grid.

*Policy and Regulatory Factors – Telecommunications Sector*. The mix of the Telecommunications Act of 1996, state law, local government discretionary authority, and court rulings have generated a complicated and varied policy context for MEUs in telecommunications. Private broadband operators are the strongest opponents of municipal broadband, and have challenged it in court and lobbied state governments to enact laws preempting it. These challenges have been based on the interpretation of Section 253(a) of the Telecommunications Act of 1996, which states that state governments cannot prevent "any entity" from offering such services. The Supreme Court ruled in 2004 that, under the United States Constitution, local governments are not "any entity" because their power is granted to them by the state government (*Nixon vs. Missouri Municipal League*). As such, state governments have the last word on whether to allow municipal broadband. The result is a complicated, and sometimes self-contradictory, policy context that is not uniform for MEUs from state to state or, in many cases, even within the same state.

### 4.2.2 Step 2 – Historical Analysis

We need to understand how the historical evolution of the system has affected its present architecture and culture. This section presents the historical analysis, with the objectives of identifying path dependence in various fronts: (i) regulatory, (ii) entrepreneurial activity, (iii) role in local economic development, and (iv) technology. Analysis of the historical conditions under which MEUs evolved will demonstrate the architectural legacy that shaped their entry into the broadband era.

The history of electric utilities (EUs) began on July 13, 1816 with the inception of another illumination technology. That day, the Peale Museum in Baltimore was the first building in the United States to have gas light. The provider of the service, Gas Light Co. of Baltimore, later Baltimore Gas & Electric, became the first energy utility in the United States[17].

Sixty years later, in 1878, Thomas A. Edison founded Edison Electric Light Co., later General Electric, in New York as the first electric company in the United States and opened Pearl Street station in 1882, serving about 60 clients (Hughes 1983; EIA 2000; EEI 2004). In that year four municipal electric systems came into operation (Vennard 1968). In the following decade, the number of privately owned central electric stations increased to more than 2000. By 1902, there were more than 3,600 private utilities.

MEUs were created to meet the increasing need for electric power in rural areas, initially for public lighting, in a time of short supply from the private sector outside large metropolitan areas. In contrast to the 3,600 private utilities in 1902 there were only 847 municipal electrics (Vennard 1968; Chung 1997; Granovetter and McGuire 1998). This number increased to 1,103 by 1905, about 400 of which celebrated their 100th anniversary by 2005[18], and reached its peak of 3,084 MEUs by the mid-1920s.

The Great Depression had an important effect on MEUs, especially in small and rural communities, which were already underserved. The number of MEUs decreased to 1,863 by 1932 (Vennard 1968). (See **Figure 4.1.**) At that point, less than 12% of rural areas had access to electricity, which was one of the underlying reasons for the Rural Electrification Act (REA) of 1936 (EIA 2000).

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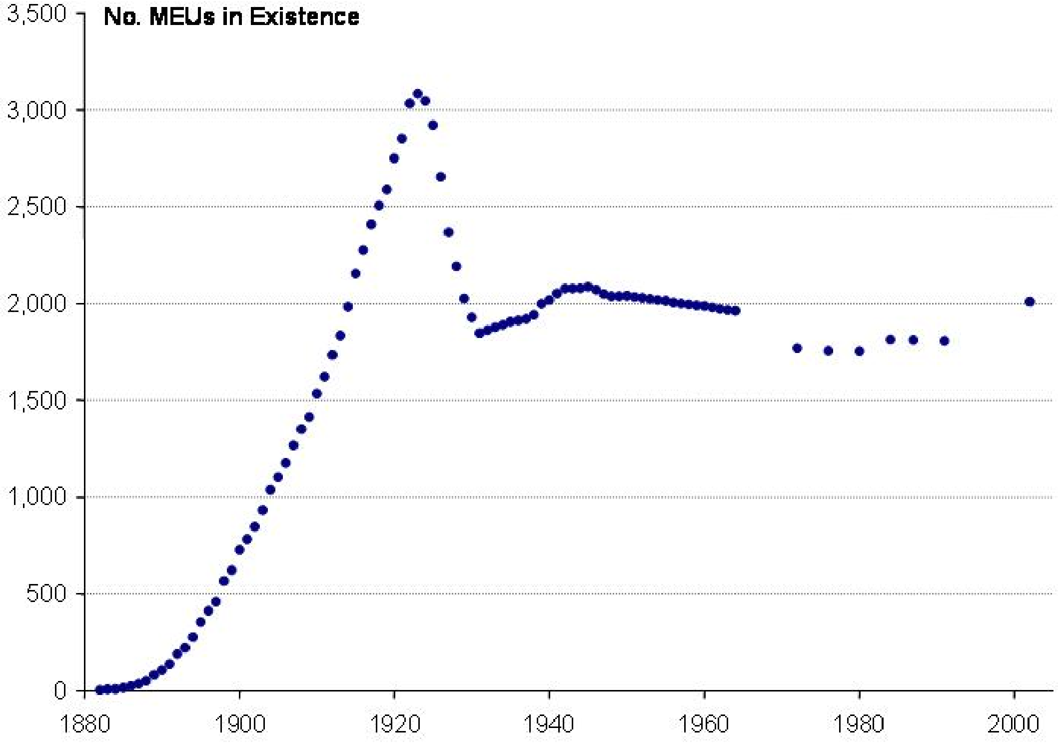
[17] See http://www.citypaper.com/2002-07-17/charmed.html

[18] See http://www.appanet.org/About/appa/APPAFactSheet.pdf

**Figure 4.1**: Number of Municipal Electric Systems in the United States, 1880-2000



Source: the author, based on Vennard (1968), Fox-Penner (1998) and APPA

Around the 1880s, two ideas were competing for the structure of the industry and architecture of EUs. First, Thomas Edison, George Westinghouse, and Samuel Insull believed that electric power should be generated in central stations and distributed to distant markets through transmission lines. This approach gained support in 1886 when Westinghouse succeeded in generating power at Niagara Falls and distributing it about 20 miles southeast in Buffalo, NY (EIA 2000). This strategy required EUs to invest capital in infrastructure for transmission and distribution, while investing in generation plants only as needed. Electric metering was invented and patented in 1888, which helped to build the business case for customized distribution on a pay-per-use basis[19].

The second idea involved local generation and distribution involving one generation system per building or group of buildings, following the example of heating systems.

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[19] See http://www.eei.org/industry_issues/industry_overview_and_statistics/history/index.htm

This concept was attractive because the construction of power plants and deployment of distribution wires was expensive. In spite of Edison's efforts, the market for independent systems was increasingly attractive as demand for electricity and the value of small generation equipment grew. In addition, many financial institutions, including J.P. Morgan and Co., backed the creation of this market.

Finally, Edison, Westinghouse, and Insull were more influential and the model of centralized generation, transmission, and distribution grew to become the system we know today (Granovetter and McGuire 1998). As Granovetter and McGuire point out, the idea of central station electric systems was "a major commitment for Thomas Edison". He mobilized his own resources and those of people working with him by founding what is today known as General Electric, and involved key collaborators in a network of decision makers in multiple firms towards that goal.

In addition to this legacy, other important business, technology, and regulatory developments have shaped the current architecture of electric utilities.

The goal of electric utilities is to meet load demand, which has grown rapidly in the United States. The invention of energy-intensive appliances such as commercial air conditioning (1902), home electric refrigerators (1913), and electric phonographs (1925) increased the demand for electricity far beyond the initial requirements for incandescent lamps (1879).

While new appliances increased demand for electric power, most of the United States did not have access to the new technology. Municipal governments started funding their own electric utilities in an attempt to accelerate the adoption of electricity and modern electric appliances and, and thus foster local development.

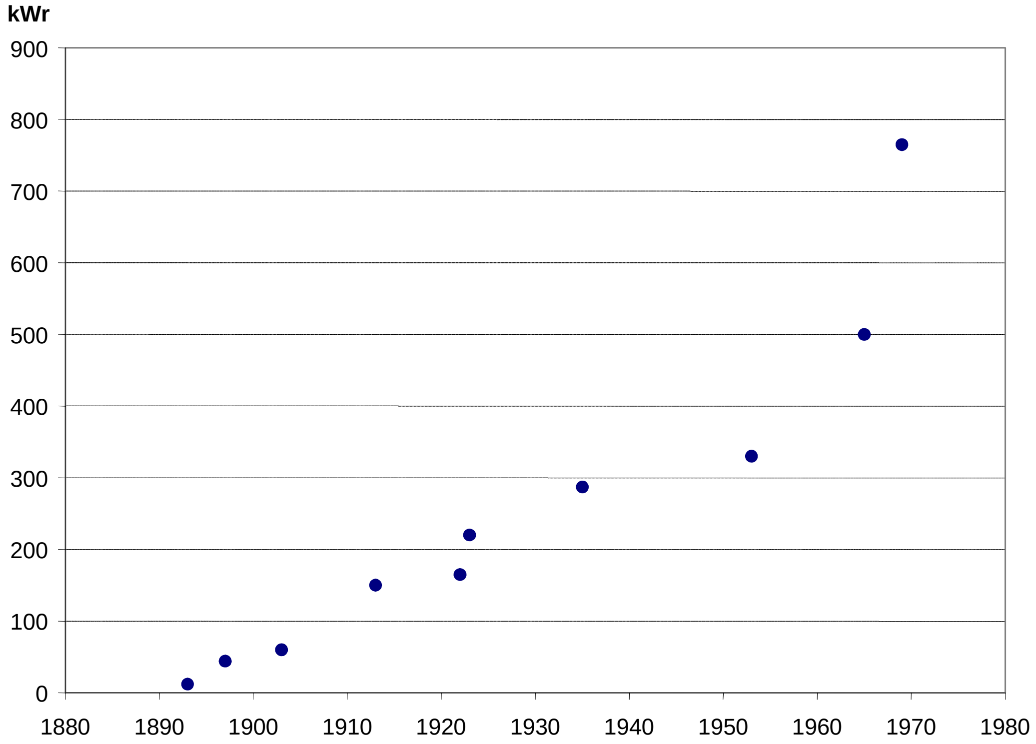
Between 1880 and the first half of the twentieth century, the electrification of the United States had a significant economic impact (Ristucia and Solomou 2002), and the number of MEUs stabilized around 2,000 (See **Figure 4.1**).

Independent stations were the only source of electricity in rural areas by 1930 (Nye 1990), which marked a strong role for MEUs in local economic development that can be traced until today. Indeed, 527 (79.2%) of the 665 MEUs that had deployed some type of communication service by December of 2005 had been founded before the end of the 1930s.

In addition to electric power and telecommunications, many MEUs also offer gas, sewer, wastewater, and water services. Of the MEUs offering broadband by the end of 2005, those founded before the 1940s provide an average of 2.8 services; those founded later offer an average of 1.9 services. In both cases, however, the median number of services in addition to electric power and telecommunications is two. The most common services are wastewater (396 utilities), sewer (436 utilities), and water (516 utilities). In many cases, as shown in the following paragraph and by case studies, MEUs grew and developed having an active role in local economic development by rendering localities self-sufficient in infrastructure-based services. This evolution represents an important sign of path dependence leading toward diversification.

The original concept for MEUs was one in which the public utility sought supply self-sufficiency, but purchased power in emergencies such as unexpected peak loads or major power outages from other utilities with excess capacity. This, however, changed during the mid-1980s. This period was critical in shaping some characteristics of the service as we know it today. For example, in the US, three-phase transmission began in 1893 in the state of California at 2,300 volts and 7.5 miles (Rustebakke 1983). Since then, generation and transmission capacity have grown rapidly (See **Figure 4.2**).

**Figure 4.2**: Growth of Generation and Transmission Capacity



Source: the author, based on Rustebakke (1983)

Nowadays, many MEUs have reduced their generation capabilities, and non-utility generators (NUG) have become important operators in satisfying public demand for power[20]. The central station architecture was increasingly important until the beginning of deregulation of the energy sector during the mid-1990s. The deregulation process called for “open access” to transmission lines, theoretically giving customers the ability to choose among vendors. Under these conditions, “wheeling”, an energy slang word used to define the movement of energy from one area to another, became increasingly important.

In terms of frequency, the current standard for 60 Hz was born in 1891, along with 50 and 25 Hz. Before that, 133 Hz was the most common. There was a battle around this until, in 1949, the Edison Company fully adopted 60 Hz as standard.

Rustebakke (1983) presents an interesting perspective on the evolution of electric utilities. In his view, the evolution of EU systems is driven by: (i) current and future expectations for load demand (similar to broadband deployment), and (ii) limitations imposed by policies and *previous decisions about the EU* (the legacy of the architecture). This is important from the perspective of how path dependence influences future architectural evolution, because the effects of some previous decisions have, in Rustebakke’s words, “constituted severe handicaps” for the future.

As electric power became a general purpose technology, the context in which EUs operated became more complex in terms of their impacts on markets, and the heterogeneity of their power sources. The broader context of these engineering systems can be defined in three complementary dimensions: (i) the local role of the MEU, (ii) its regulatory environment, and (iii) the broader context of the United States National Grid.

The first dimension can be defined in terms of: (i) people and organizations a system serves directly; (ii) non-customer stakeholders who would be affected by failures of the system; and (iii) stakeholders affected by any other environmental, social, health, or economic externality derived from the operation of the utility. This defines in important ways the role of MEUs in the community.

The second dimension can be defined in terms of the system’s regulatory environment. This includes the actions of the Federal Energy Regulatory Commission (FERC), the different state Public Utility Commissions (PUC), state legislatures, federal

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[20] Non-Utility Generators are independent power producers not owned by an electric utility, which core business is satisfying the demand for distribution capacity of EUs.

laws, and self--regulatory bodies such as the National Association of Regulatory Utility Commissioners (NARUC) and the North American Electric Reliability Council (NERC).

In the third dimension, we understand each electric utility as part of the larger context of the national power grid. Since 9/11 and the August 2003 Blackout, the importance of independent system reliability has become critical for national security and the reliability of the national infrastructure[21]. Benjamin Carreras, of Oak Ridge National Laboratory, commenting on the 2003 Blackout observed that:

> *The United States is so dependent on electricity that it requires a very reliable, very interconnected, very First World grid—the exact kind that we have. But that demand for reliability—and the intolerance for small blackouts—creates the risk for blackouts like yesterday's.*[22]

One of the latest changes in EU's architecture has been the adoption of SCADA and AMR to improve system control and make the grid more robust. MEUs first implemented SCADA and AMR using twisted-pair telephone lines during the late 1970s and early 1980s (Tamarkin 1992). This architectural legacy proved significant for the deployment of external broadband services during the late1990s, 2000, and 2001.

In the late 1990s, the twisted-pair telephone technology used for old-generation SCADA and AMR systems began to fail. At the same time, the electric power sector was being deregulated. MEUs started evaluating new options for replacing such infrastructure. As electric utilities have traditionally invested in technology with distant investment horizons-- between 20 and 40 years—they were not afraid to look at more expensive options. As a result, many implemented SCADA systems using hybrid fiber optics coaxial (HFC) and fiber optic networks which, unlike twisted-pair or power lines for carrying data, were not affected by electromagnetic radio frequency.

This is interesting from the perspective of the system's architecture. While it does not represent a major change in the externally delivered function of MEUs (providing electric power), it is a major change from the perspective of the internal function of system control: the adoption of these technologies marked the departure from analog and dedicated communication channels and the adoption of IP-enabled digital communications. This allowed convergence among communication channels, and enabled two-way communications and remote and real-time control of active components.

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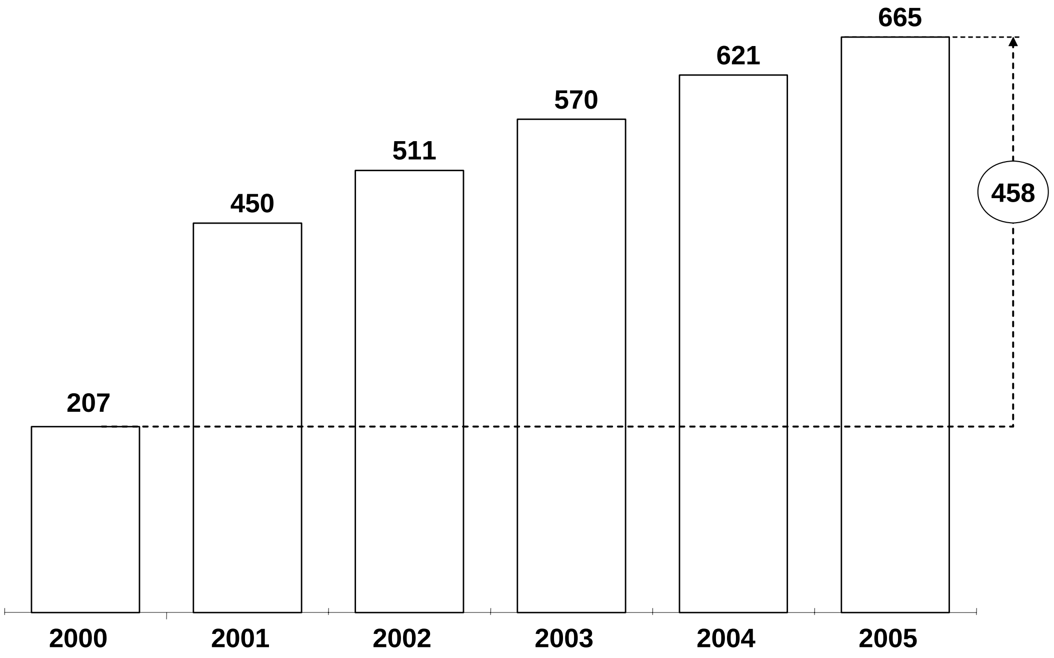
[21] See http://www.electricity.doe.gov/news/blackout.cfm?section=news&level2=blackout for various information

[22] See Sullentrop (2003)

These changes did not affect the core concept of MEUs, but it changed the alignment between the concept and the physical components and capacities of the systems. This change in the way some components were interconnected created an architectural innovation with important implications for the subsequent diversification of MEUs into telecommunications.

Operating SCADA over high-speed networks under Transmission Control Protocol/Internet Protocol (TCP/IP) created an endowment of resources that has been the base for a new service offering: advanced telecommunication services, including broadband Internet access and cable television. As a result, the number of municipal electric utilities offering advanced telecommunication services has more than doubled between 2000 and 2005. (See **Figure 4.3.**)

**Figure 4.3**: MEUs in Telecommunication Services



Source: the author, based on data from APPA

As mentioned before, diversification is not new among municipal electric utilities. This is important for two reasons. First, it shows a tradition of diversification by MEUs into local infrastructure-based utility services. Second, this willingness to diversify caused MEUs to develop the "ability to integrate, build, and reconfigure internal and external competences to address … changing environments" (Teece, Pisano et al. 1997). This definition of dynamic capabilities is a critical factor for organizational learning and adaptation. Teece, Pisano and Shuen suggest that, given path dependence and a market position, the dynamic capabilities of an organization reflect its ability to achieve "new and innovative forms of competitive advantage".

All three case studies demonstrated the importance of this history in the decision to deploy external telecommunication services. While the initial purpose of deploying advanced communications networks was to increase the reliability and efficiency of their existing operations, the tradition of responding to local economic development needs was a major driver--in the sense of the term used in the CLIOS Process—for an MEU to become a broadband provider.

The analysis in this section supports some of our initial hypotheses about (i) the role of regulatory and technical changes in triggering the adoption of IP-enabled communication networks by MEUs, and (ii) the MEUs' capacity for learning, adaptation, and entry into new services. While can say with confidence that MEUs have shown such capacity in the past, we now have to show that it carried over into the case of external broadband services.

### 4.2.3 Step 3 – Identification of Major Subsystems of the CLIOS System:

For the purpose of our research, we have defined three subsystems of interest in the Physical Domain of our CLIOS System: "Electric Power", "Broadband Division", and the "Economic Activity" subsystems.

The Electric Power Subsystem (EPS) represents the physical subsystem designed to perform the externally delivered function of providing electric power. This subsystem is responsible for generation, transmission, and distribution of electric power, and the monitoring and control of these operations. These functions are performed by major elements of the physical infrastructure: (i) generators, (ii) step-up and step-down substations, (iii) transmission and distribution lines, (iv) distribution transformers, (v) SCADA and AMR Systems, and (vi) equipment on consumer premises.

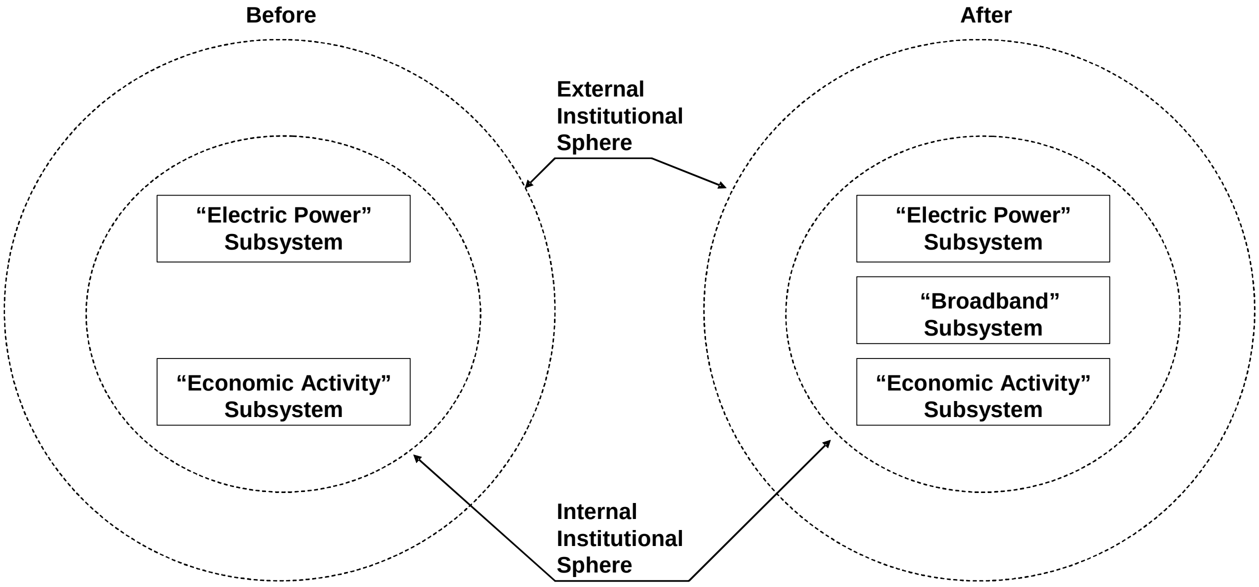
In the specific case of our CLIOS System, EPS is important for two reasons:

i. EPS as target of major Regulatory and Technical Changes: our hypotheses suggest that the architectural evolution of MEUs was triggered by regulatory and technical changes on the architecture of MEUs' electric power infrastructure. Thus, our approach to testing these hypotheses focuses on this infrastructure as an important unit of analysis.

ii. EPS exhibits Important Sources of Path Dependence and Architectural Legacy: EPS is the reason why MEUs were created in the first place; its current state reflects path dependence and, most importantly, is the result of legacy of past architectures. From this perspective, EPS also contributes to the architectural evolution and legacy. It is part of the context linking the deployment of external broadband services with regulatory and technical changes.

Our second subsystem is the Broadband Subsystem (BbS). It represents the subsystem that results from the architectural evolution of MEUs. **Figure 4.4** illustrates this by representing the physical domain before and after the architectural evolution of MEUs. We want to understand why and how the Broadband Subsystem was created.

**Figure 4.4**: Major Subsystems



Source: the author

The BbS was designed to channel data and communications through broadband Internet access. We can divide this overall function into four basic sub-functions that parallel the basic functions of electric power: (i) acquiring IP addresses (by connecting to the Internet), (ii) routing packets, (iii) providing IP addresses (by providing Internet connectivity to multiple types of hosts), and (iv) ensuring reliable and secure data transmission. From a physical perspective, the broadband infrastructure can be decomposed into: (i) routers, (ii) firewalls, switches and combiners, (iii) different types of servers, (iv) optical line terminations, (v) outside plant network, and (vi) customer premise equipment.

Finally, we define a third subsystem of the physical domain: the Economic Activity Subsystem (EAS). EAS has not been "designed" in the sense of the previous subsystems. It represents how the interaction of components, drivers, and functions performed by the electric power and broadband infrastructure, plus policy levers, affect economic growth and economic activity. For the purpose of our research, EAS is affected by (i) the creation of new firms, which is closely related to local economic growth and associated with increasing business opportunities and wealth; (ii) the provision of electric power; (iii) the provision of broadband internet services; and (iv) the creation of public value from collective action.

We chose these functions because we want to understand how they are related to the other subsystems of interest, and especially to the Internal Institutional Sphere.

We build a generalized representation of each subsystem (in section 4.3), gather data from field research based on the generic model and hypotheses (in section 4.4), and validate the model based on this data (in section 4.5).

The next step presents the actors in the Internal and External Institutional Sphere, and defines the way in which they affect the subsystems of the physical domain.

### 4.2.4 Step 4 – Population of Internal and External Institutional Sphere:

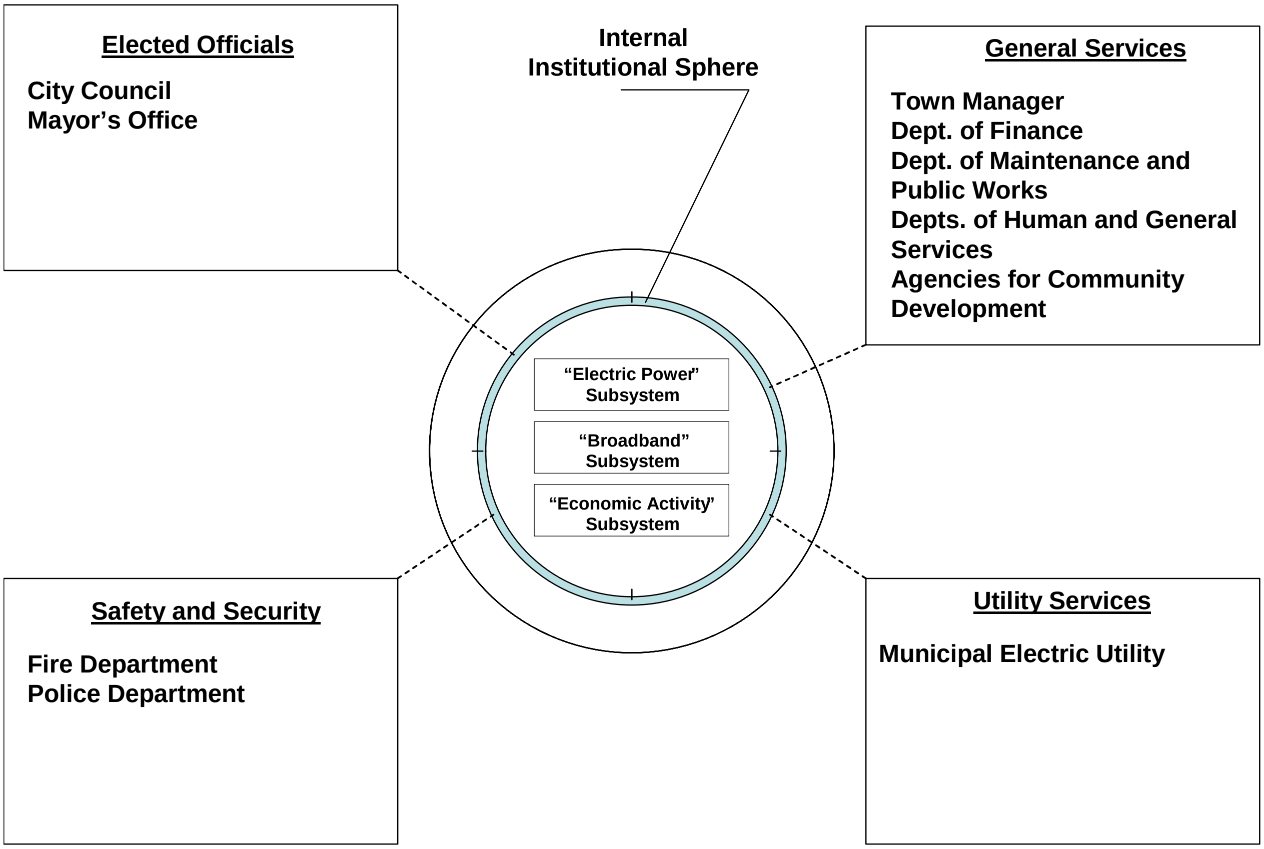
In this step, we identify the organizations in both the Internal and External Institutional Spheres, explaining their relevance and ways in which they affect the physical domain directly and indirectly. We want to understand how institutional actors are affecting the physical domain of our CLIOS system, and to integrate the architectural analysis of dominant influences into the representation process. This allows us to see and understand more clearly how various actors influence the functions and forms of the different subsystems.

#### 4.2.4.1 Internal Institutional Sphere

Usually, we would define the Internal Institutional Sphere (IIS) as only the organization hosting the technical infrastructure we are studying. Municipal Electric Utilities, however, are usually a department of the local government and subject to its jurisdiction. For this reason, we have included in the definition of the Internal Institutional Sphere the most important departments of the local government, including the municipal electric utility or municipal electric department. Thus, the IIS includes (i) the City Council and the Mayor's Office and departments of (ii) finance; (iii) community development; (iv) maintenance and public works; (v) human and general services; (vi) public safety, police, and the fire department, and (vii) the MEU.

**Figure 4.5** illustrates the IIS. The creation of the "Broadband Division" is the only difference in the state of the system before and after the deployment of external broadband services by MEUs.

**Figure 4.5**: Main Actors in the Internal Institutional Sphere

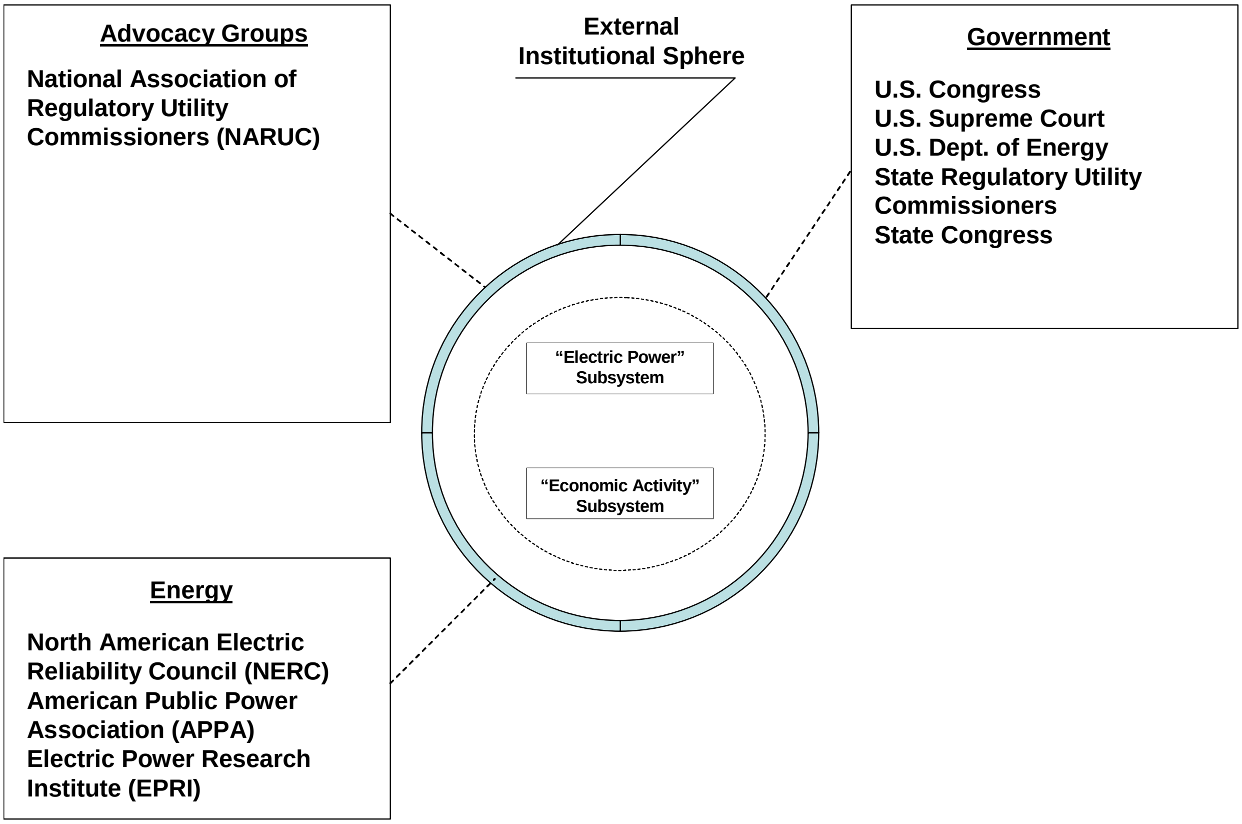


Source: the author

### 4.2.4.2 External Institutional Sphere

The External Institutional Sphere (EIS) corresponds to the institutional sphere in the traditional sense of the CLIOS Process. Its actors are divided into four groups: (i) judiciary and federal and state level government agencies; (ii) players in the telecommunication sector; (iii) actors in the energy sector; and (iv) advocacy groups. We can populate the EIS at two periods in time: before and after the architectural evolution of MEUs and their diversification into broadband services. **Figure 4.6** illustrates the organizations in the External Institutional Sphere before such evolution.

**Figure 4.6**: Main Actors in the External Institutional Sphere before Architectural Evolution

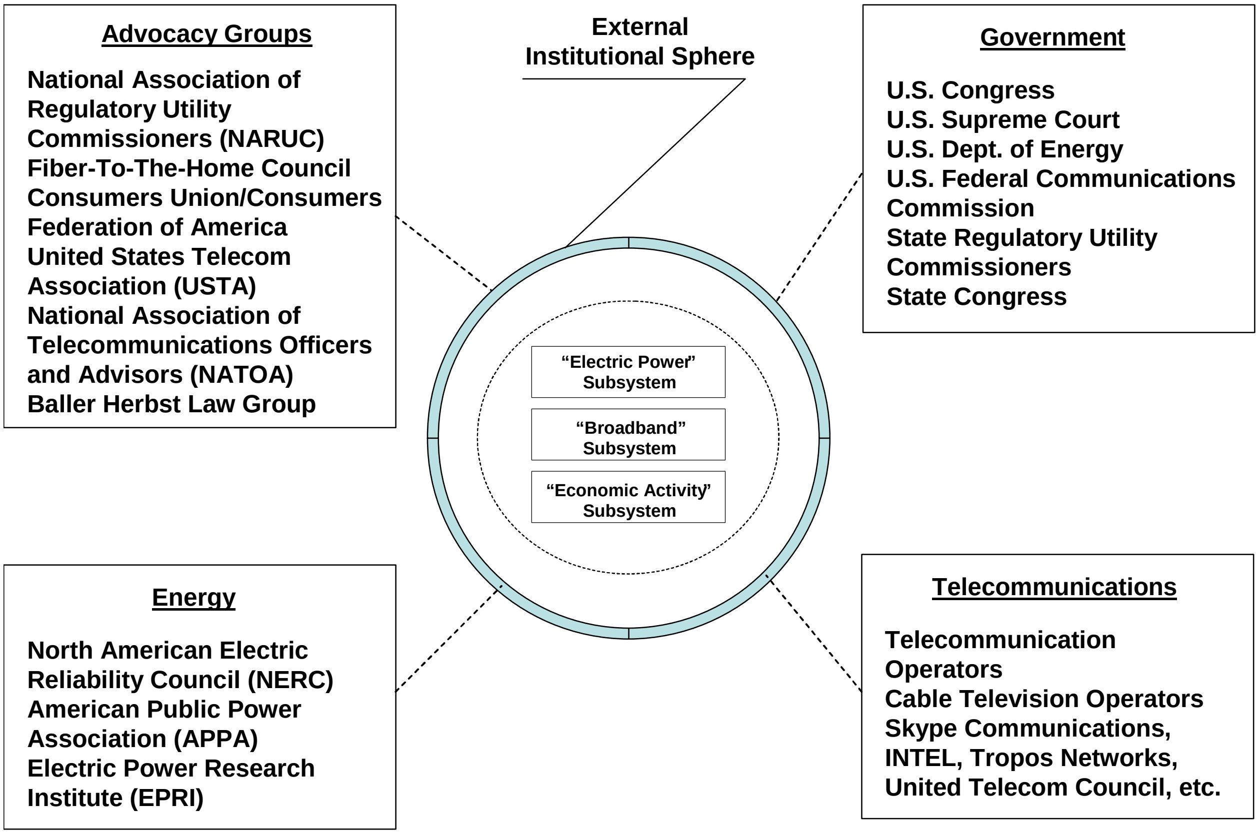


Source: the author

It is interesting to compare the difference between the number and type of actors on the EIS before and after MEUs became active in deploying external broadband. The deployment of broadband considerably increased the number and variety of advocacy groups and actors in the telecommunications sector, which significantly influenced the context in which the MEU was operating, and affected the relationship between government actors and MEUs.

**Figure 4.7** presents the EIS after the evolution of MEUs, where a whole new type of actors start playing a role in influencing the Physical Domain.

**Figure 4.7**: Main Actors in External Institutional Sphere after Architectural Evolution



Source: the author

*Government Actors*

There are several actors from the judiciary and federal and state level governments in the external institutional sphere.

At the federal level, Section 253(a) of the Telecommunications Act of 1996 (TA96) says that state governments may not prevent "any entity" from providing any telecommunication service. In other words, state governments cannot prohibit any third organization from providing telecommunications. The Federal Communications Commission interpreted this section to mean that political subdivisions of the state are not "entities" because they are not "third" parties, but only parts of the state government (FCC 2001). In 2004, the Supreme Court of the United States agreed. In *Nixon vs. Missouri Municipal League* the Court ruled that that "*the class or entities contemplated by §253(a) does not include the State's own subdivisions, so as to affect the power of States and localities to restrict their own (or their political inferiors') delivery of telecommunication services*" (U.S. Supreme Court 2004).

This ruling allowed state governments to enact legislation limiting the involvement of municipal electric utilities in telecommunications[23]. The United States Congress is currently debating four proposals that could have a significant effect on regulating municipal broadband. (See **Table 4.2.**)

**Table 4.2**: Legislation in the United States Congress Affecting Municipal Broadband

| Supporting Municipal Broadband | Restricting Municipal Broadband |
|---|---|
| • **Advanced Internet Communications Services Act of 2005 (H.R. 214)** introduced on January 4, 2005, with the objective of promoting the "*deployment of and investment in advanced Internet communications services*[24]." | • **Preserving Innovation in Telecom Act of 2005 (H.R. 2726)**: introduced in May 2005 in order to "*prohibit municipal governments from offering telecommunications, information, or cable services except to remedy market failures by private enterprise to provide such services.*[26]" |
| • **Community Broadband Act (S.1294)-** introduced on June 23, 2005, with the objective of solving the ambiguity in Section 253(a) of TA96 by stating that "*the Telecommunications Act of 1996 to preserve and protect the ability of local governments to provide broadband capability and services*[25]." | • **Broadband Investment and Consumer Choice Act of 2005 (S. 1504)**: introduced on July 26, 2005, with the objective of "*establish[ing] a market driven telecommunications marketplace, to eliminate government managed competition of existing communication service, and to provide parity between functionally equivalent services*[27]." |

Source: the author

Municipal Electric Utilities are not regulated by the U.S. Federal Energy Regulatory Commission (FERC) or the U.S. Department of Energy (DoE), but by each state Public Utility Commission (PUC) also known as the Regulatory Utility Commission (RUC). However, guidelines issued by the DoE, are very important in promoting technological innovation in energy and enhancing reliability of the electric power system.

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[23] As of June 2006, fourteen states have enacted such legislations: Arkansas, Florida, Missouri, Minnesota, Nebraska, Nevada, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, Washington, and Wisconsin.

[24] See http://www.govtrack.us/congress/bill.xpd?bill=h109-214

[25] See http://www.govtrack.us/congress/bill.xpd?bill=s109-1294

[26] See http://www.govtrack.us/congress/bill.xpd?bill=h109-2726

[27] See http://www.govtrack.us/congress/bill.xpd?bill=s109-1504

### *Energy Organizations*

Three important actors from the energy industry influenced the MEUs move towards broadband. These include the North American Electric Reliability Council (NERC), the Electric Power Research Institute (EPRI), and the American Public Power Association (APPA). NERC is a self-regulatory organization whose mission is to ensure the reliability of the national grid. It is divided into eight regional councils. These voluntary councils set standards and provide education and training, coordination, and also assessment, monitoring, and standards enforcement among members. Many MEUs have joined and are subject to NERC regulation and coordination.

EPRI is a major research organization with the mission of bringing solutions to the many challenges in electric power. EPRI membership is varied, including investor and publicly owned electric utilities. EPRI has special programs on enhancing the reliability and performance of the transmission and distribution of electric power through systems assessments and the transfer of new technology.

The APPA is an organization whose mission is to serve and support the development of "community-owned electric utilities"[28]. Founded in 1940, as many MEUs were being organized, APPA has provided technical support and served as a network for technology transfer and the discussion of a wide variety of issues in utility operations, such as utility governance, utility security, system reliability, disaster planning and restoration, etc.

### *Advocacy Groups*

The National Association of Regulatory Utility Commissioners (NARUC) is a non-governmental organization funded in 1889 with the mission to "improve the quality and effectiveness of public utility regulation. It includes the public utility commissioners of the all the states, including Puerto Rico, the Virgin Islands, and the District of Columbia.

The National Association of Telecommunications Officers and Advisors (NATOA) has been an active supporter of municipal broadband, as have the Fiber-to-the-Home Council, the United Telecom Council, the Consumers Union, and the Consumer Federation of America. Finally, some law firms played major institutional player in the municipal broadband arena. From all, the Baller Herbst Law Group has been the major provider of legal advice, services and research to individual MEUs, the APPA, NATOA, and other institutions.

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[28] See http://appanet.org/aboutappa/index.cfm?ItemNumber=9487

*Telecommunication Organizations*

The role of organizations on the telecommunications sector has been mixed. For one hand, the entry of MEUs into broadband increases the demand for hardware and software suppliers, but on the other hand MEUs compete with telecommunications service providers:

- Application service providers and equipment vendors such as Skype Communications, Intel, and Tropos Networks have traditionally supported municipal broadband due to the increased demand for equipment, software and services.
- Cable television and telecommunication operators, however, have traditionally been against the deployment of telecommunication services by electric utilities in general, and MEUs in particular. The United States Telecom Association, the trade association that represents the providers and suppliers of telecommunication services in the nation, has also been very active in opposition to municipal broadband.

The organizations in these four groups (Advocacy groups, government, energy, and telecommunications) are the most important actors in the institutional sphere. The impact of their positions on MEU diversification into telecommunication has been varied and is discussed in the following sections. The focus here is on identifying how each actor has affected the architectural evolution of MEUs.

The difference in number and type of institutional actors in the EIS is striking. Their arrival might have had important effect on MEUs at the organizational and technical level. The next sections explore this through the building of a generic model for the architectural evolution of MEUs, and its validation through case studies.

### *4.3 Stage 2 - Building a Generic Representation*

In this stage we build a generic representation of our CLIOS System based on our initial understanding of the problem and our hypotheses about the architectural evolution of MEUs. The objective is to use the *process of representing the system* as a way to learn about it, and make observations for the reasons and process of architectural evolution. In this stage, the “data” for representing the system is found in publicly available information, literature and the hypotheses about the problem. We then subsequently validate our representation through fieldwork and case study analysis.

### 4.3.1 Step 5 – Form and Functional Decomposition

Now we need to identify sources of architectural legacy that could explain the architectural evolution of MEUs, and find the adequate hierarchical level of decomposition for representing the subsystems of the Physical Domain:

- The identification of sources of legacy in the architecture is a major aspect in the theory of system architecture. The evolution of a system's architecture is highly determined by its legacy aspects: the future of a system's architecture is based on pre-existent components (form), functions or concepts that are not affected by change. Thus, as these factors (form, function and concept) are not affected by change, they become part of the system's architectural legacy and represent active constraints to, or opportunities for, its evolution.
- From a methodological perspective, finding the appropriate level of hierarchical detail for representation enables us to focus on the issues that are relevant for learning about the architectural evolution of our CLIOS system. The researcher needs to look for a level of detail that will maximize learning about the system, while excluding unnecessary detail. Thus, we can represent the system at a level just before unnecessary complexity begins to obscure relevant information. Dodder, McConnell, Mostashari, Sgouridis, and Sussman (2006b) present several heuristics for dealing with this. Here we add an additional option that is based on the hierarchical decomposition of elements of form and functions, and a close examination of the contribution of detailed representation to learning about the system.

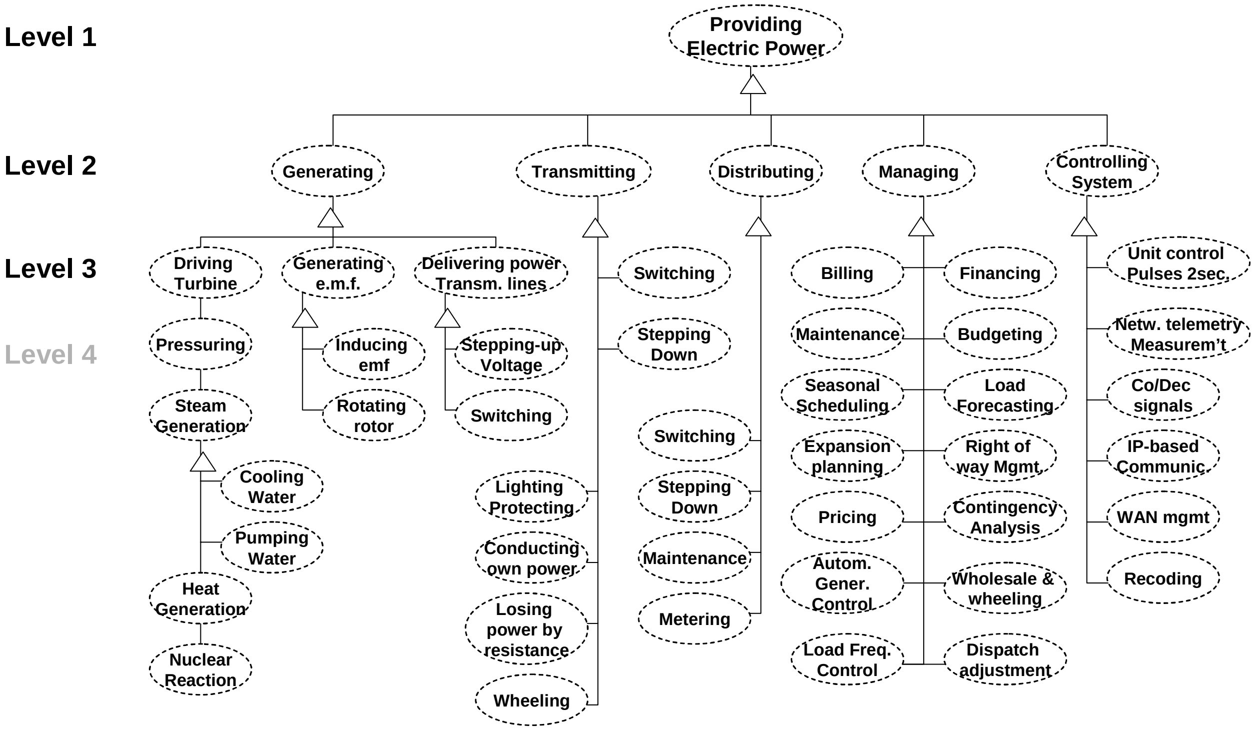
From the perspective of architectural legacy, we want to identify the existence of a technical-based legacy that could explain the evolution of MEUs from being providers of electric power to being providers of broadband services. From that perspective, we need to decompose the system in terms of function and form (components).

In the case of our research, it is clear that the Electric Power Subsystem is the one that intuitively should *ex-ante* present the sources of architectural legacy. Other cases, however, could present less clear choices and thus form and functional decomposition must be carried out across various subsystems of the physical domain. If an architectural legacy is present in the Electric Power subsystem, then it should be possible to identify one or more functions related to communications and data transmission. If at least one of these previous functions exist, we then should be able to identify the structural legacy (components of form) associated with such functions.

Identifying legacy is relevant because the pre-existence of a technological base suggests the pre-existence of a related knowledge base. In this case, identifying architectural legacy is relevant because could help us identify the existence of technology-based economies of scope. It could also signal the existence of an internal endowment of knowledge that can be leveraged.

**Figure 4.8** illustrates the functional decomposition of an Electric Power subsystem. From the perspective of system architecture, we found legacy function at the third hierarchical level: communications infrastructure used for controlling the system.

**Figure 4.8**: Functional Decomposition for Electric Power Subsystem



Source: the author

The adoption of information technologies by municipal electric utilities is not new. Their experiments with telecommunications began at least 30 years ago (Tamarkin 1992) with the testing of AMR and SCADA through telephone lines. This legacy enhanced performance when MEU's adopted IP-enabled communications during the 1990s (IBM Business Consulting Services 2004; Black 2005).

The new IP-enabled technologies required deployment, management, and operation of the Wide Area Network[29] connecting the various active components of the MEU's

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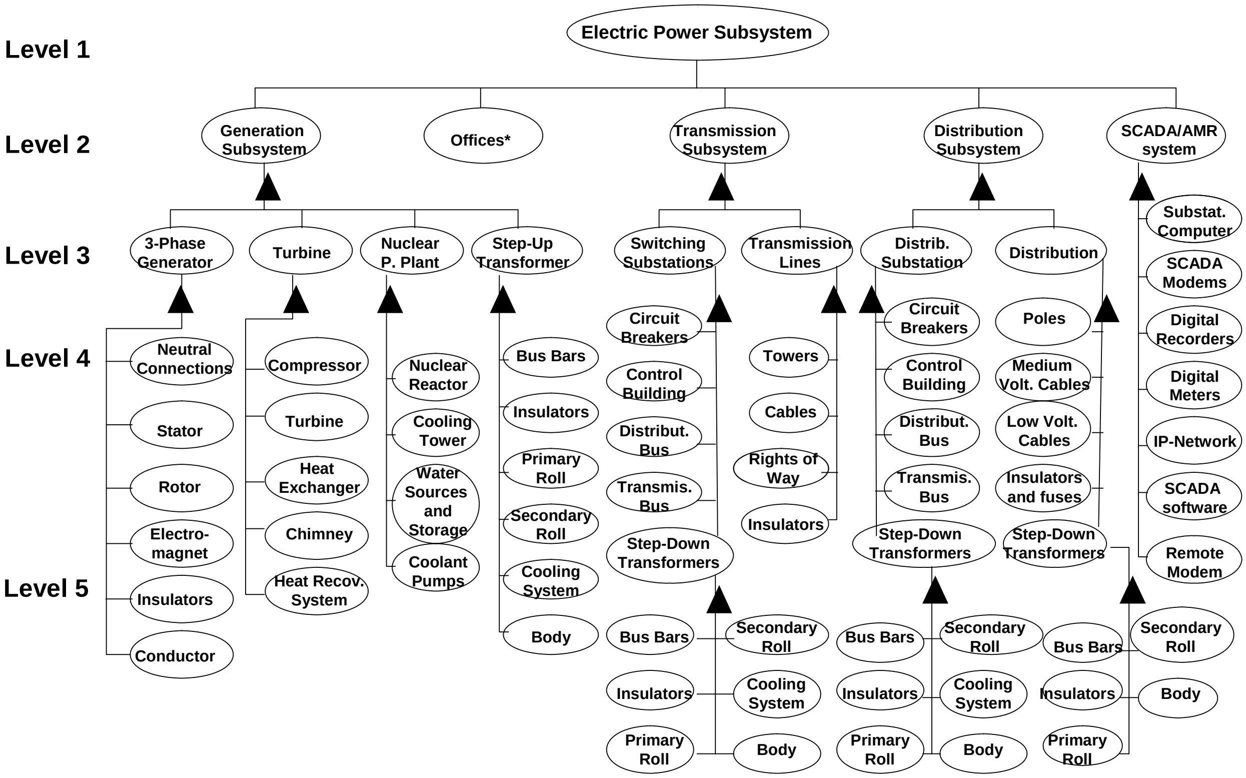
[29] A Wide Area Network (WAN) is a computer network used to connect Local Area Networks (LAN) distributed across different geographic locations. Thus, on the MEU case, the central office and each

electric power network. According to the figure, these functions are subsidiary to the second-level function of monitoring and controlling the system.

These functions are associated with structural components (form): IP-enabled communications are provided over an IP-enabled network. Thus, we can identify legacy at two levels:

1. The first adoption of communications infrastructure by MEUs happened decades ago for the purpose of operating SCADA. This represents a legacy that guided the adoption of new-generation technology which performed the old function in new ways.
2. The adoption of new IP-enabled communication technologies represents a legacy for the architectural evolution that followed their adoption.

**Figure 4.9**: Form Decomposition for Electric Power Subsystem



Source: the author

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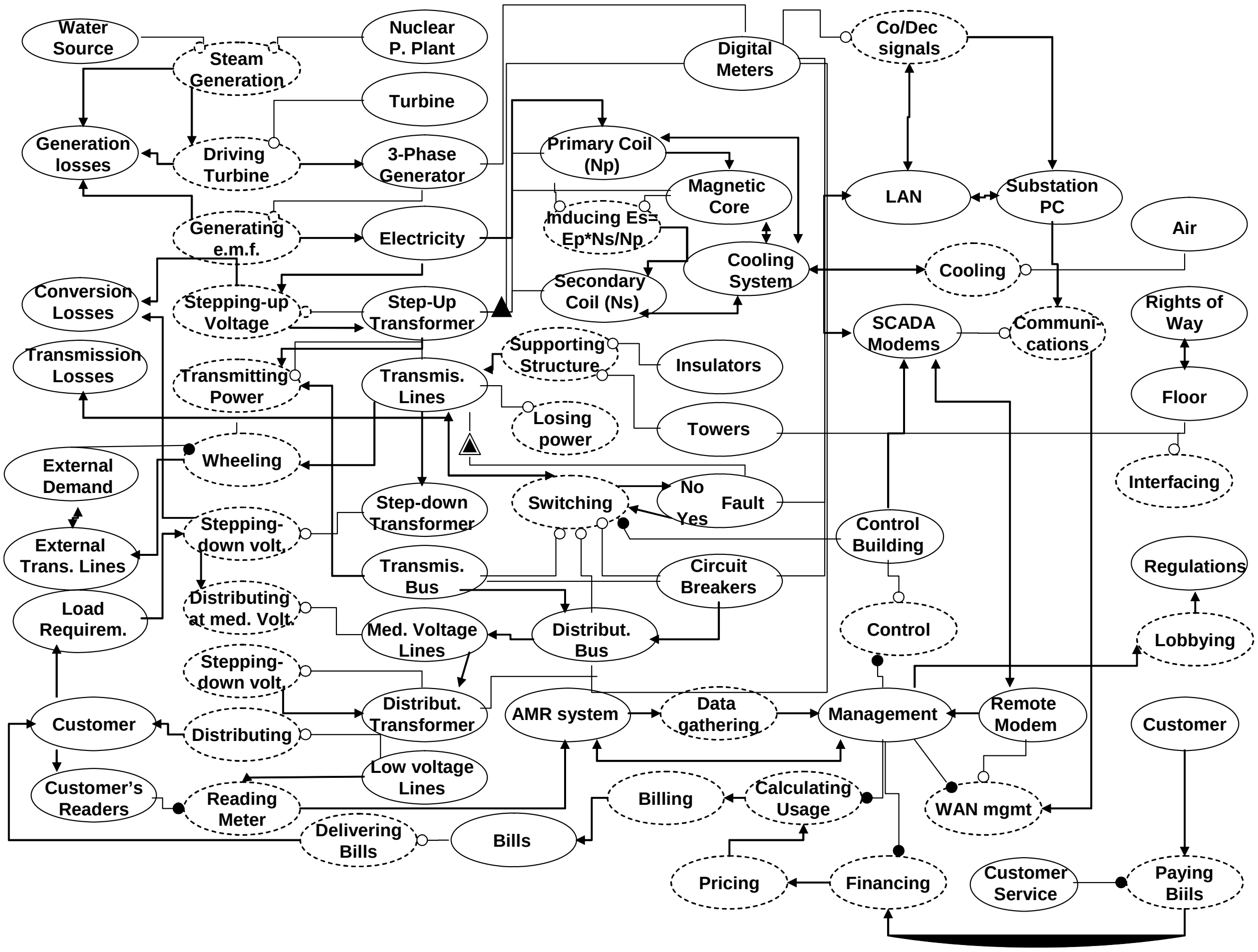
substation would have their own LAN. The control of the overall system is then possible by operating SCADA and AMR from the central office and connecting the LANs through a backbone.

**Figure 4.9** presents the form decomposition of the Electric Power subsystem. We can see the IP-enabled communications network as a third-level component (which can be further decomposed).

From the perspective of finding an appropriate level of analysis, we find that most of what is presented in **Figure 4.8** and **4.9** is not useful for our research purposes. The first representations of the electric power subsystem were made at four levels of disaggregation (The fourth level applies only to the function of generation.) This representation was detailed enough to allow learning, but it is too detailed for the purpose of representing all subsystems in our analysis. Even a third level of disaggregation added no additional insight with the sole exception of the function for "Controlling System", where we see "IP-Based Communications".

**Figure 4.10**: Form-Function Representation of Electric Power Subsystem



Source: the author

The decomposition of form of the same subsystem at four and five hierarchical levels provides little useful description for the purpose of our research beyond the third level (See **Figure 4.9**). **Figures 4.8** and **4.9** can be joined into a single form-function representation (See Figure **4.10**), but the resulting representation is too detailed to be helpful for analysis.

In the same manner, looking only at the first or second hierarchical levels of form and function does not provide enough information about the system as we wish to understand it.

The appropriate level lies somewhere in between and includes the combined representation of forms and functions into a single diagram that (i) is clear enough to offer the amount of information that, in the judgment of the researcher, maximizes learning; (ii) combines functions and form at a deep enough hierarchical level to illustrate the general concept of the subsystem and its overall context; and (iii) provides enough insights about its behavior. This is illustrated in the next steps.

Besides helping us to find the appropriate level of detail to represent our CLIOS System, the analysis of the Form and Functional Decomposition for the Electric Power Subsystem also builds support for our hypotheses. We identified internal functions of data transmission based on new generation communication networks within the Electric Power subsystem. This means there is a pre-existent technological base for broadband communications, which is associated with a pre-existent knowledge base for its operation. This technological base, however, is also related to the pre-existence of a specific knowledge base that, when perceived as a resource, can be leveraged to support diversification into broadband services.

### 4.3.2 Step 6 – Population of Each Subsystem in the Physical Domain:

We populate the three subsystems in the Physical Domain: "Electric Power", "Economic Activity" and "Broadband Division" based on our hypotheses, our understanding of the problem, and on information from industry documents and the literature.

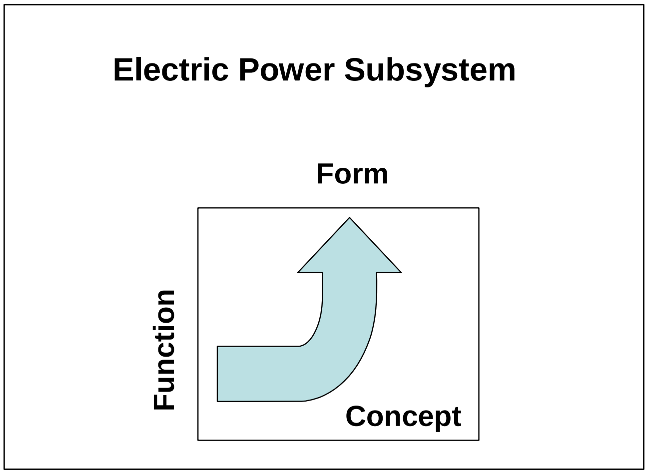
#### 4.3.2.1 Electric Power Subsystem

This subsystem is defined by the physical infrastructure of the MEU, which was presented in the previous step. Its major objective is to generate and purchase electric power, and then transmit and distribute it to fulfill load demand from residential and business customers.

A simple way to represent this subsystem would be through **Figure 4.11**. We have defined previously that the architecture of the Electric Power Subsystem can be understood in terms of its externally delivered function, its form and the underlying concept that gives form to its function. In this context, we want to understand architectural evolution from the perspective of the dominant influences on each of these dimensions.

The historical analysis in Section 4.2.2 helped us understand the evolution of the current concept of municipal electric utilities and their path dependence, and the form and function decomposition in Section 4.3.1 help us understand the way this concept matches form to function.

**Figure 4.11**: Abstraction of the Architecture of the Electric Power Subsystem

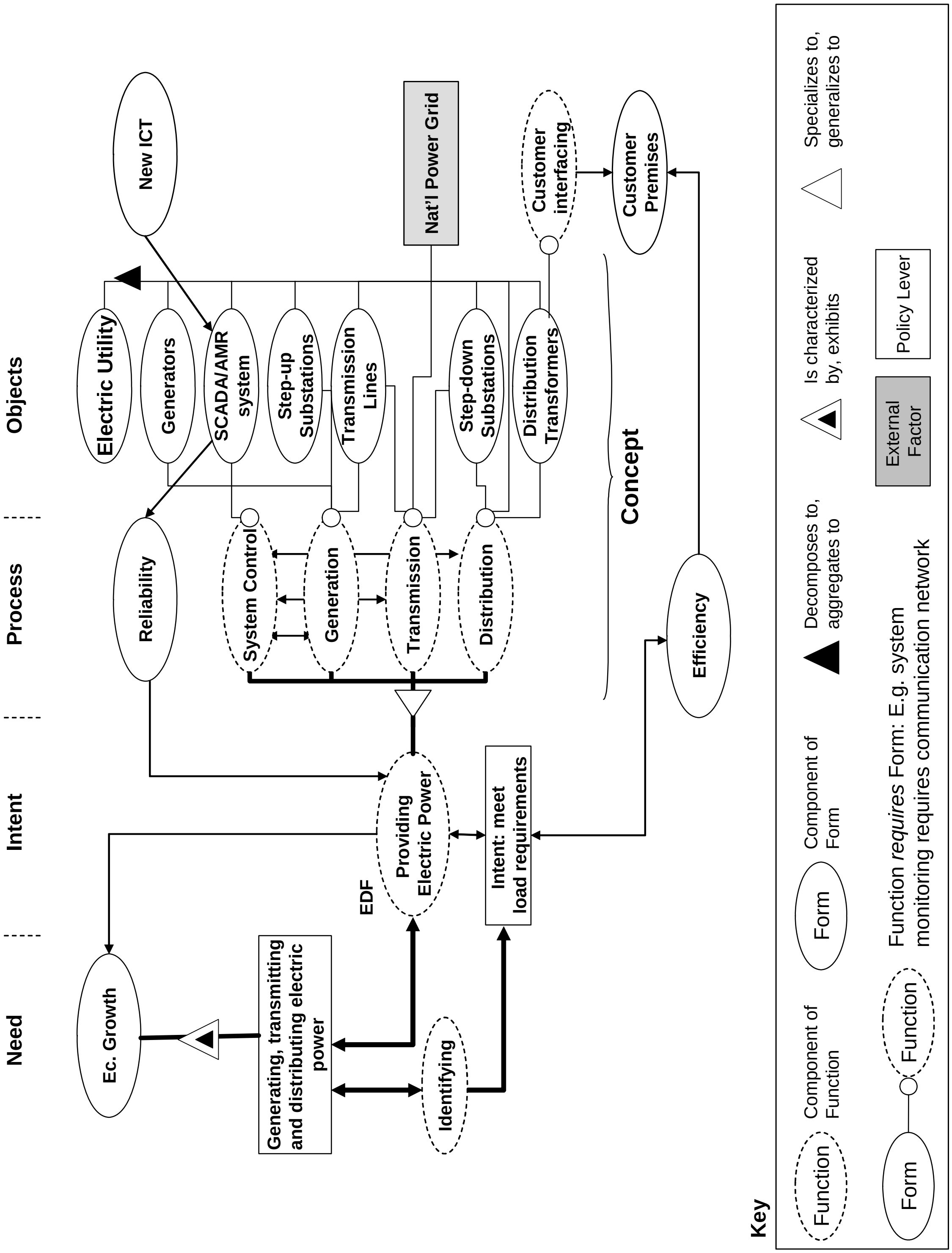


Source: the author, based on Crawley and Weigel (2004)

Thus, **Figure 4.11** works as an abstraction of the architecture of this subsystem, but it is too simple to be helpful for the analysis. The Electric Power Subsystem, however, can be decomposed into system control, electric power generation/purchasing, transmission, and distribution. These functions require the work of several components of form (e.g. substations, distribution transformers, transmission and distribution lines, SCADA and AMR systems). In the previous section, we presented a highly detailed decomposition of the form and function of a MEU.

We have distilled the information that is relevant for our analysis and for representing the Electric Power Subsystem going beyond the abstraction in Figure 4.11 and by including the components and functions that give a sense of its overall concept, and include the minimum relevant information without adding unnecessary complexity to the representation. This is shown in **Figure 4.12**.

**Figure 4.12**: Electric Power Subsystem



Source: the author

**Figure 4.12** represents the Electric Power subsystem according to the following dimensions:

1. The *need* to be fulfilled: economic growth requires the generation, transmission and distribution of electric power.
2. The *intent* of fulfilling this need through the subsystem's externally delivered function (EDF): the provision of electric power
3. The internal *functions* that allow the delivering of the EDF,
4. The *structural components of form* of the subsystem that deliver the internal functions, and
5. The underlying *concept* which is the way in which components of form and function are related.

The figure shows how each function is associated with specific physical components, and how they create the overall concept of the subsystem (Please note the key to understand the representation). This concept, as described in the previous chapter and previous section, is that electric power is generated in one place, and then transmitted and distributed over long distances.

The typical MEU is formed by one or more generation plants or powerhouses, if it generates at least part of its energy. Generators can convert energy from fuel into electro-motive force (efm) from varied sources (nuclear, fossil fuel, hydroelectric, or a combination of the above). Each of these sources implies a different architecture for generation. Each power station has a switchyard, which uses transformers to raise the voltage so that market demands can be met despite transmission and conversion losses[30]. In some cases, MEUs purchase all the power they distribute from third parties.

The functional goal or externally delivered function (EDF) of the subsystem-–to provide electric power—reflects customers' need for electric power as required for local economic growth. The EDF is characterized by four major components of function: (i) system control, (ii) generation and purchasing of electric power, (iii) transmission, and (iv) distribution of electric power.

Transmission is carried out through poles and power lines, which are built over land granted by rights of way (which are owned by the local government). Transmission depends on a number of transmission substations, with different numbers and types of transformers to reduce voltage from high to medium depending on the distance, type

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[30] See Powell (1955).

and number of customers, and loads. Special substations may be deployed for large industrial customers[31].

A number of distribution substations also decrease voltage in order to supply final customers through distribution transformers installed on poles and in vaults. The number of distribution transformers depends on the number of customers and their load demand. These elements of the system architecture affect the load and the number of transformers needed to serve a given number of customers. While the average number of residential users served by a distribution transformer in the United States varies between four and 15, this number reaches 50 in Europe[32].

There are various reasons for this. First, Europe and the United States have different approaches to network architecture reflecting estimations of demand growth. Second, during the last 25 years of the twentieth century, the average size of American homes increased almost 40%, almost double the size of average homes in Europe, which has implications for both household density and demand per household[33]. Finally, according to the Energy Information Administration (EIA), the United States is "by far the largest residential energy consumer in the world"[34]. The EIA suggests that this might result from higher income levels and greater dependence on electricity-based appliances than the average households in Europe. These factors combined explain the large difference in the number of residential users served by distribution transformers in the United States and Europe.

The purpose of SCADA systems is to monitor and control the reliability of the electric operations, the quality of service, load variations, etc. SCADA systems can also be implemented in terms of different concepts and architectures, for instance: (a) using power lines for communicating data, (b) using telephone twisted-pair lines, and (c) using fiber optics networks. Regardless of the technology selected, SCADA systems operate over a communication network and have the function of command and control for generation, transmission, and distribution.

The high clockspeed in information technology and telecommunications have advanced communication networks to a level never seen before. IP-based telecommunications are more reliable, and have more capacity and better performance

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[31] See Nasar (1985) and McDonald (2003)

[32] See National Research Council (2002) and Edison Electric Institute, in Electric Perspectives August 2001 at http://www.eei.org/magazine/editorial_content/nonav_stories/2001-07-01-connection.htm

[33] See http://www.worldwatch.org/node/808

[34] See http://www.eia.doe.gov/oiaf/ieo/enduse.html

than analog communications over dedicated lines. Of all options currently available, fiber optic networks have the greatest capacity for data communication. Most MEU towns are relatively small, making it possible to deploy Passive Optic Networks (PON) for controlling the IP-enabled SCADA and AMR systems from the central office. This increases the robustness of the communication network and the reliability of the SCADA and AMR solutions even more.

Additionally, there are four factors that have guided the deployment, evolution and operations of MEUs: (i) economic growth, (ii) reliability of the electric power subsystem, (iii) efficiency of the system, and (iv) adoption of new information and communication technologies (ICT). All of them have important influences on the architecture of the subsystem at different levels:

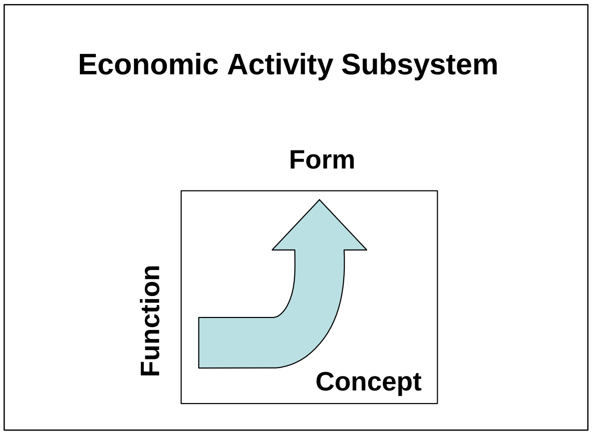
- *Economic Growth* was the major need to be fulfilled by the creation of the MEU.
- *Efficiency* is a major driver in both meeting load requirements and the operation of the infrastructure, so load requirements can be met at minimum cost (which enhances public value).
- *Reliability* is a major issue in the provision of electric power, and a reason for the deployment of automated solutions for command and control and real-time monitoring of the grid.
- *New Information and Communication Technologies* have increasingly become a focus of attention for utilities services in general, and electric utilities in particular, due to the ease of managing information and command and control, and increased internal efficiency.

#### 4.3.2.2 Economic Activity Subsystem

The Economic Activity Subsystem is special because is not *engineered* in the sense of the Electric Power and Broadband subsystems. One could create an abstraction of the Economic Activity Subsystem similarly to the Electric Power Subsystem as in **Figure 4.13**.

While one could argue that economic systems can be architected (i.e. central government planning), others would state that they are result from the collective effect of the individual enterprise, which would follow from Adam Smith’s “invisible hand” (Smith 1776). Without entering into this argument, we will assume that in either case there is a central concept that also gives form to the major function of a system like this. In some cases, the major function will be creation of wealth while in others, it will be welfare.

**Figure 4.13**: Abstraction of the Architecture of the Economic Activity Subsystem



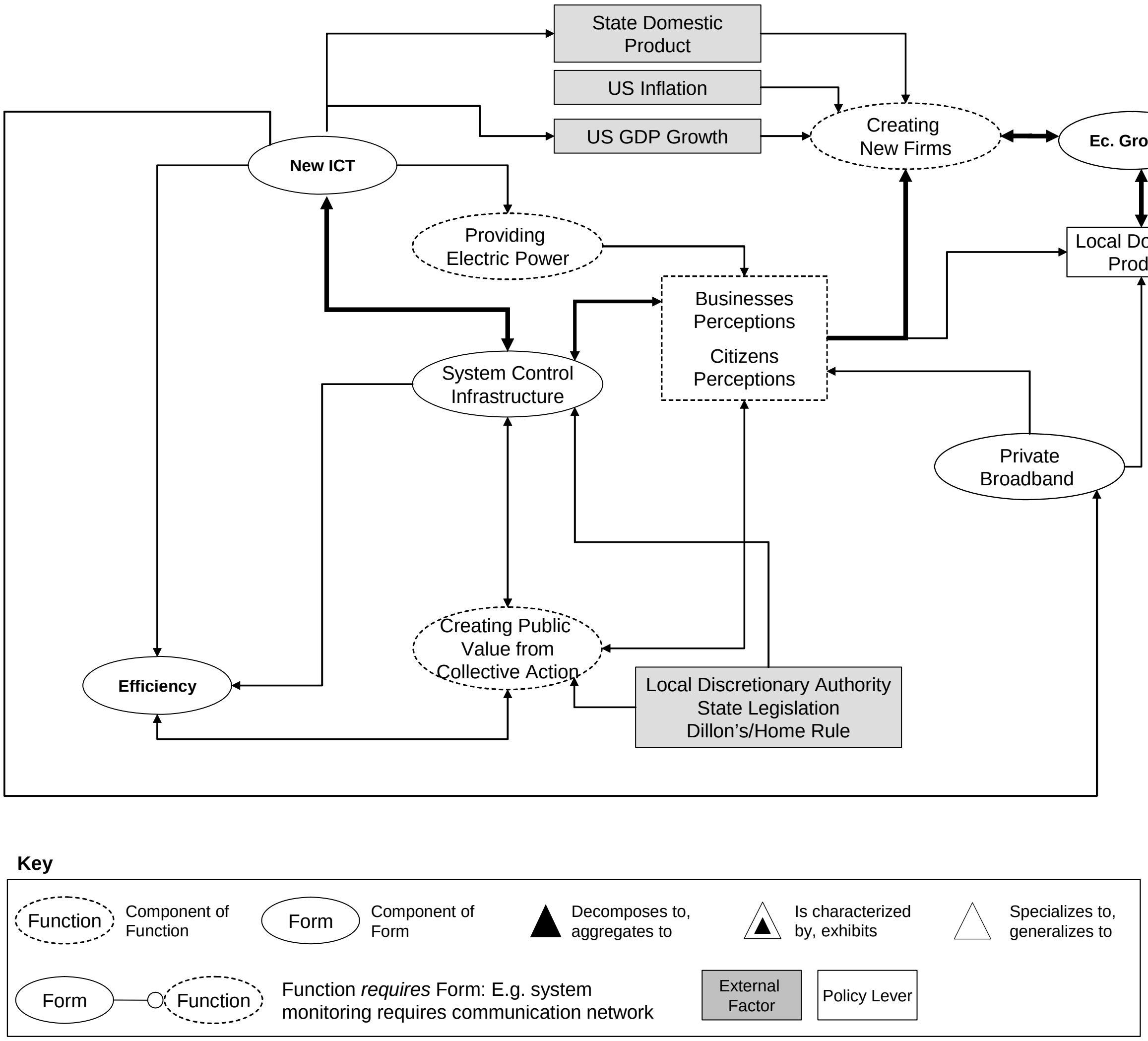
Source: the author, based on Crawley and Weigel (2004)

As in the previous case, we could take a closer look to the Economic Activity Subsystem. In this case, however, it is important to look at it before and after the deployment of the Broadband Subsystem, which we will analyze in the following section.

**Figure 4.14** presents the Economic Activity subsystem before the creation of the broadband division. Up to this point in time, there had been an important evolution in the capacity and cost of information and communication technologies in general, including fiber optics technology, over the last decade (Jorgenson 2004). These changes have been positively affecting the world economy, and especially the growth of the United States (Jorgenson 2001; Stiroh 2002; Stiroh 2002b; Jorgenson 2004).

The representation of this subsystem in **Figure 4.14** includes the components directly associated with the level of local domestic product, in particular, and overall economic growth and development in general. The level of detail in representing this subsystem is sufficient to highlight relevant components and functions and identify those that play critical roles in fostering economic growth based on broadband availability.

**Figure 4.14**: Economic Activity Subsystem (before creating the Broadband Subsystem)



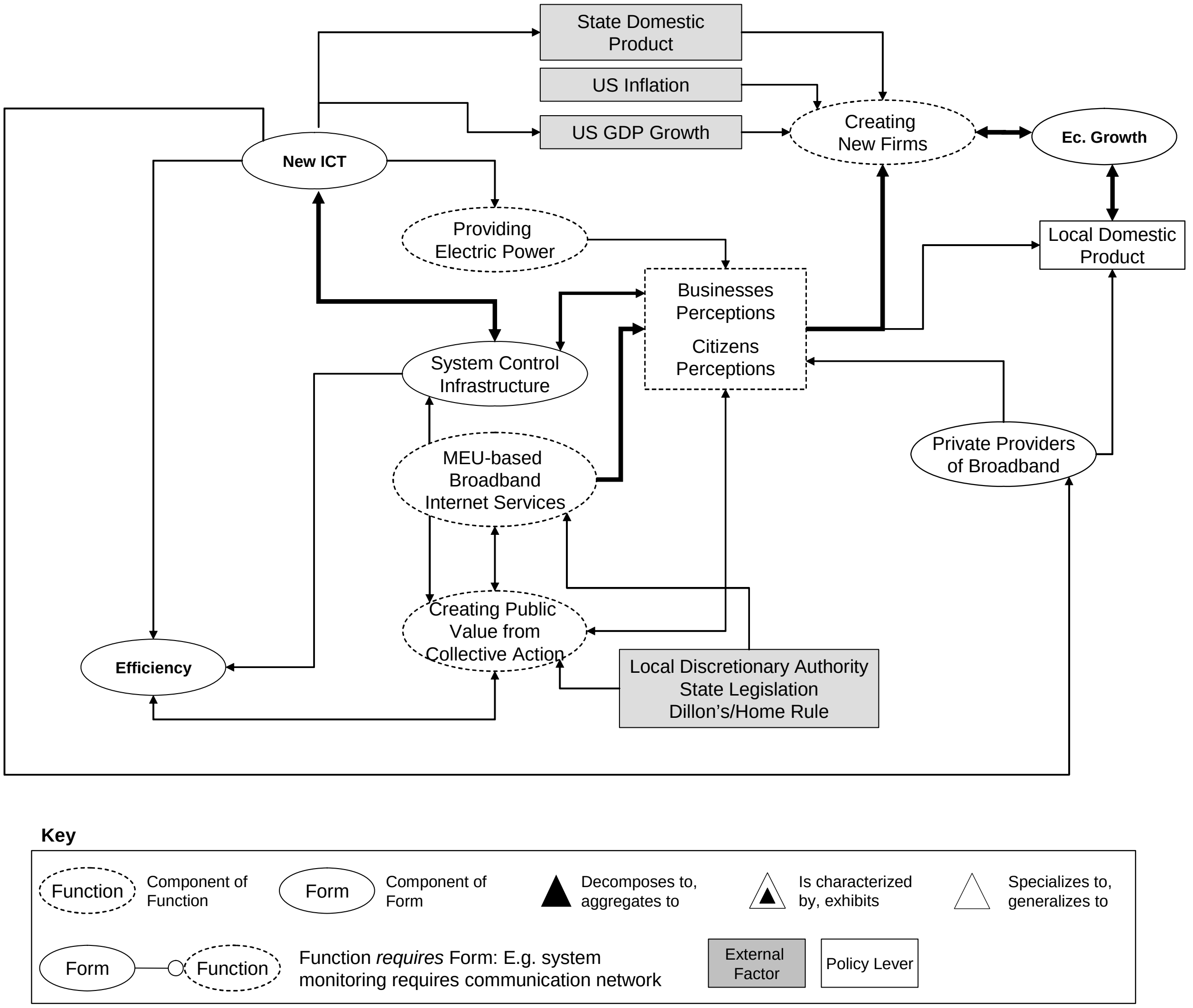
Source: the author

The change in the landscape following the deployment of municipal broadband by MEUs is represented by **Figure 4.15**. First, there is a major change toward using the discretionary authority of the local government for creating public value by using the new infrastructure to provide broadband services. A basic assumption in the local government is that the availability of broadband infrastructure will attract economic development.

This affects the perceptions of citizens and businesses about the possibilities for creating and attracting new firms, which in turn affect local economic growth. The adoption of broadband-based technologies by firms and their effect on local economic development is, however, subject to the existence of a local supply of private broadband.

Research has shown that information technologies can potentially increase the market value of firms, increase productivity, and decrease transaction and coordination cost (Brynjolfsson, Hitt et al. 2002). This is represented in **Figure 4.14** and **Figure 4.15** by the relationships between the New ICT and national and state economic growth, and control systems for the provision of electric power. While the adoption of ICT was mostly focused on the operation of reliable and more efficient electric power operations, efficiency was mostly focused on the operation of the local electric power grid, and the creation of public value.

**Figure 4.15**: Economic Activity Subsystem (after creating the Broadband Subsystem)



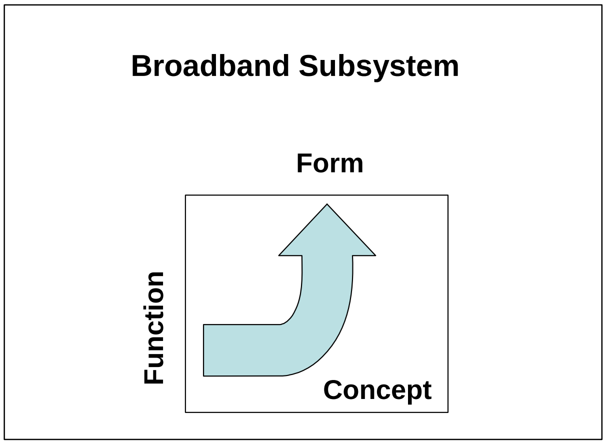
Source: the author

At a national level, econometric analysis has show that broadband availability in the United States has a positive effect on economic development by increasing the growth rate of business establishments, employment, share of business establishments in IT-intensive sectors, and raising the value of real estate (Lehr, Gillett et al. 2006). The specific role of MEU broadband in these phenomena has not, until now, been considered.

### 4.3.2.3 Broadband Subsystem

We define as "Broadband" the physical subsystem deployed to provide high-speed Internet services and to channel packets for business and residential customers. We identified the relationship between broadband availability and the objective of economic growth during the discussion and analysis of the "Economic Activity" subsystem, and the literature review. The intent to provide broadband Internet access defines the Externally Delivered Function (EDF) of the Broadband Subsystem. The underlying concept is represented by the "*End-to-End Argument*" (Saltzer, Reed and Clark 1984). This became one of the main principles in the design of the Internet and IP-based applications.

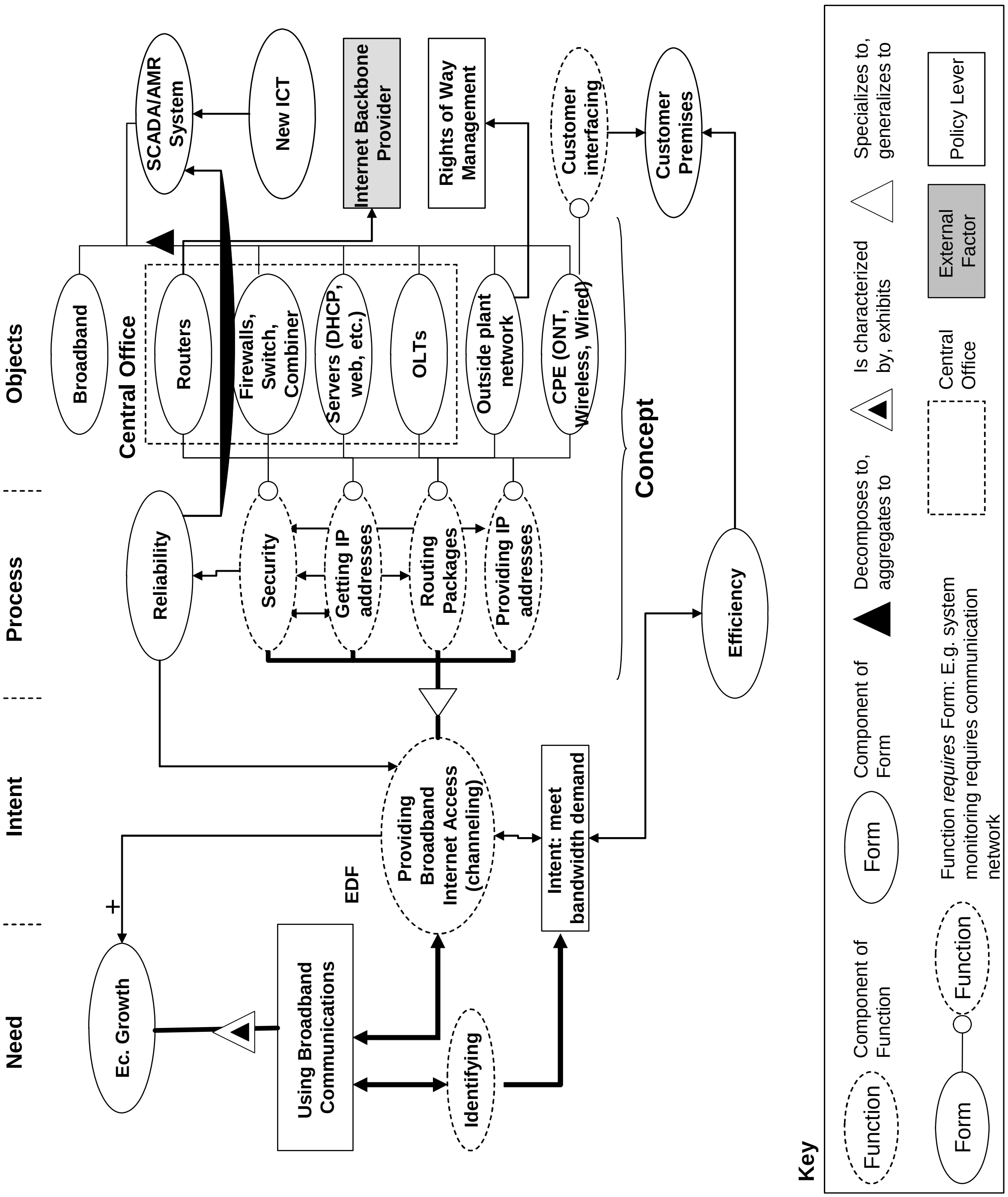
**Figure 4.16**: Abstraction of the Architecture of the Broadband Subsystem



Source: the author, based on Crawley and Weigel (2004)

However, as in the previous cases, one can take a closer look to the Broadband Subsystem by decomposing its form and function into various components and internal functions. As in the case of **Figure 4.12** (Electric Power Subsystem) we represent this subsystem in terms of its (i) need, (ii) the intent to fulfill this need through an externally delivered function, (iii) the internal functions or processes in which the EDF is decomposed, (iv) the physical components that aggregate into the Broadband infrastructure, and (v) the overall concept of its architecture. This is represented in **Figure 4.17** as follows.

**Figure 4.17**: Broadband Subsystem



Source: the author

Using a metaphor similar to the Electric Power Subsystem, the EDF of the Broadband Subsystem can be decomposed into four general internal functions: (i) getting connected to the Internet (by connecting the external Internet and obtaining IP addresses), (ii) connecting others to the Internet (by providing IP addresses to their hosts), (iii) routing packages, and (iv) providing reliable and secure channels.

An MEU's communication infrastructure is based on a fiber optic network that, depending on the case, supports a variety of services and last-mile access options. According to the APPA, in 2005, 105 MEUs provided cable television, 57 provided local telephone, and 47 offered long-distance telephone services in addition to broadband Internet service provision (DSL, Cable Modem, Fiber-to-the-Premises, and wireless) and internal services (SCADA, AMR, municipal network data, and voice services).

For this reason, **Figure 4.17** has been designed at a level of aggregation that can include the high heterogeneity of broadband solutions by MEUs. It is separated into a Central Office (CO) that is the physical place that hosts various types of network elements, Outside Plant Network (OPN), and Customer Premises Equipment (CPE). Each will be explained in more detail later in this section.

This section considers these general sub-functions and components as a system that is valid regardless of the technology deployed. Currently, one can find MEUs that provide broadband, as well as telephone and cable television services. In this scenario, for instance, the central office will have to gain access to the external Internet backbone, the Public Switched Telephone Network (PSTN), and a video content supplier.

*Central Office*. (Marked with a dashed-line box) The components in the central office respond to the Internet, cable, and telephone services provided by the MEU. In terms of broadband services, it includes firewalls, routers, servers (email, HTTP, DHCP, etc.), Asynchronous Transfer Mode (ATM) switch, Optical Line Terminals (OLTs), and Optical Combiner for a specific type of wavelength division multiplexing (xWDM). The ATM switches, OLT, and optical combiners are also used for telephone and video services, which also require a switch and optical amplifier, respectively.

*Outside Plant Network*. This network starts with the fiber cable that goes outside the plant and contains two types of components: (i) a series of passive optical splitters (in the case of Passive Optic Networks (PONs), the most common among MEUs), and (ii) an Optical Network Terminal (ONT) or Optical Network Unit (ONU). The splitters are used to create a point-to-multipoint network. Then, depending on the options for providing broadband, fiber optic cables are terminated using ONUs or ONTs. ONUs are used mostly by business customers, or when the MEU provides fiber-to-the-curb (FTTC). In these cases, MEUs might choose other options for last-mile technology (e.g. wireless, DSL).

*Customer Premises*. In the case of a fiber-to-the-premises (FTTP) alternative, fiber optic cable is terminated using ONTs at the customer premises in Customer Premise Equipment (CPE). Types of CPE vary according to the type of broadband service delivered (e.g. antennas, cable or DSL modems, etc.)

As we have discussed previously, SCADA and AMR systems are the component of the Electric Power subsystem responsible for the internal function of system control (See **Figure 4.12**). New IP-enabled control systems, however, share much of the infrastructure needed to provide external packet-switching communication services. **Figure 4.17** illustrates this by showing that *the Broadband Subsystem and the SCADA/AMR System decompose into, and share, the same basic network elements*. One can see this by comparing the composition of the broadband network in **Figure 4.17** and the SCADA/AMR system in the Form and Function Decomposition of the Electric Power Subsystem in **Figure 4.8** and **Figure 4.9**.

The SCADA/AMR System have special remote telemetry units, applications, graphical user interfaces, and sensors attached to breakers, transformers, and other critical elements of the electric power network. Commercial broadband services also have to dedicate a special infrastructure to serving customers. At the core, however, both types of services need the same basic network infrastructure. Shared infrastructure for offering broadband Internet access and operating system control solutions is the most important source of economies of scope in MEUs. Various components of the central office located in the MEU headquarters support both provision of broadband and the system control solutions. Similarly, portions of the outside plant network are used for providing broadband and running SCADA or AMR. This is represented in **Figure 4.8** and **Figure 4.9** as the IP-Network as a component of form at the third hierarchical levels, which is part of the SCADA/AMR System.

The analysis in this section builds on our previous findings. The representation of the subsystems shows the existence of infrastructure that can be used for providing two different externally delivered functions: electric power and broadband communications. Both functions require the same basic function (IP-enabled communications). However, in the first case IP-enabled communications are only visible internally at a third hierarchical level, while in the second they represent the externally delivered function. This signals the existence of economies of scope between providing electric power and broadband services. This also signals the existence of a surplus resource (extra capacity for high speed communications), which is scarce in rural and suburban areas and could have led MEUs to diversification, as they did with other utility services decades ago.

### 4.3.3 Step 7 –Identify Common Drivers and Add Projections from Internal Institutional Sphere to Representation in Step 6

In this step, we build on the representations of step 6 by identifying common drivers across the subsystems of the Physical Domain, and adding projections from actors in the Internal Institutional Sphere.

Identification of Common Drivers

A close examination of **Figures 4.12**, **Figure 4.15**, and **Figure 4.17** allows identifying –in the sense of the CLIOS Process- four *drivers* that are *common* to at least two, and in some cases, all the subsystems: (i) reliability, (ii) efficiency, (iii) economic growth, and (iv) new information and communication technologies. According to the components shapes presented in **Figure 3.7**, these common drivers will now represented as diamonds in the graphical representation of the subsystems in **Figure 4.18**, **Figure 4.19** and **Figure 4.20** (the figures are shown in the following pages for clarity purpose).

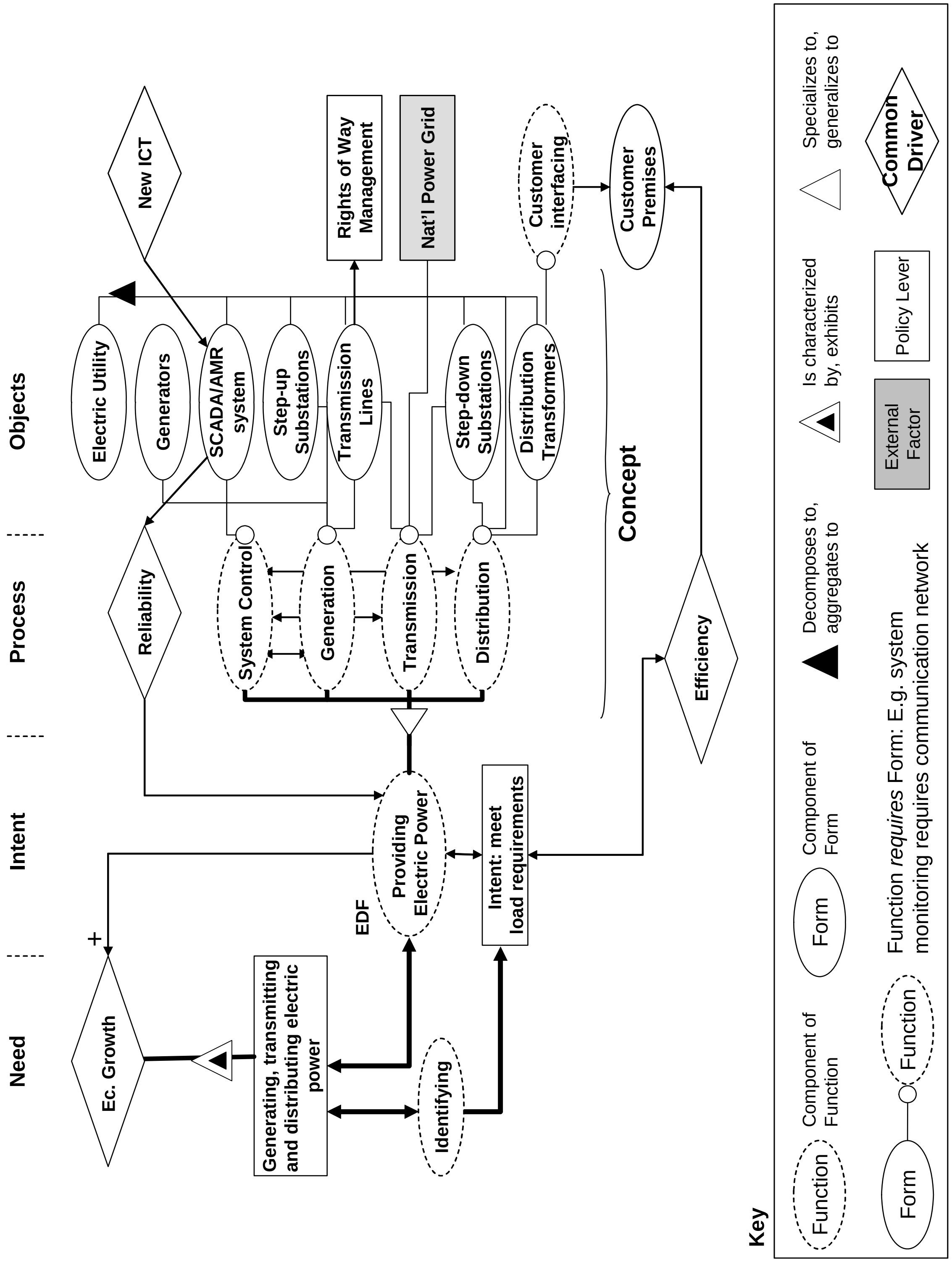
The new representation helps us to understand a few new things about the subsystems of the physical domain:

1. *Reliability* of the local grid and electric power operations is a major driver for the adoption of SCADA and AMR. It is present as a driver for the Electric Power and Economic Activity subsystems, but it is also a driver for the Broadband Subsystem. This is because security breaches in broadband communications can be a major problem for the reliability of the grid when SCADA and AMR communications are compromised.

2. *Efficiency* is also a common driver across subsystems of the Physical Domain. For the Electric Power subsystem, the adoption of SCADA and AMR also follows the expectation of gains by real-time pricing and savings from preventing malfunction and loss of infrastructure. In the case of the Economic Activity subsystem, efficiency is associated with the adoption of new technologies by the municipal government, and the creation of public value, especially by digital means (Osorio 2002). Efficiency is also the reason for taking advantage of economies of scope of the new network infrastructure and deploying external broadband.

3. *Economic Growth* is *the* major common driver in all three subsystems. It was the reason for the creation of MEUs, it is the reason of the economic activity subsystem, and it is the reason for the deployment of external broadband.

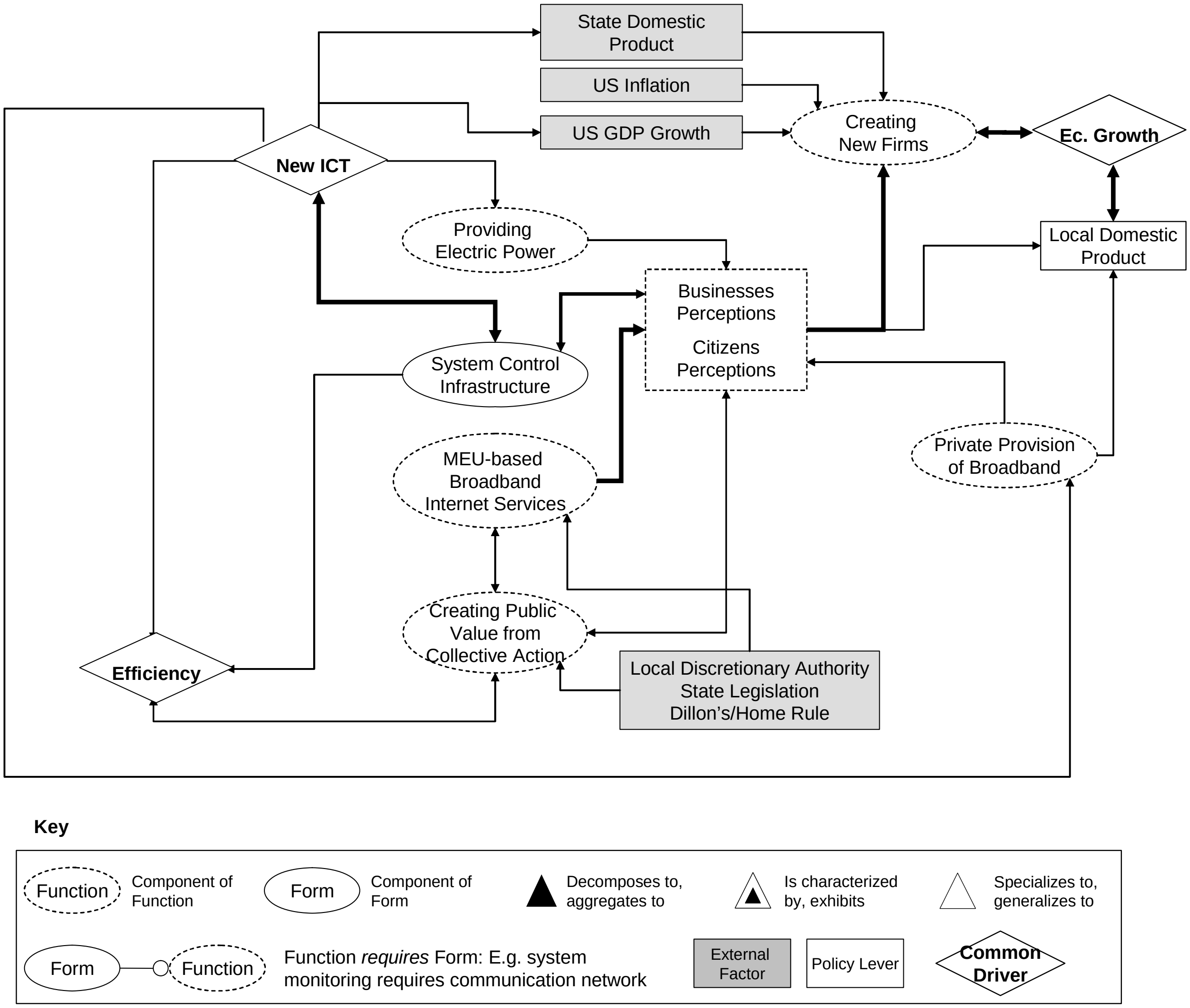
**Figure 4.18**: Electric Power Subsystem, with Common Drivers



Source: the author

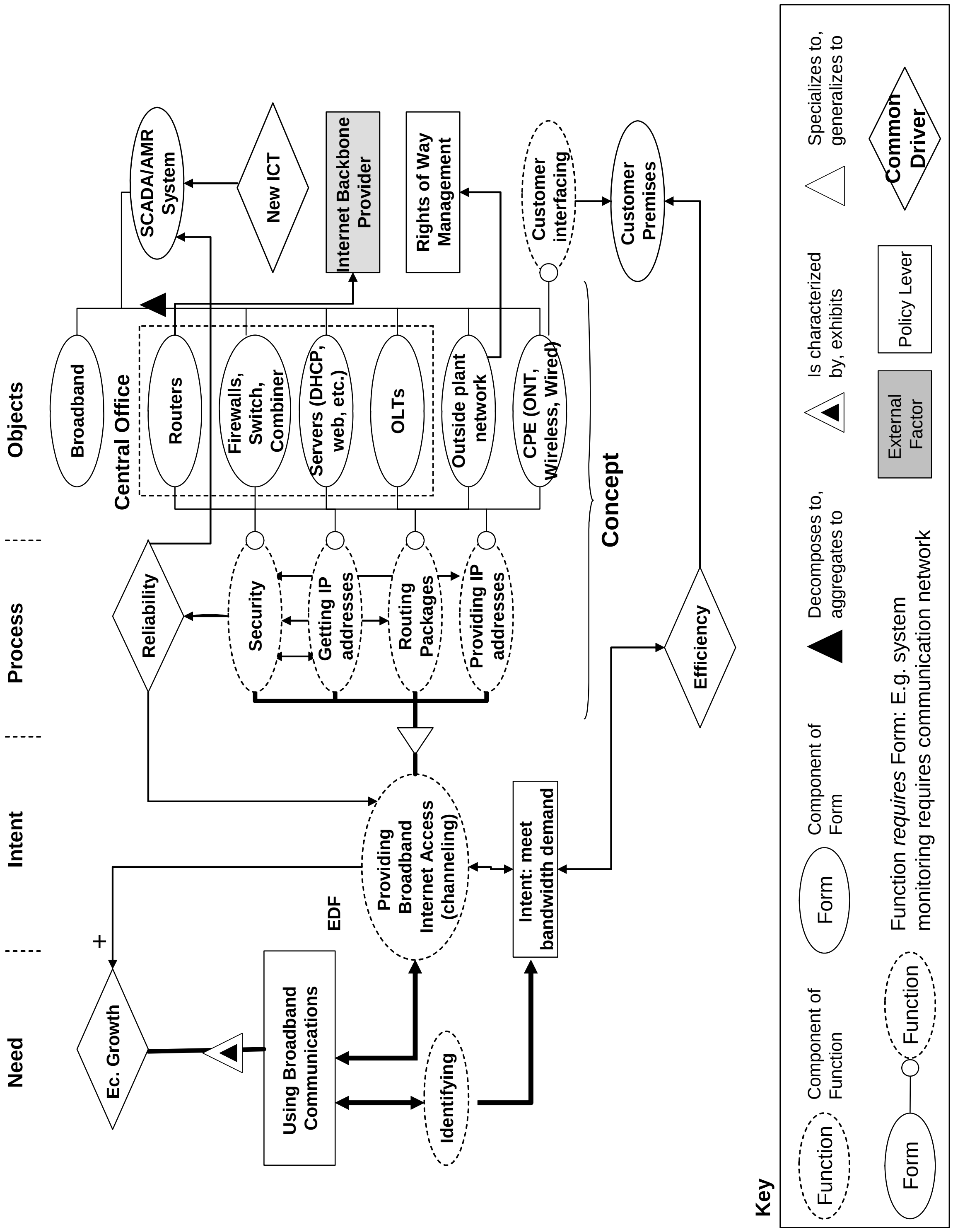
4. *New Information and Communication Technologies* are common across all subsystems of the physical domain, including the Economic Activity subsystem. ICTs are a driver among electric utilities (Electric Power subsystem); in the adoption of IP-enabled systems for command and control (Black 2005); and in the deployment of external communication services (Broadband Subsystem). They are a driver for local governments' deployment of digital government solutions (Fountain 2001; Osorio 2002) and for firms' adoption of access and business intelligence solutions (Forman, Goldfarb et al. 2003b)

**Figure 4.19**: Economic Activity Subsystem, with Common Drivers



Source: the author

**Figure 4.20**: Broadband Subsystem, with Common Drivers



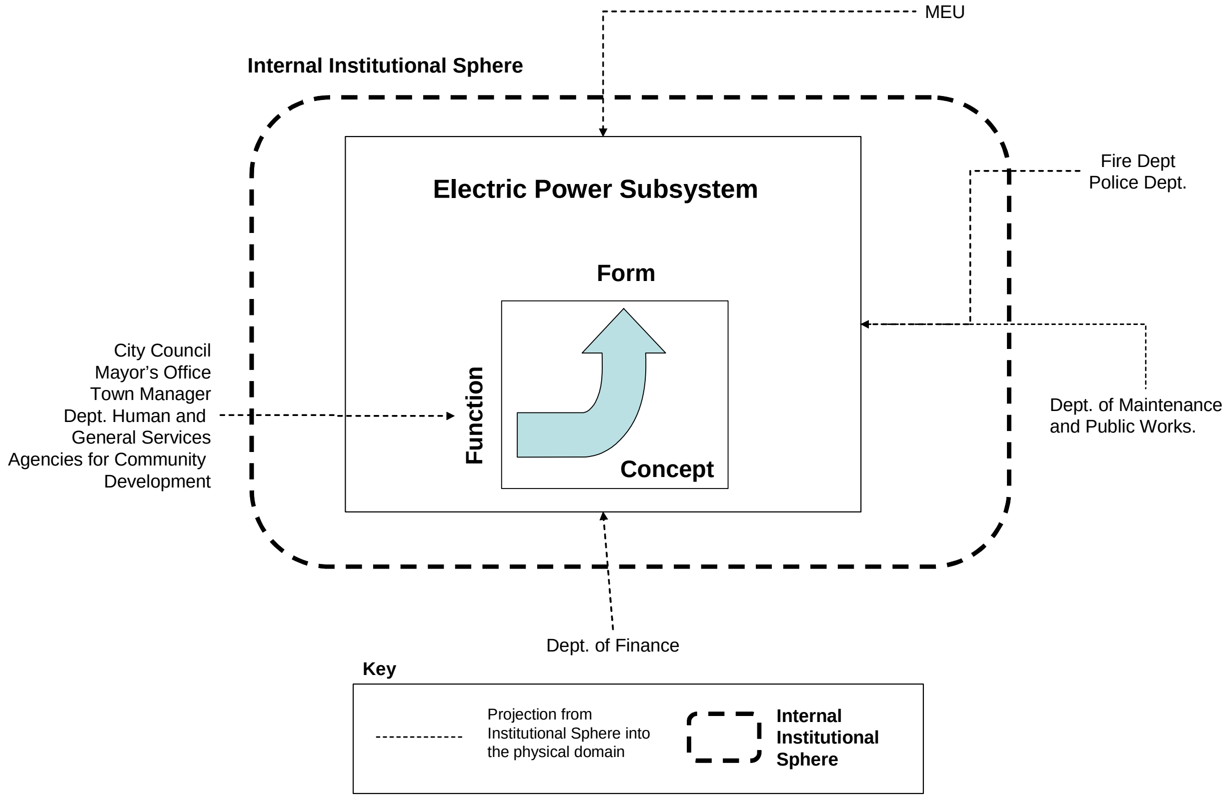
Source: the author

Projections from the Internal Institutional Sphere

In Section 3.2 we presented a general framework for studying the influences in system architecture, and represented it in **Figure 3.1**. From the perspective of the CLIOS Process, some important influences are created from institutions in the Internal and External Institutional Spheres.

The objective of this section is to illustrate the influences of actors on the Internal Institutional Sphere on the architecture of each subsystem in the physical domain. By definition, then, we will not present all the actors on the Internal Institutional Sphere, but only those affecting each subsystem. An abstraction derived from **Figure 3.1** is used to represent such influences for the Electric Power in **Figure 4.21**.

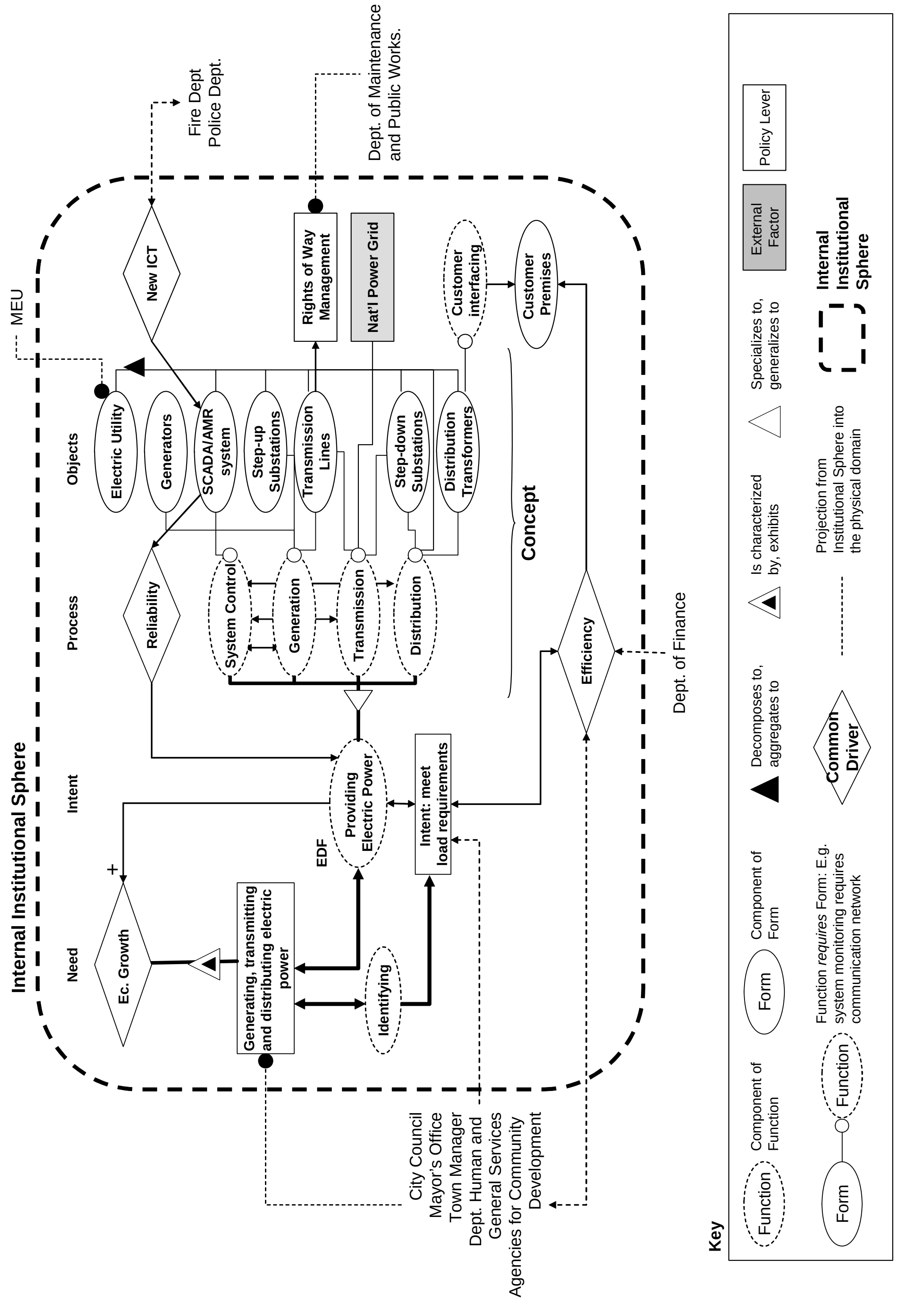
**Figure 4.21**: Abstraction of the Electric Power Subsystem, with influences from the Internal Institutional Sphere



Source: the author

**Figure 4.22** illustrates the influences of actors in the Internal Institutional Sphere on the Electric Power Subsystem.

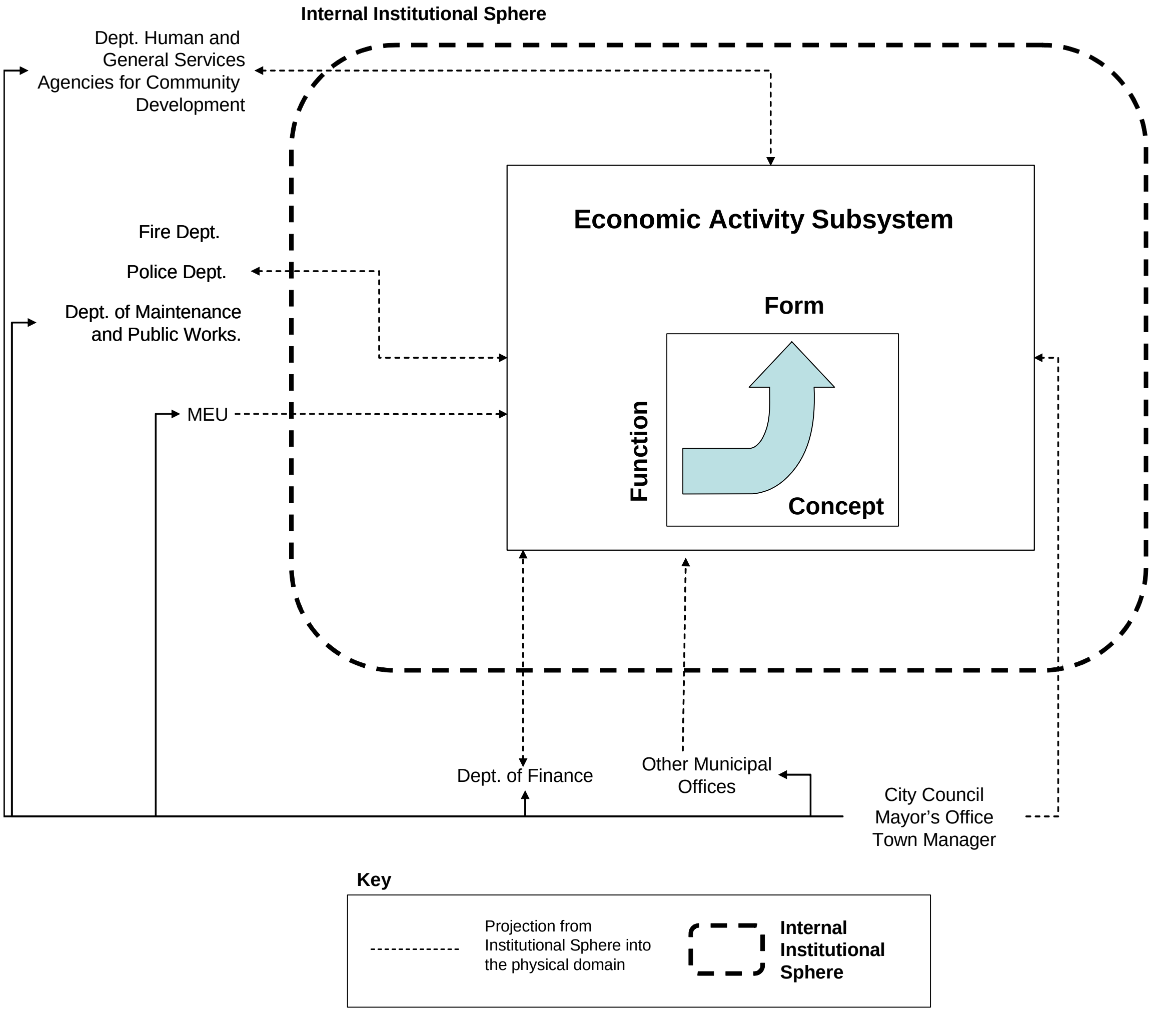
**Figure 4.22**: Electric Power Subsystem, with influences from the Internal Institutional Sphere



Source: the author

**Figure 4.22** represents how architecture of the Electric Power Subsystem is influenced by local government agencies. It illustrates how the MEU –as part of the local government- manages the infrastructure of this subsystem, and how the Dept. of Finance monitors and manages the efficiency in public expenditure, which reflects the pressure that MEUs face for self-financing and increasing efficiency of operations. Also, **Figure 4.22** illustrates how Fire and Police departments request the use of some of MEU's ICT infrastructure in order to have feedback about problems and share some services. Other municipal bodies, such as the Office of the Mayor, Town Manager, and City Council among others, are sensitive to about the gap between citizens' needs and service being provided by the subsystem: the wider this gap, the more intense will be their attempts to influence over the Electric Power Subsystem.

**Figure 4.23**: Abstraction of the Economic Activity Subsystem, with influences from the Internal Institutional Sphere



Source: the author

**Figure 4.23** represents an abstraction of the influences of actors on the Internal Institutional Sphere on the Economic Activity Subsystem. This list is partial because, as in the previous case, it only represents the actors that have some influence.

The primary source of influence from the Internal Institutional Sphere comes from the City Council, Office of the Mayor and Town Manager thought the discretionary authority of the local government, fueled by their input and feedback from their constituencies (local residents and businesses).

The three local government actors just mentioned have the administrative and political power to affect the Economic Activity Subsystem by controlling at least in some degree other actors. A mayor driver of their action is economic development, expressed by the health and growth of the local economy.

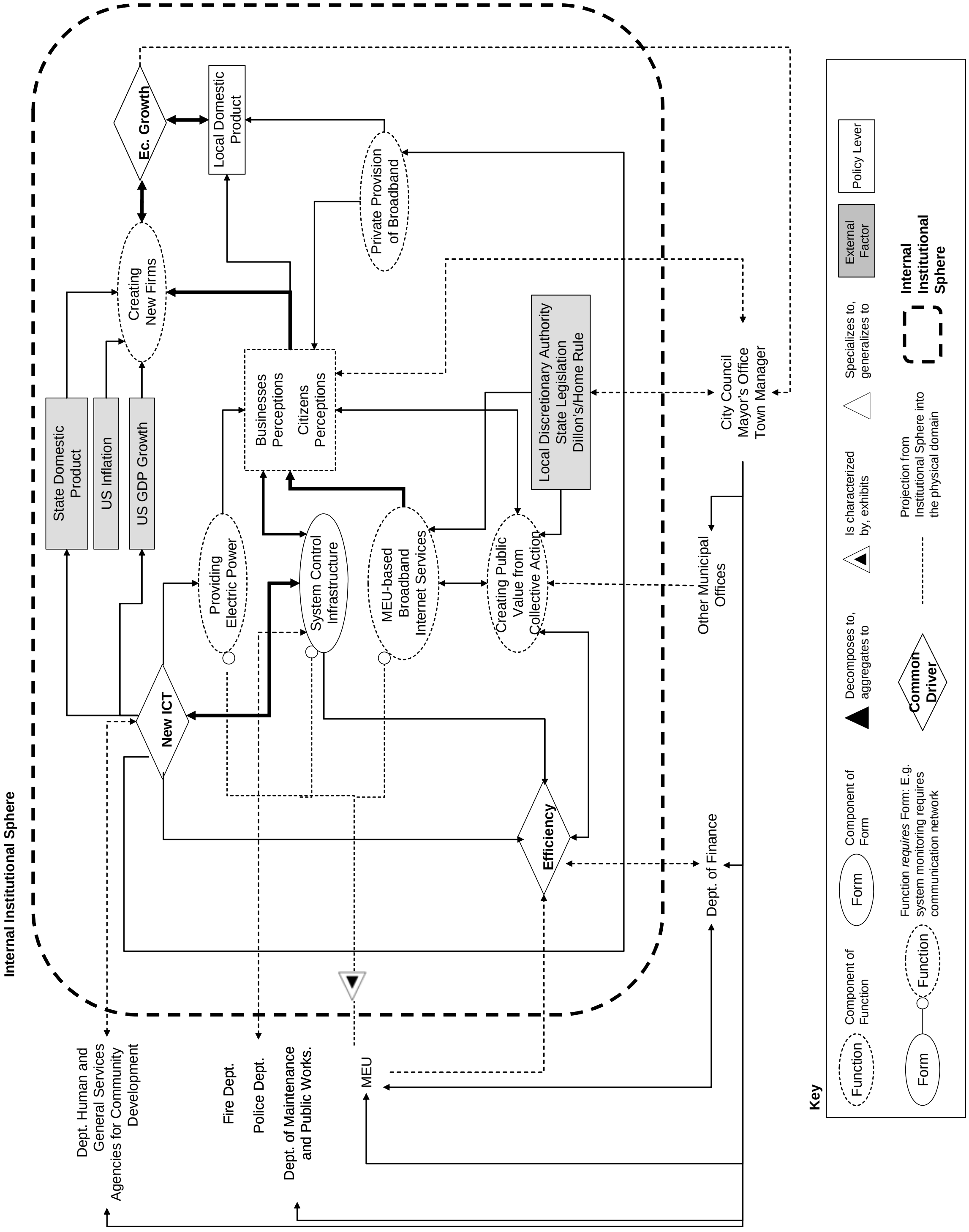
Although all local government agencies are oriented towards the ultimate goal of creating public value through collective action, some play a special role. The Department of Finance is especially concerned with the efficiency of public operations on the process of creating public value. For this reason, it also has an important indirect effect over the subsystem due to its direct influence over other various units of the local government. While decisions about new investments or increase in expenditure are decided in conjunction between City Council, Mayor, and the input of local residents, the Town Manager and Dept. of Finance play a major role.

From the perspective of our research questions, the Municipal Electric Utility (MEU) plays a major role by providing two major inputs for the operation of the Economic Activity Subsystem: electric power, and broadband services. With respect to this, the common drivers of efficiency and new Information and Communication Technologies play a major role on the MEU as source of some of its decisions, especially the adoption of IP-enabled SCADA and AMR in order to improve the operations of the Electric Power Subsystem (see **Figure 4.22** for more information).

The relevance of digital government during the 1990s (Fountain and Osorio 2002) and availability of New ICTs create demand from various other local government agencies to share some of the services and infrastructure.

The influences of the actors in the Internal Institutional Sphere and the relationships among them can be seen in greater detail in **Figure 4.24**.

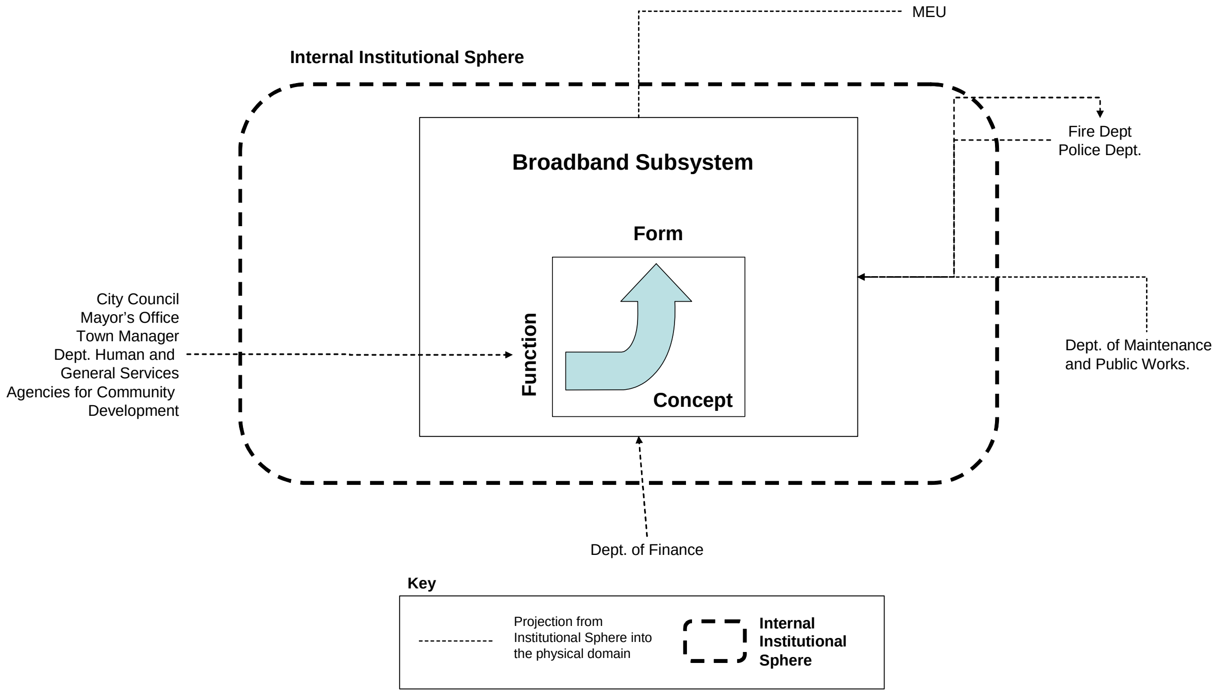
**Figure 4.24**: Economic Activity Subsystem, with influences from the Internal Institutional Sphere



Source: the author

Finally, we present the below the influences of the Internal Institutional Sphere on the Broadband Subsystem following the same procedure: (i) we first present an abstraction of these influences on the subsystem (**Figure 4.25**), and (ii) then present a detailed representation of it (**Figure 4.26**, in the next page).

**Figure 4.25**: Abstraction of the Broadband Subsystem, with influences from the Internal Institutional Sphere



Source: the author

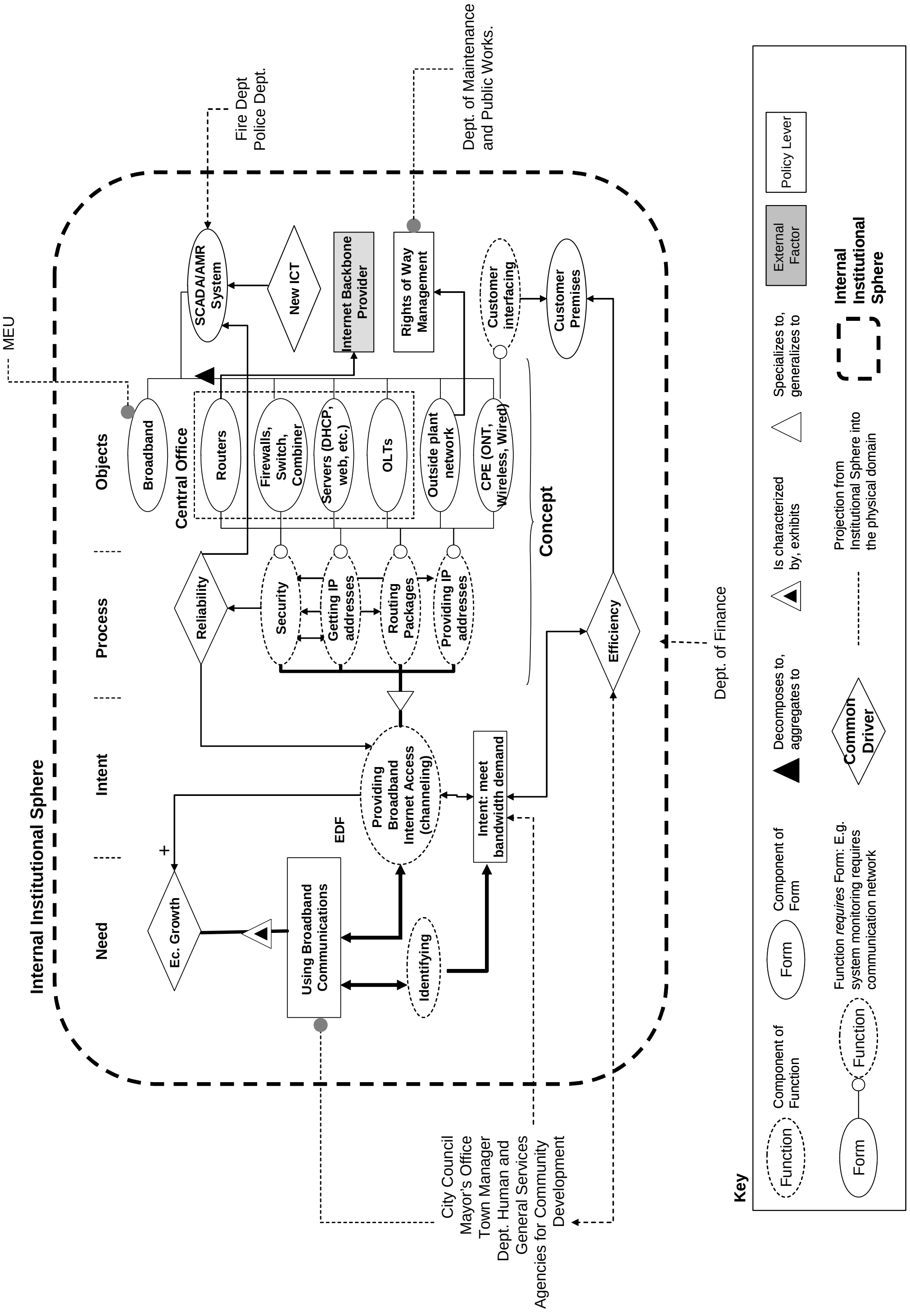
The various agencies of the local government are a major source of influence on the architecture of this subsystem for various reasons:

(i) The Municipal Electric Utility deployed the SCADA/AMR, from which emerged the Broadband Subsystem; the MEU also manages the Broadband Subsystem;

(ii) Some departments, such as Police and Fire department, demanded sharing the information infrastructure for their internal purposes,

(iii) The Mayor, City Council and Town Manager played a mayor role in identifying and channeling the need for broadband services, as well as shaping the intent to fulfill it by offering broadband using at least part of the fiber optics network already available.

**Figure 4.26**: Broadband Subsystem, with influences from the Internal Institutional Sphere



Source: the author

The inclusion of actors in the Internal Institutional Sphere gives us an idea of how the MEU, as an organization, and the various departments of the local government affected the architecture of our CLIOS System. While the MEU manages the Electric Power and Broadband Subsystems, it depends politically and administratively on the local government.

In turn, the local government has a major role in the local economy and deciding investments that can have important future effects. Thus, any intent to fulfill a local need is first approved and, in most cases, funded thru the local government. The local government owns the rights of way, which are needed to deploy cable and antennas.

In the next section, we explore the influences of actors in the External Institutional Sphere on the subsystems of the Physical Domain of our CLIOS System.

### 4.3.4 Step 8 – Add Projections from External Institutional Sphere to Representation in Step 7:

In this step we add projections from the External Institutional Sphere in order to understand the influences from external actors on architecture. The new representations are shown following the same procedure followed in the previous section: (i) we show an abstraction of the representation, and then (ii) present a detailed version with the relevant information.

We know that the Electric Power and Broadband Subsystem are managed by the MEUs, and that MEUs are subject to the jurisdiction of their local government. We also know, however, that there are many institutional actors that play a relevant role influencing the Electric Power, Economic Activity and Broadband subsystems. The influence of various actors on these subsystems is represented in **Figure 4.27** to **Figure 4.32**. Each of these figures is included in a separate page at the end of this section for clarity purposes.

**Figure 4.27** adds the influences of actors in the External Institutional Sphere to **Figure 4.21**, which represented the abstraction on the Electric Power Subsystem and the projections of the Internal Institutional Sphere. The detailed representation is illustrated by **Figure 4.28**. **Figure 4.29** and **Figure 4.30** illustrate similar representations for the Economic Activity Subsystem, and **Figure 4.31** and **Figure 4.32** for the Broadband Subsystem.

We are able to identify the impacts of external actors, such as the United States Supreme Court and Federal Communications Commission, on the subsystems. The deployment of Broadband services was only possible in states without laws prohibiting local governments from offering telecommunication services. Previous work shows that Dillon's Rule, which limits the discretionary authority of local governments, has an effect but it is not statistically significant on limiting such endeavors (Gillett, Lehr et al. 2006). The same research finds that the existence of private broadband providers diminishes the likelihood that municipalities will deploy broadband services.

The Department of Energy, Federal Energy Regulatory Commission (FERC) and each state's Public Utility Commission have the prime regulatory effect on an MEU's EDF, and have been fostering the adoption of IP-enabled SCADA and AMR solutions in the electric power industry in order to increase reliability of the National Grid. As we have discussed, this has been a major driver in the architectural evolution of MEUs. This gives additional information supporting the hypotheses that the initial adoption of IP-enabled communication networks was triggered by changes in the electric power industry.

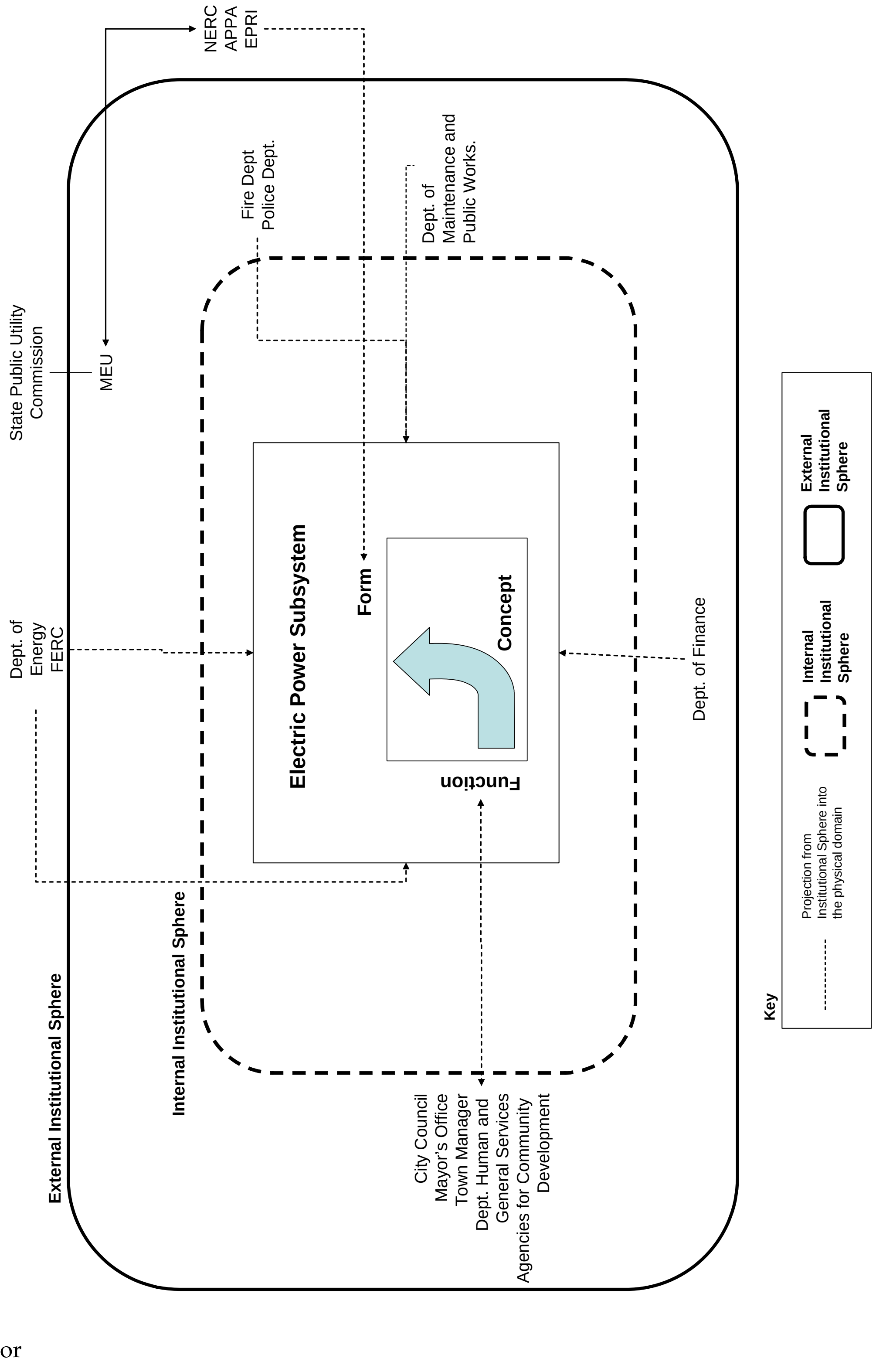
The North American Electric Reliability Council (NERC), American Public Power Association (APPA), and Electric Power Research Institute (EPRI) are the three most important non-governmental organizations for MEUs with respect of their electric power business. NERC and EPRI join the DoE in fostering the adoption of information technology for monitor and control of electric power operations.

On the broadband side, the Fiber-to-the-Home (FTTH) Council, NARUC, and APPA have been very active in fostering the deployment of external broadband services by MEUs. Since 2001, all these organizations have either fostered the adoption of IP-enabled networks for deployment of external broadband, or approached and provided support to MEUs that already have this infrastructure so they can deploy their external broadband services. Before 2001, however, the external deployment of MEU-based broadband seems to have resulted mostly from a process of discovery, learning and adoption, and information search.

The internal institutional sphere regulates and manages the technical infrastructure of municipal electric utilities and grants them power and funds for investment. We have also assumed that MEUs started to use the new IP-enabled network for internal communications and, given the importance of these technologies for delivering public value, the local government should have been increasingly important in demanding part of those resources for internal use.

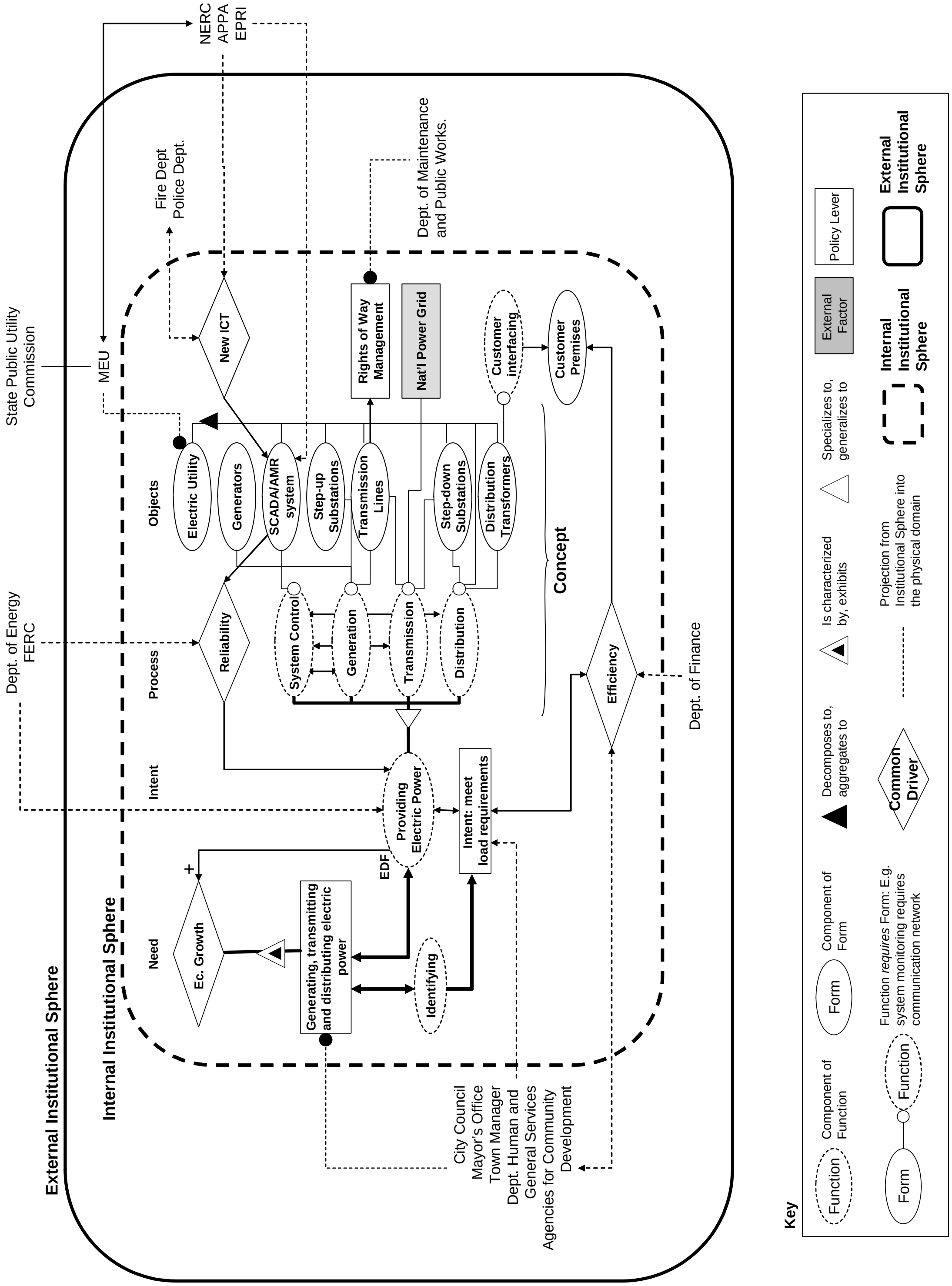
From all actors on the External Institutional Sphere, the U.S. Supreme Court and State Governments are the two with the highest direct effect on the Electric Power and Broadband subsystems. The effect of most of the others could be classified as indirect, first influencing the local government or MEU, which in turn can decide whether or not to act upon the physical infrastructure.

**Figure 4.27**: Abstraction of the Electric Power Subsystem, with influences from the Internal and External Institutional Spheres



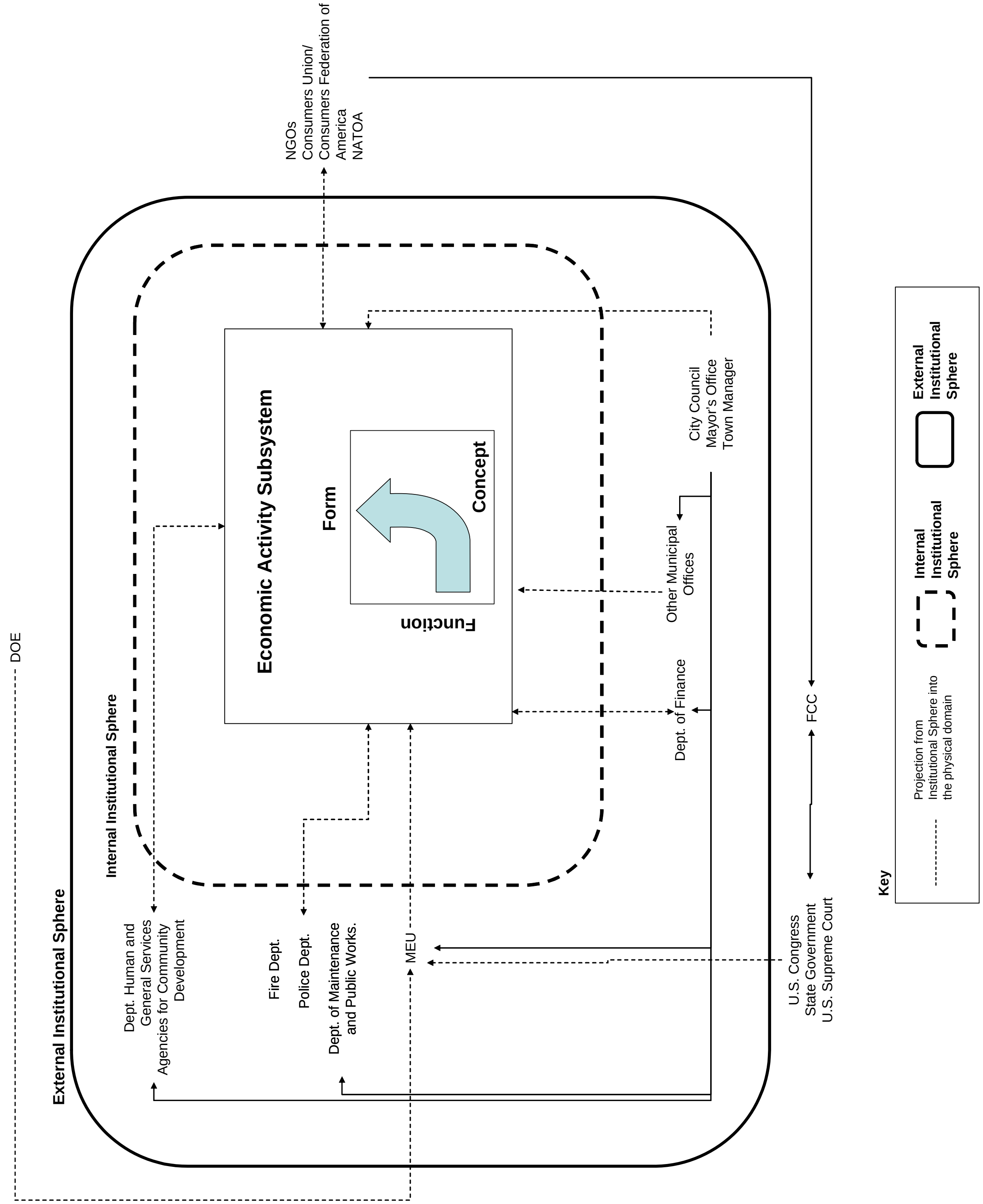
Source: the author

**Figure 4.28**: Electric Power Subsystem, with influences from the Internal and External Institutional Spheres



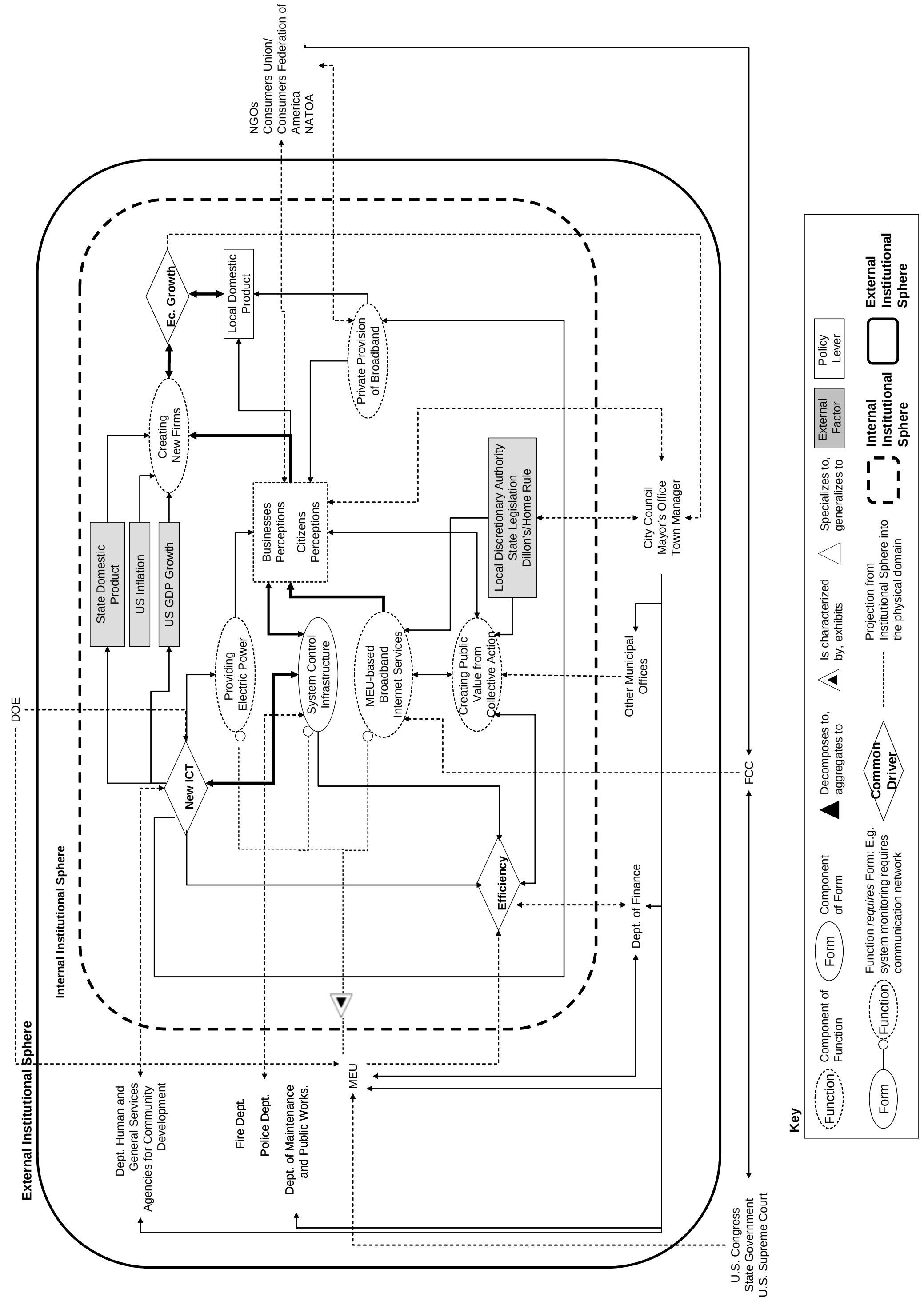
Source: the author

**Figure 4.29**: Abstraction of the Economic Activity Subsystem, with influences from the Internal and External Institutional Spheres



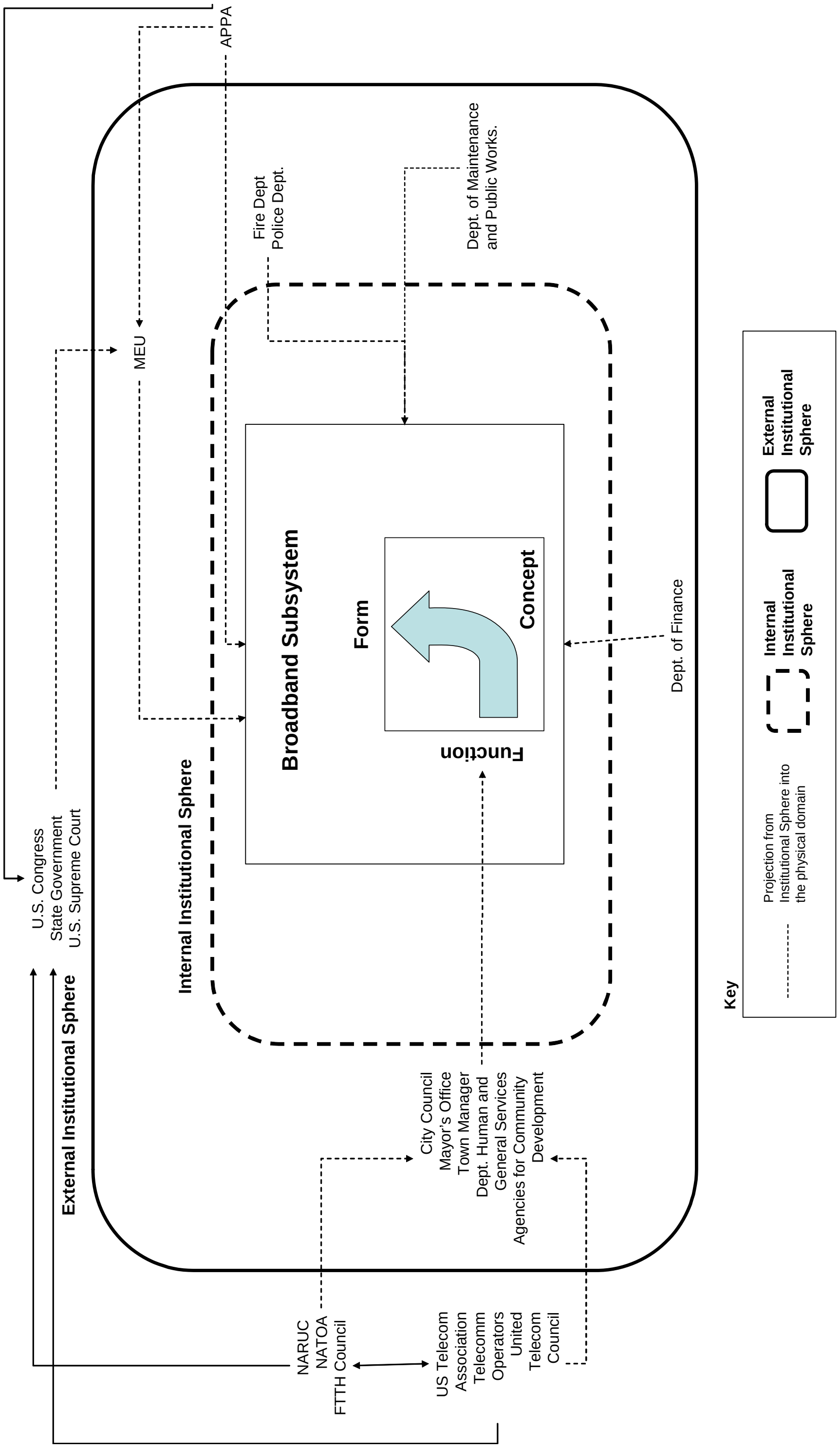
Source: the author

**Figure 4.30**: Economic Activity Subsystem, with influences from the Internal and External Institutional Spheres



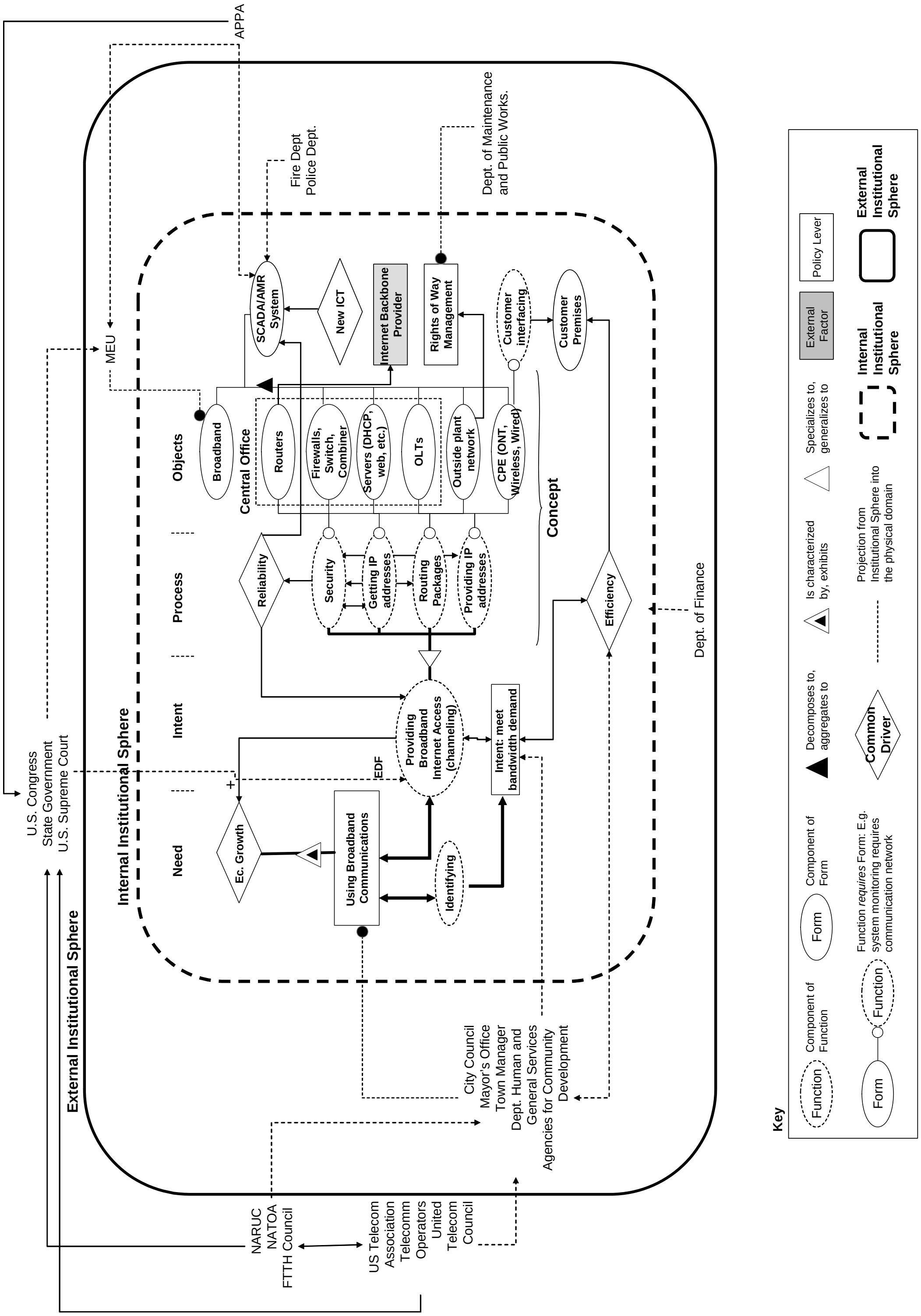
Source: the author

**Figure 4.31**: Abstraction of the Broadband Subsystem, with influences from the Internal and External Institutional Spheres



Source: the author

**Figure 4.32**: Broadband Subsystem, with influences from the Internal and External Institutional Sphere



Source: the author

### 4.3.5 Step 9 – Representation of Institutional Sphere:

As discussed in Chapter 3, we have taken an approach to representing the institutional sphere that is different from the CLIOS Process. In our research, we separate internal organizational actors from external institutional actors. We first analyzed relationships between the physical domain and its Internal Institutional Sphere, for then look at the relationships between the Physical Domain and the Internal Institutional Sphere with actors on the External Institutional Sphere.

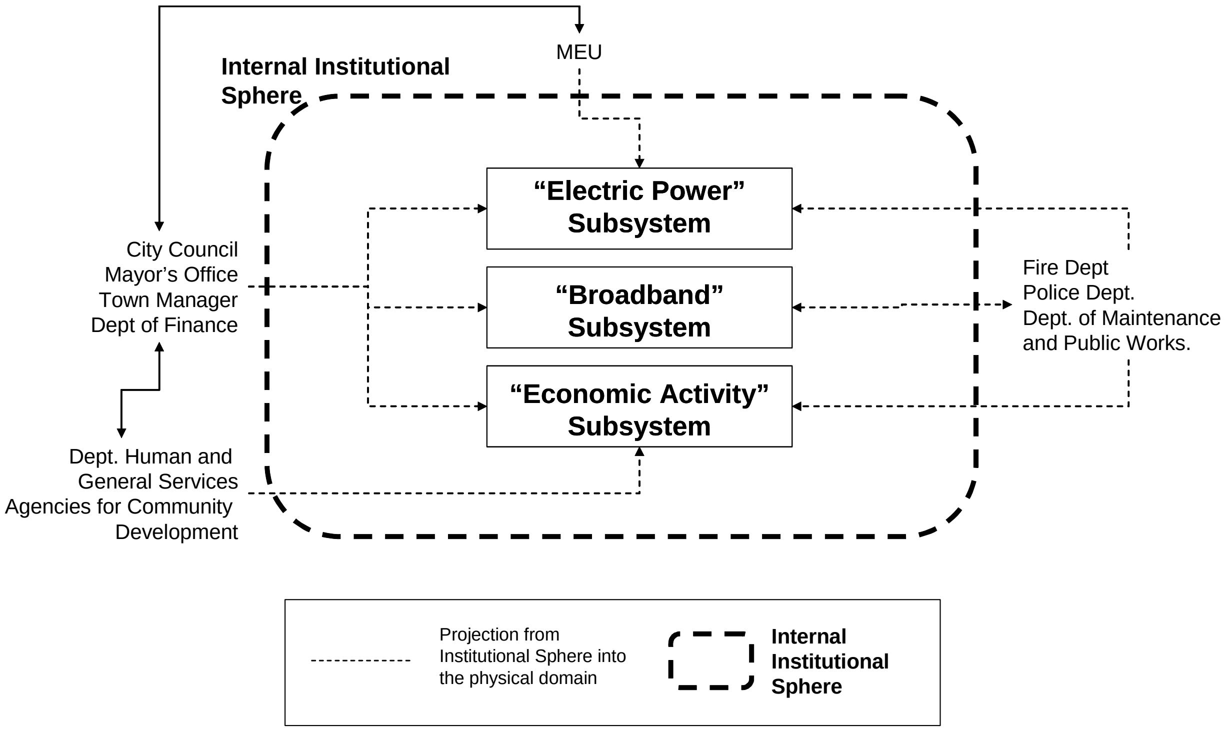
The first simplified version of the institutional sphere was presented in **Figure 4.7** and included its most important actors and the subsystems of the physical domain. We later represented the various subsystems of the Physical Domain, and included projections from the relevant actors on the institutional sphere in order to represent their influence.

Based on our Extended Notion of Nested Complexity, presented in **Figure 3.10**, there are three types of relationships: (i) relationships between actors in the External Institutional sphere and the physical system's technical components (i.e. specific regulations about the technology or functions); (ii) relationships between actors in the External and Internal Institutional Spheres (i.e. regulations that are specific to the organization –the MEU– but not specific to the technical components); and (iii) relationships influences from actors in the Internal Institutional Sphere on the physical domain. All relationships between actors in the institutional sphere and physical system are shown with a discontinuous line.

This section presents a more detailed representation of the institutional sphere. The institutional sphere is composed of the different public and private groups and actors that have a stake in the major issues of interest in the CLIOS System, and have relationships with either the physical system or its organization (the MEU).

Here we take an approach similar to the previous sections. We first present a representation of the Internal Institutional Sphere that includes an abstraction of the three subsystems the Physical Domain. Then, we take the first representation, and a second layer representing the External Institutional Sphere. The Internal Institutional Sphere is represented in **Figure 4.33**.

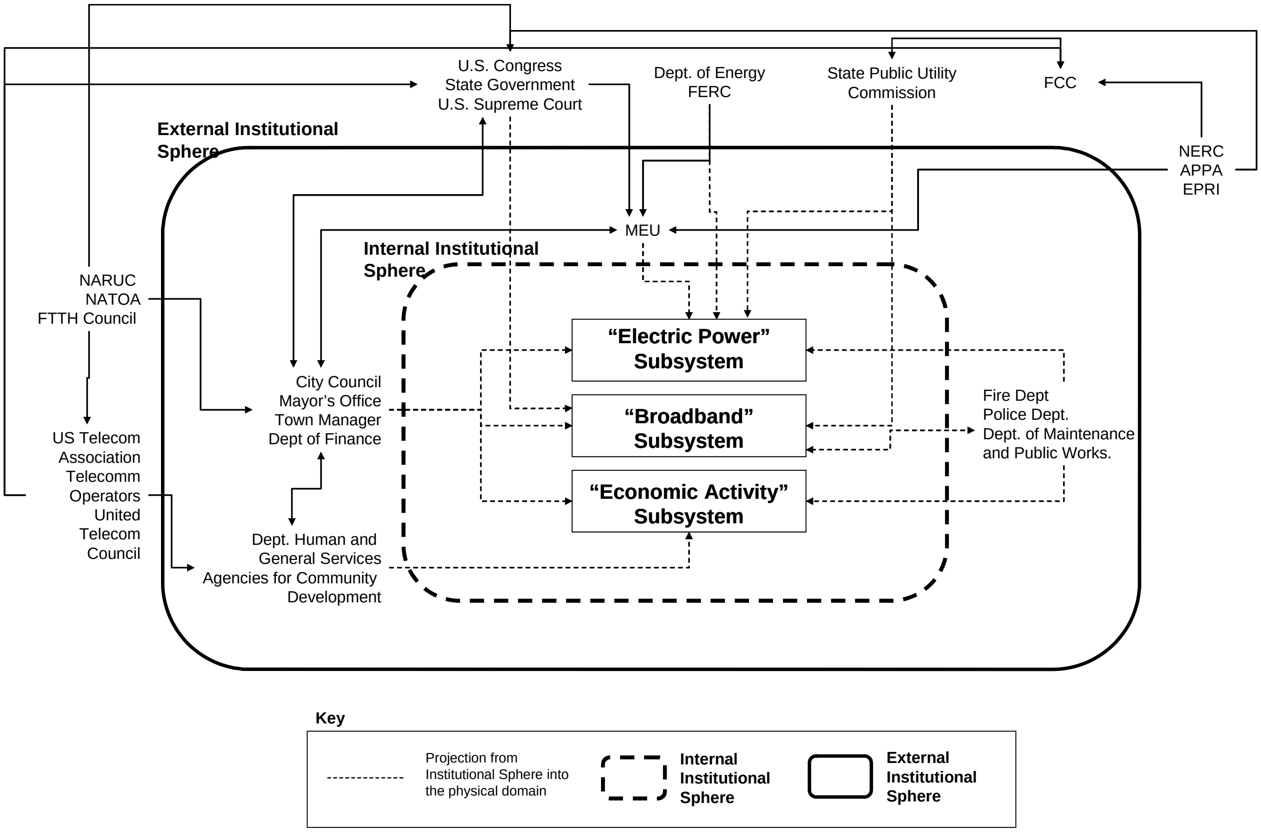
**Figure 4.33**: Internal Institutional Sphere



Source: the author

A more detailed representation, however, should also include the actors on the External Institutional Sphere. This is illustrated in **Figure 4.34.**

**Figure 4.34**: Internal and External Institutional Sphere



Source: the author

As municipal electric utilities started to offer broadband services, telecommunication companies began lobbying the FCC, state public utility commissions, and Congress to prevent MEUs from doing so (Osorio 2004). The argument focused on Section 253(a) of the Telecommunications Act of 1996 (TA1996) which stated that: *"No State or local statute or regulation, or other State or local legal requirement, may prohibit or have the effect of prohibiting the ability of* *any entity* *to provide any interstate or intrastate telecommunications service"*[35] (emphasis added). The FCC decided that a municipal utility could be considered "any entity" under Section 253(a) only if had an *"independent corporate identity that it is separate from the state"*[36]. This was later ratified by the US Supreme Court, which ruled that is up to the states to decide whether municipal utilities can offer external broadband services (Osorio 2004). Currently, 14 states have approved requests backed by privately-owned broadband providers to limit municipal involvement in

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[35] See http://www.fcc.gov/Reports/tcom1996.txt

[36] See http://www.fcc.gov/statelocal/docs-98-122-order.htm

broadband services[37]. To the knowledge of the author, most existing initiatives already have been grandfathered.

As mentioned previously, MEUs have received support from the APPA, the FTTH council and NARUC in fighting these restrictions and lobbying legislators at the federal and state levels. These lobbying efforts have focused on several federal legislative projects proposed to either allow or limit municipal broadband (See **Table 4.2**).

All these influences have affected the architecture of MEUs in two ways:

1. *Adoption of new generation communication technologies*: We have discussed the importance of the legacy of old SCADA and AMR systems in MEU architecture in previous sections. The EIS and IIS provide additional pressure for the adoption of new-generation information technology. The adoption of these technologies implies an increase in the structural complexity of the technical system, as components of the electric power network are connected to a new communications network, and the system begins to operate a system that works differently from the previous analog-based SCADA systems.
2. *Deployment of external communication services*: The actors in the IIS were responsible for first deploying external broadband services, by (i) generating internal demand and (ii) allowing learning and organizational adaptation. The actors on the EIS, however, have influenced the evolution of architecture by either imposing restrictions on the entry of MEUs into telecommunications, or lobbying to affect the language of these restrictions.

Until now, we have gained understanding about the reasons and process of architectural evolution of MEUs based on our representation of the system, and our hypotheses. In the next section we present the data gathered in field research that will be later used to test our hypotheses.

### *4.4 Field Research: Step 10*

As stated in Chapter 3, the objective of this step is to obtain the data to test the validity of the hypotheses, and research assumptions, and system representation. In this study, we will apply information derived from quasi-structured interviews and case study research, with a special focus on the reasons for and the process of the architectural evolution of MEUs. We transcribed the interviews and wrote the case

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[37] http://www.appanet.org/files/PDFs/Telecom-Flyer.pdf?sn.ItemNumber=2042&tn.ItemNumber=10002 These states are Arkansas, Florida, Missouri, Minnesota, Nebraska, Nevada, Pennsylvania, South Carolina, Tennessee, Texas, Utah, Virginia, Washington, and Wisconsin.

studies from the perspective of the architectural evolution of the individual systems. At this point, there is no analysis of the cases, but only a description of facts and the evolution. The analysis of case studies continues in Section 4.5.

### 4.4.1 Selection of Case Studies

Case study material illuminates the similarities across the underlying processes within specific MEUs as they occur within their context. Then, some processes can be identified as "general" in terms of theoretical propositions. The MEUs selected for case study were chosen on the basis of: (i) the status of the initiative; (ii) the existence of legal challenges to municipal broadband; (iii) technology deployed; and (iv) time since deployment. The relevance of these criteria is explained as follows:

1. **Year of Deployment**: We are interested in understanding how the underlying processes have affected, and been affected by, the context. We are not interested in MEUs that purely mimicked others in deploying broadband networks. Thus, we are interested in cases in which the MEU deployed its IP-based communication network before or by 2000 (before the American Public Power Association became active in promoting community broadband).
2. **Legal Challenges to Municipal Broadband**: From a practical perspective, the existence of lawsuits prevents MEU officials from sharing information and participating in interviews. For this reason, case studies were chosen from communities with no or low risk of legal challenge to municipal broadband.
3. **Technology deployed**: We want to understand if and how the process is affected by the choice of technology deployed for external broadband services. For this reason, we focus on the three more common options: Hybrid Fiber Coaxial (HFC) cable, wireless and fiber-to-the-premises (FTTP).

We wanted the analysis to include comparison of three broadband options, wireless (five communities), fiber (eight), and HFC (two). Based on preliminary case analysis three utilities were chosen: (i) Braintree Electric Light Department (BELD) in Braintree, MA, which deployed cable modem broadband over a HFC network, (ii) Hometown Utilicom (HU) from Kutztown, PA, which deployed fiber optic networks to residential and business customers, and (iii) Owensboro Municipal Utility (OMU) from Owensboro, KY, which has deployed wireless broadband for residential and small business and FTTP for large companies. Based on these criteria, 15 communities were pre-screened (See **Table 4.3**).

**Table 4.3**: Candidates for Case Study Analysis

| MEU | Technology | Started Operation | Status of Deployment | Legal Challenges |
|---|---|---|---|---|
| Chaska, Minnesota | Wireless | 1998 | Upgraded to metropolitan mesh-wireless network | None |
| Grand Haven, Michigan | Wireless | Fall 2003 | The entire town is wireless as of July 29, 2004[38] | None |
| ***Owensboro, KY*** | ***Wireless*** | ***1997*** | ***Operative*** | ***None*** |
| Adel, GA | Wireless | 2003[39] | Operative | None |
| Moorhead, MN | Wireless | 2004 (Fiber ring deployed in 2000) | Operative | None |
| ***Kutztown, PA*** | ***FTTH*** | ***1999*** | ***Operative*** | ***None*** |
| Sallisaw, OK | FTTH | 2003 | Operative | None |
| Dalton, GA | FTTH | 2003[40] | Operative | None |
| Cedar Falls, IO | FTTB | 1995-2000 | Operative | None |
| Palo Alto, CA | FTTH | 2003 – on hold[41] | Operative | Rumors of lawsuit by SBC and Comcast[42] |
| Windom, MN | FTTH | Spring 2005 | Operative | None |
| Provo, UT | FTTH | 2003 | Operative | None |
| Reedsburg, WI | FTTH | 2003 | Operative | None |
| ***Braintree, MA*** | ***HFC*** | ***1995*** | ***Operative*** | ***None*** |
| Tacoma, WA | HFC | 1999[43] | Operative (Note: network was built primarily for internal use) | None |

Source: the author based on data from APPA (2000-2005), and sources listed in footnotes.

In the three cases, the internal networks were deployed on or before 2000. HU and OMU deployed technologies that are expected to be pervasive in the future (wireless and fiber). HU deployed its network against the opposition of Verizon, but it was grandfathered by a state law that prohibiting new municipal broadband ventures.

Important parts of the data were gathered through site visits and fieldwork that included several interviews. The interviews were conducted following a semi-structured protocol focused on getting a deep understanding of the (i) deployment and architectural evolution of the system; (ii) the visible effects of broadband deployments in local economic development; (iii) context before and during the deployments; and

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[38] See http://www.walkersands.com/Was-Grand-Haven-Really-First.htm

[39] See http://www.wi-fiplanet.com/wimax/article.php/3080481

[40] See http://telephonyonline.com/home/news/Dalton_Muni_FTTH_090205/

[41] See http://www.cpau.com/fiber/trial/ftindex.html

[42] http://www.paloaltoonline.com/news/show_story.php?id=1608

[43] See http://www.historylink.org/essays/output.cfm?file_id=5149

(iv) dynamics with telecommunication operators and regulators. A copy of the interview protocol can be found in **Appendix 1**. The subjects of interviews included MEU executives and operators, customers, members of the business community, and local government officials.

In addition to the interviews, we participated in industry meetings, interviewed members of the American Public Power Association (APPA), reviewed APPA manuals for deploying municipal broadband and other documentation, and studied public and private reports on the issue. All these sources of information form parts of the data used in performing the qualitative analysis of our problem.

### 4.4.2 Case Studies: Summary

The qualitative research is based on the study of the three municipal electric utilities that have become broadband providers. They are Braintree Electric Light Department (BELD) from Braintree, MA; Hometown Utilicom (HU) from Kutztown, PA; and Owensboro Municipal Utilities (OMU) from Owensboro, KY.

BELD deployed internal communication services for its electrical operations in 1995, and expanded its operations to external telecommunication services in 1999 by offering cable modem high-speed Internet access through Hybrid Fiber optic Coaxial (HFC).

HU deployed a fiber optic network in 1999 to upgrade the SCADA system it was using for its water system, replacing the system of light alarms used in its electric power distribution network, and deploying automatic meter reading (AMR). In order to do AMR, HU wired the 2,200 buildings and homes in Kutztown with fiber optic cable and, taking advantage of Kutztown's small area, deployed a Passive Optical Network (PON)[44]. Three years later, in 2002, HU began offering high-speed Internet access through fiber-to-the-premises.

In 1997, Owensboro Municipal Utilities decided to replace its old microwave SCADA system with one enabled by Internet Protocol over a fiber optic network. The old system was being used in electrical operations among substations, and linked the Water Department with other water districts. OMU started offering commercial broadband through fiber in 1999, and wireless broadband to residential and small business customers in 2002.

These three MEUs were founded in the early years of the rural electrification of the United States, at the end of the 19th Century or the beginning of the 20th. Two of them

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[44] A Passive Optical Network does not require active electronic elements to repeat the signal over the network and, thus, it is less expensive and more reliable than network with active elements (Sirbu and Banerjee 2003).

are among the large number of utilities with a history of diversification, having added gas, sewer, wastewater, and water to their electric power services. Of all MEUs that deployed some internal or external telecommunication services by December of 2005, 78.8% of them had diversified into at least one of these services.

**Table 4.4** summarizes several details of the three cases. This section presents a summary and some observations from the cases studies. The next sections contribute more understanding by adding analysis through COIReM.

**Table 4.4**: Summary of Case Studies

| | Braintree, MA | Kutztown, PA | Owensboro, KY |
|---|---|---|---|
| Population | 33,828 | 5,067 | 54,067 |
| Households (Occupied Housing Units) | 12,652 | 1,874 | 22,659 |
| Area (sq. miles) | 13.4 | 1.6 | 17.4 |
| Median Income per Capita (2000) | \$28,683 | \$18,803 | \$17,968 |
| Year of Founding | 1891 | 1902 (branded as Hometown Utilicom in 2002) | 1900 |
| Utility Services other than Electric Power and Telecommunications | none | Sewer, Water and Wastewater | Water |
| Deployment of Internal Services, Technology (Year) | Internal communications and AMR, SONET Ring (1995) | SCADA, Fiber Optic Network (1999) | Update SCADA, Fiber Optic network (1997) |
| Motivations for Deploying Internal Services | Replacing twisted pair-based communications with power plant and substations, and installing AMR. | Updating SCADA system from water department. | Updating old SCADA microwave system among substations, water dept. and two other water districts |
| Deployment of External Broadband Service, Technology (Year) | Mostly Cable Modem (1998), some FTTP lately | Fiber-to-the-Home (2002) | Commercial fiber (1999), and residential and commercial wireless (2002) |
| Telecommunication Services other than Broadband | Cable Television (CATV) | CATV, Telephone (including VoIP), web hosting, and security systems | None |
| Learning and Adaptation | “Linemen learned very fast how to handle Hybrid Fiber optic Coaxial cable” | “We could hang the wire ourselves” | “Linemen learned to splice fiber, and some learned telecom work” |

Source: the author based on case study analysis

Some reasons these three MEUs diversified can be understood from an historical perspective. They were founded to be active participants in local economic development. Today’s managers understand the mission of their MEUs in this context.

Their raison d'etre ranges far beyond the sole provision of high-quality and affordable electric utility services.

In all three cases, initial investments in new-generation communication networks were motivated by the need to improve the reliability of existing utility services. At that time, the deployment of external broadband services was neither an issue nor the goal for such investments. While local contexts varied, adoption of the new networks were all closely related to the effects of liberalization of the electric power market, and the increasing need for reliability of the local and national grid.

Also in all three cases, a particularly relevant aspect of the context is the openness of the process and social involvement. Local authorities and the population knew about the investment options and, in the cases of Braintree and Kutztown, also had an active voice in town hall meetings. This was less true in the case of Owensboro, where initial investments were made with funds from OMU.

An additional characteristic of the context is the high accountability of MEUs' senior management to local authorities and citizens.  While accountability to local authorities seems to be a constant across cases, direct accountability to citizens seems to be higher in smaller towns such as Kutztown. Here, citizens know each other; the general manager of an MEU can receive calls and visits from customers with unsolved problems.  This has been a major factor in maintaining quality and accountability in customer service; problems in quality of service can rapidly turn into political problems. This has been pointed out as a major difference in accountability for quality of service compared to that provided by operators of large private networks.

Two or three years lapsed between the investment and deployment of infrastructure for internal IP-enabled services and the offering of external commercial broadband. In all three cases, the purpose of the initial investments was to increase reliability of the electric power system by upgrading or installing IP-enabled SCADA and AMR. Initially, there were no indications of interest in deploying telecommunication services for serving external customers.

Information from our interviews indicate that the main reasons for the decision to invest in fiber optic networks were two: (i) this option is not affected by electromagnetic and radio frequency interference and (ii) electric utilities are used to invest in long lived infrastructure. In addition, the cost of the technology was decreasing. The MEUs expected to recover their investments in fiber in about 20 to 30 years.

Interviews revealed that the emergence of external telecommunications as a business line resulted from the convergence of two processes: (i) the organizational adaptation and learning within MEUs, and (ii) increasing awareness in the local population about the potential of the new technology.

All three cases show evidence that adaptation began as SCADA engineers quickly learned about the new system, and linemen promptly became adept at handling and hanging fiber optic cable. Additionally, some technology-savvy utility workers participated actively in the adoption of the new technology, becoming active in the deployment process and later in the operation of the new technology.

As the people working in MEUs learned about the new technology, they identified an increasing number of communications and information-related applications and services that could be channeled through the infrastructure. The first step was to lay more cables to connect town buildings, provide Internet access to the local government and, in some cases, give access to the local school district.

As a result, the number of local government services that used the infrastructure increased, leading to additional learning within the local MEU about how to provide broadband services, and increasing awareness about the potential and reality of the new technologies. At this point in the process, MEUs had become *de facto* broadband providers.

The transition was facilitated by the open nature of the planning processes for the deployment of the new infrastructure for internal utility operations and approving the necessary funds. Whether or not an MEU would later require some external funding, it needed to interact with the local commissioner or council member that dealt with electric power or utility services.

The requirements for presenting a proposal in a town meeting and types of voting and approval processes vary across towns, but in all cases the process was open to the community. In all cases, the process increased awareness of the existence of plans to upgrade the communications infrastructure of the local MEU, and also the existence of lead users who were surprised the local utility was investing in fiber optic networks and started asking whether they would provide local broadband access.

As local awareness about the potential of this technology increased, the original purpose for investing and deploying it changed. The purpose went from solely increasing the reliability of utility operations to using the technology to provide local broadband access. The assumption was that this would foster local economic development, including in some cases triggering the deployment of a wide range of telecommunication services (See **Table 4.4**).

Appendices 2, 3, and 4 present detailed descriptions of the cases in terms of the towns and the electric utilities; the local context before making the investments; deployment of the internal and external solutions; reaction from incumbent broadband providers; funding options; and perceived impact at the local level.

The research questions posed in this dissertation cannot be answered through case study research alone. Complementary methodological and theoretical approaches enhance and add meaning to case study analysis. We have applied underlying concepts of the theory of system architecture to understand the architectural evolution of MEUs, and have integrated two methodological approaches to study better understand this evolution through a detailed representation of the system: CLIOS Process and Object Process Methodology.

## *4.5 Stage 4: Validation and Advancing of the Findings:*

Field research provided rich information supporting some of our previous findings, and also giving a new perspective into some of its aspects. Here, at Stage 4, with our field research finished, we test the validity of our understanding of the system by looking at our initial representation developed between Step 3 and Step 9, with special emphasis on the reasons and processes for change. Our generic model represented our hypotheses, and in this step we are testing it by using data from the field.

### 4.5.1 Step 11 – Revision and validation of COIReM Representation:

In terms of representation of the physical domain and the institutional sphere, our initial representation was very accurate, with a few exceptions about the process of change. A methodological finding from contrasting information from field research with our representation is that COIReM *can represent the architecture of the system* before and after, but *cannot represent the process of change*. For this reason case study research has proven to be highly valuable, to complement and validate findings. We present revision and validation of the previous steps as follow:

1. The initial description of the system did not make a distinction between MEUs that deployed before and after 2001. Interviews and field research evidence pointed out that as the first MEUs began to deploy SCADA and AMR, they were not thinking about broadband. Initially, when MEUs started to diversify into broadband, the American Public Power Association (APPA) was not as positive about the idea as it is today. When the APPA was convinced about the potential of the new technologies, about 2001, it became very active in the diffusion of the idea among MEUs.

This observation is important, because we are interested in studying a process of evolution of MEUs that results from a process of *information search* (Fleming and Sorenson 2001). These authors define such a process as one where people and organizations acquire new information in order to manage ambiguity, uncertainty and risk. From this perspective, the involvement of the APPA as catalyst and major broadcaster of the possibility to become a broadband provider, eliminates the search process and makes the evolution of the next cohort of MEUs to deploy broadband considerably different. This difference has important implications for the quantitative analysis, as we will see in Chapter 5.

2. Besides the architectural legacy discovered in section 4.3.1 (Step 5), field research revealed another source of legacy: (i) maintenance of the electric power distribution network (knowledge-base of the linemen), and (ii) later operation of the SCADA system. Interviews revealed that linemen shown high capacity to learn how to handle fiber optic cable, and became instrumental in the deployment of the networks. Also, some of the people working with the SCADA system, and others with working knowledge or interest in computer networks became very active in the deployment and operation of the network.

3. Field research also shows that, among the innovator MEUs, customer need for broadband was identified following the deployment of the infrastructure for operating the new solutions for system command and control. In the case of Braintree, for example, the initial network was of little use for providing broadband because the fiber was deployed according to the location of substations and water and sewage infrastructure; there was little residential housing in its path.

4. Those interviewed described the adoption of new ICT inside the municipal government as key, especially for the way in which MEU personnel learned to manage and operate the new technology, which contributed to diversification. Fire and police departments were among the first municipal offices to be connected.

   Braintree Electric & Light Department, for instance, started connecting town buildings in order to give Internet and telephone service to the local government. Hometown Utilicom, in Kutztown, also connected borough offices, the police and fire departments and included a security function. Owensboro Municipal Utility first deployed external services to the city government departments and local schools.

5. Historically, MEUs have had a local focus and a customer base defined by the geographic boundaries of local governments. They understand their mission in terms of the needs of their customer base related to local economic development. Case studies showed that the deployment of IP-enabled services preceded

diversification into external telecommunication services by a period of two or three years. The identification of customer need for broadband was critical for the emergence of the new externally delivered function (EDF) of providing Broadband Internet access.

These needs were identified through a gradual social process parallel to the approval process required to deploy and fund the internal networks. The next step, as suggested by case study research, was to develop the intent to fulfill that need and meet bandwidth demand. Interviews and documentation revealed a process driven mostly by customers and facilitated by the openness of the due-diligence process preceding the investment in SCADA and AMR systems.

6. Interviews revealed that some MEUs had to agree to no-layoff policies before adopting the new IP-enabled SCADA and AMR, and also train some of its own personnel in order to perform some functions. This was not part of our initial hypotheses and, thus, was not included on our representation. This is relevant because the no-layoff policies and training to MEU personnel were partially responsible for the creation of in-house capacity for deploying and operating IP-enabled networks, and the later adaptation and organizational learning.

### 4.5.2 Step 12 – Observations about the Evolution of the System's Architecture:

This chapter presents our observations and learning about the reasons and process of architectural evolution of MEUs. The observations in this chapter come from integrating our findings from the different stages of COIReM: (i) the understanding of the setting, changes in context and technology, and the historical path dependence of the system, (ii) the understanding gained by building a detailed graphical representation of the system, based on our hypotheses and assumptions about the architecture of MEUs, its relationships with their immediate organizational and economic contexts, and the influence of actors in their institutional spheres, (iii) performing field research in order to gather data to validate such hypotheses, and (iv) validating the hypotheses and drawing conclusions. This analysis helped us test our initial hypotheses about the evolution process of MEUs, which happened in four stages:

1. The combined effect of innovation and technical changes in information technology and changes to the regulatory context in the electric power industry led MEUs to update their systems for command and control of electrical operations by adopting new IP-enabled solutions operating over fiber optic networks.

2. Electric utilities are accustomed to investing in expensive, long-lived assets for increasing the capacity and reliability of their grid. For this reason, a major, long-term investment, such as fiber optic and new generation network technology, was not unfamiliar to them. An important advantage of fiber optic technology is that it is not affected by electromagnetic and radiofrequency interference, which is an important improvement in quality and reliability compared to systems working over telephone lines. The additional possibility of channeling data communication from various sources using the same cables represented an important advantage over an analog system that required a dedicated line for each component under monitoring.

3. MEUs appear to have high absorptive capacity and dynamic capabilities, which allowed them to learn from the new technology, adopt new knowledge, put it to work, and create the option to diversify into new services.

4. Finally, the decision to diversify resulted from the learning process mentioned above and especially from open decision-making processes that raised local awareness about the broader potential of the new technology, the existence of local demand for broadband services, and opportunities for the local economy.

The next sections present a more detailed explanation of each stage in this evolution.

#### 4.5.2.1 Adoption of IP-Enabled Solutions by MEUs: the effect of regulatory and technical changes in critical components

The adoption of Supervisory Control and Data Acquisition (SCADA) and Automatic Meter Reading (AMR) by electric utilities began in the 1960s and 1970s, respectively (Tamarkin 1992). At that time, these services were mainly operated through leased lines from telephone companies over twisted-pair telephone cable. Because leasing network capacity from telephone companies was expensive, MEUs started to deploy proprietary networks for running SCADA and AMR (Tamarkin 1992). At this time, the technology required a dedicated line for each device that needed to be monitored. Given the high associated investment and cost, monitoring could not be deployed to cover every network element. SCADA and AMR were limited to basic features such as failure alarms and control of voltage. In addition, each monitored element on the electric power network needed a separate cable.

By the late 1990s, many of these telephone cable networks had degraded. Lightning, and electromagnetic and radiofrequency interference had also become important issues affecting the operation and reliability SCADA and AMR systems and, by consequence, the reliability of electric power networks.

At the same time, the clockspeed in the information and communication technologies sector was increasing, especially since the mid-1990s. After the privatization of the National Science Foundation Network (NSFNet) in 1995, the Internet started to become the medium in which all communications were converging (NRC 2001; NTIA 2001; NRC 2002). The demand for bandwidth has increased due to new, more, and better use of access technologies, content, and applications for personal and business use (NRC 2002). Some typical examples are email, web browsers, search engines, and Internet commerce companies. More sophisticated solutions include applications and business models for electronic commerce, business intelligence, resource management and planning, and system monitoring and control (Forman, Goldfarb et al. 2003b).

Additionally, the electric power sector became a target of regulatory changes during the same period. In 1992, the United States Congress passed the Energy Policy Act of 1992, which aimed to increase the efficiency of the electric power market by creating competition. The implementation of the act was executed by the Federal Energy Regulatory Commission (FERC) in 1996[45]. State governments followed by enacting similar legislation that would allow competition in their retail electricity markets, and requiring the divestiture of generation to non-utilities. By February 2001, 24 states had enacted legislation restructuring their electric power markets. Of these, one state (New York) had issued a comprehensive regulatory order on the issue; 18 initiated investigations led by special commissions or legislative bodies; and eight had no activity on the issue other than the legislation[46].

The combined effect of these changes, plus technical change in critical components for electric power, triggered the adoption of new solutions for the command and control of electric power systems enabled by Internet Protocol. In order to understand this, we need to understand changes in the architectural legacy of such systems.

As general purpose technology, the Internet is becoming a medium of convergence across various services and industries. Our research is one example of it. In this context, the technical changes in telecommunications, innovations in information technologies, and regulatory changes that triggered the update of SCADA and AMR systems began to affect MEUs in two ways:

1. The traditional analog technologies for SCADA and AMR were replaced by new generation digital solutions based on Internet Protocol (IP). Unlike the old solutions, new IP-enabled SCADA and AMR allowed real-time and remote monitoring and control of network assets, meters, and even electric appliances on

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[45] See http://www.eia.doe.gov/cneaf/electricity/page/fact_sheets/restructuring.html

[46] See http://www.eia.doe.gov/cneaf/electricity/page/fact_sheets/rdescr2.html

customer premises. The new solutions provided much more detail and high quality information for real-time decision making and failure prevention.

Also, elements being monitored by IP-enabled SCADA and AMR could share a common network backbone, producing scale economies. Thus, many of these MEUs choose to deploy their own networks for running IP-enabled SCADA and AMR. By owning their networks rather than leading lines from telecommunications providers, MEUs could generate important savings.

2. There were alternatives to the traditional cable telephone lines, even in the presence of digital communications. The cost and difficulty of deploying fiber optic networks was decreasing at the same time that Wavelength-Division Multiplexing (WDM) had become commercially available. WDM enabled the channeling of various services along a single wire. Unlike twisted-pair or power lines, these cables were not effected by electromagnetic and radio frequency interference.

   These changes were, in some cases, also being driven by regulatory change or the expectation that a private utility would eventually enter the market. For these reasons, some MEUs decided to build a network infrastructure, deploying their new internal IT-based services over a single backbone, in some cases comprised entirely of fiber optic technology.

In adopting these technical changes, the MEUs were making architectural innovations and unintentionally creating capabilities that would be discovered later.

#### 4.5.2.2 Electric Utility Mentality: reliability and long-term investments

Why did MEUs choose to build networks using a new, expensive, and complicated network technology in which they had no experience? This type of investment was more appropriate for telecommunication companies. Furthermore, much of the fiber deployed by telecommunication companies still remained unused, raising doubts about whether such investments were good business for public utilities. Part of the answer may be found in the mentality of electric utilities and their capacity for organizational learning and adaptation.

A major driver for the upgrade of SCADA and AMR was the desire to improve the reliability of the electric power system (See **Table 4.4**). Two major reasons were the competitive effects of the deregulation of the electric power industry, and the overall context of the reliability of the United States National Grid.

Fiber optics greatly increases the reliability of the command and control systems for various reasons. First, digital fiber optic networks allow constant connectivity which enables real-time two-way communications. These features allow not only reaction to crises, but correction and crisis prevention based on ex-ante identification of likely problems. Second, communications and command and control based on fiber optics is more reliable because they are not affected by electromagnetic or radiofrequency interference. Third, current jacketing solutions make fiber optics as durable as copper equivalents (Barnett, Groth et al. 2004). Fourth, the cost of deploying fiber optic networks has decreased significantly, making low-end fiber optics less expensive that high-end copper cable. Finally, fiber optics allows a maximum distance of 18,000 feet without need for repetition of the signal. In small towns, like Kutztown, PA, this allows the deployment of a Passive Optic Network (PON), which is less expensive and more reliable than active networks that require active components in the field.

Additionally, electric utilities are used to investing in long-lived assets. The design life of electric utility infrastructure can reach 40 years, and the average of its assets is calculated to be between 24 and 30 years in the United States, depending of the type of asset (CIGRE 2000). When people consider the investment rationale for fiber optic cable, they usually do so from the perspective of the telecommunication industry, the major users of fiber optics, where the investment horizon is usually five to seven years.

It is not surprising that MEUs were willing to invest in fiber optics for internal reasons: (i) it increased the reliability and efficiency of the electric power operations; (ii) the cost of fiber optics has decreased to the point where a meter of low-end fiber optic cable is less expensive than a meter of high-end copper (Barnett, Groth et al. 2004); and (iii) MEUs could amortize the investment over a 30-year period.

#### 4.5.2.3 Organizational Adaptation: absorptive capacity and dynamic capabilities

A separate question, however, is whether municipal electric utilities had the expertise to manage and operate this new technology. Some critics thought that new generation communication networks were far too complex to be managed by municipal electric utilities (Bast 2005). As result of our interviews, we find evidence that MEUs' capacity to learn, adapt, and create new capabilities has been beyond the expectations of their own managers.

The ability of MEUs to utilize new knowledge gained from IP-enabled solutions and fiber optic networks is grounded on the knowledge base already existing at the organizational and personal level. This type of relationship between existing knowledge and the acquisition of new knowledge was coined by Cohen and Levinthal (1990) as "absorptive capacity". It is defined as the ability to identify the usefulness of new information, recognize its importance, and apply it to the creation of value.

Our case study analysis shows that MEUs exhibited high organizational capacity to adapt to the new technology. This has been an important factor for their successful adoption of fiber optic networks and diversification into telecommunication services. Qualitative research revealed three major reasons for the adoption of this technology by MEUs, and their capacity to learn about it, operate it, and position themselves to diversify into telecommunications.

There were many sources of internal knowledge in MEUs that facilitated the adoption of the new technology. Engineers and linemen already possessed the skills to quickly learn the new system.

Operating electric power services, computer networking and telecommunications require similar types of engineering knowledge. Personnel operating old SCADA systems are likely to be people interested in computer networks; field research shows that many were doing related work as hobby or outside their working hours at the MEU. They saw in the new projects the opportunity to apply their knowledge and do something new. Some MEU department heads defined it as a "geek culture" that not only simplified the adoption of the new technology, but also accelerated learning. MEU managers identified this interest as a way to engage people in the process of change.

The linemen working at MEUs were another important source of absorptive capacity. They are in the business of handling the cable, and fiber optic is just another type of cable. The linemen possessed the basic knowledge that allowed them to quickly learn how to deploy and handle fiber optic cable. In some cases, external contractors' labor costs for laying fiber was too high, which encouraged MEU management to train their own linemen to do the job. The response from linemen in handling fiber optics cables surprised MEU senior management, especially in the case of Kutztown, and Owensboro.

As we have mentioned before, the cost, time, and complexity of working with fiber optic cable has decreased during the last years. This is due to three new developments: (i) the benefits of new technologies for polishing the core of a fiber optic cable after a cut; (ii) connectors that not longer require the polishing step; and (iii) the use of index-matching gel in connectors that enhances the quality of the connection. These improvements make splicing and connecting fiber optic network much easier to learn and to do, requires less sophisticated specific knowledge, and facilitates the acquisition of new knowledge.

These dynamics, in the context of an organizational path dependence exhibiting social concerns, responsibility for local economic development, and diversification into other infrastructure-based services, encouraged the creation of *Dynamic Capabilities*. Dynamic capabilities are defined as the ability of organizations to "integrate, build and reconfigure internal and external competences to address… changing environments" and "reflect an organization's ability to achieve new and innovative forms of competitive advantage"(Teece, Pisano et al. 1997). Dynamic capabilities are the results of an organization's absorptive capacity which is built, in turn, on the absorptive capacity of its members, which takes time (Cohen and Levinthal 1990).

The dynamic capability of MEUs was expressed in terms of the capacity to deploy of broadband services. Based on this discussion, the fact that MEUs invested in fiber optics and new-generation communication infrastructure might be more related to their character as "electric utilities", than as "municipal". This question is suggested for further research.

#### 4.5.2.4 Diversification: from internal IT-based solutions to external broadband services

Our analysis shows that the emergence of the externally delivered function of providing broadband services and the Broadband Subsystem results from technical, social, organizational, and regulatory changes. According to the case studies, the overall process from using the new communication infrastructure solely for running internal services to starting to offer external telecommunications services took between two and three years (See **Table 4.4**). This section explores four complementary causes of this evolution:

1. According to our case studies, the openness and accountability of local government approval processes were critical in raising awareness (i) among citizens and businesses that fiber optic technology was being deployed in town, and (ii) among MEU and town officials about the existence of demand for broadband services.

   The process of deploying new-generation communication technologies by MEUs is very open compared to similar processes in the private sector. As public organizations, MEUs respond to the local government and community. Independent of the mechanism used for funding the new technology, many of the discussions about investing in fiber optic networks were open to the public; people knew what was happening.

   Historical analysis helps explain this process in a context of path dependence. The deployment of broadband in rural areas resembles the origins and rationale for the deployment of electric power in rural areas almost a century ago. A major reason for the creation of MEUs was the high cost and inadequate deployment of electricity during, roughly, the first three decades of the twentieth century. Similarly, an important factor for the entry of MEUs into broadband services was the high cost and dearth of high-speed Internet access. MEU have historically responded to the requirements for economic development in their communities by diversifying. As conversations about the deployment of new technologies developed in public forums, some technology-savvy residents started asking what else MEUs could do with the available infrastructure.

2. Organizational dynamics of learning and adaptation enabled creativity and identification of new opportunities for taking advantage of the new infrastructure, triggered by some drivers common to some of the subsystems of our CLIOS System.

   As MEUs learned and adapted their capabilities through the adoption of the new IP-enabled SCADA and AMR systems, they gained the necessary know-how to deploy and operate communication networks. Through interaction with equipment and solutions providers, MEU managers also learned about different business options the technical capabilities of the new infrastructure could deliver.

   Following the implementation of SCADA and AMR for their own purposes, MEUs extended the use of their new networks to include communication and information technology services for other local government agencies. The adoption of new information and communication technologies for government operations was also driven by increased emphasis on efficiency. MEUs connected municipal buildings and departments, gave Internet access to public schools using some of their spare capacity, added security features including, in some cases like HU, the operation of security cameras in municipal buildings, etc. At this point, for practical purposes, MEUs were operating as *de facto* broadband providers for the internal municipal market. This had an ever greater effect in increasing local awareness about the possibility that MEUs might become providers of broadband Internet access.

3. MEUs had already deployed fiber optic networks for their utility operations. As result, an important part of the infrastructure required to offer broadband access was already in place. Depending on the case and according to the plans for their utility operations, some MEUs had installed their fiber networks in some or all residences in town. The operation of SCADA and AMR, however, left MEUs with spare bandwidth capacity that represented a valuable resource for local residents and businesses.

   As result, the attention of elected government officials and MEU senior management was directed towards telecommunication services by various converging changes: (i) there was increasing awareness about the availability of the new resources and their potential for uses other than internal monitoring and control of electric utility operations, (ii) there was increasing local demand for broadband services, and (iii) there was more and new evidence about the possibilities of taking advantage of the network's economies of scope.

MEUs had two major options for taking advantage of such economies of scope: (i) opening the network to allow established private telecommunication operators to serve residents and businesses (this option is known as open access), or (ii) diversifying into telecommunications services themselves. Most MEUs decided on the second option for various reasons, including the fact that their first attempts to offer broadband through open access found no interested private parties (Lehr, Sirbu et al. 2004).

The main reason for private telecommunication and cable television providers to refuse the open access option was lack of control over the "last mile" of cable leading to a residence or business building. In the traditional model, private operators "own the house", i.e. own the network infrastructure (and sometimes the customer premises equipment). In the open access model, however, the MEU has control of the last mile.

4. MEUs sought approval and funds from their local governments, their own internal boards, or both. Open discussions about findings and investments offered the opportunity to discuss and discover new possibilities for using the infrastructure. In this context, the case for diversification was based on (i) the existence of spare valuable resources that could be used more efficiently, and (ii) the potential to stimulate local economic development by deploying infrastructure known to be a critical driver for future social and economic growth. One of the expected outcomes was the attraction of new knowledge-based businesses based on the availability of information infrastructure.

Among innovator MEUs, diversification into telecommunications was not evident when new-generation technologies for SCADA and AMR were adopted, but arose gradually from these converging trends[47]. Once they had reached the diversification stage, they realized that even more options lay beyond broadband. They could use their networks to offer various converged services that include telephone services over Internet Protocol (VoIP), cable television, and security services. By December of 2005, 292 MEUs were offering some type of external telecommunication service, 260 of them were offering high-speed Internet access, 105 provided cable television services, and 57 offered telephone services.

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[47] As stated throughout this analysis, evidence suggests that MEUs that adopted this technology after 2001 responded to different reasoning and followed a different process. The study of this process is left for further research.

There are still two aspects to follow up. This qualitative analysis provides some answers by helping us to test our hypotheses about the reasons (*why*) and process (*how*) of architectural evolution. However, it does not give us information about the magnitude effect. This will be matter of analysis in Chapter 5. But, before turning into that quest, we first need to evaluate how useful was the COIReM for our analysis. This is done in the following section.

### *4.6 Evaluation of COIReM Analysis*

The use of COIReM was critical in testing our hypotheses about why and how MEUs became broadband providers. The study of the setting and historical analysis allowed us start exploring our hypotheses by better understanding the changes in context and technology and role of path dependence.

By integrating the strengths of the Representation Stage of the CLIOS Process and Object Process Methodology, COIReM allowed us to learn about the evolution of the architecture of our CLIOS System *through the process of representing it*. Here, learning resulted from the immersion process of detailed representation of the three subsystems of the Physical Domain and the influences that various institutional actors had on function, form and concept.

We built a generic representation of their structure by detailing the relationships among form and functional elements across the different subsystems of the physical domain based on our hypotheses about the architectural evolution of MEUs. This allowed the representation of form and functions within a single diagram. While it increased the number of components of each diagram, this made them simpler to understand by adding information about behavior and reducing the need for detailed hierarchical structure decomposition.

The detailed hierarchical decomposition of form and function of the Electric Power Subsystem was critical in demonstrating the existence of the architectural legacy that components and function for data communications would have in the later deployment of broadband infrastructure. Additionally, varying the level of complexity from the representation of the CLIOS System by scaling the Electric Power subsystem helped identify the adequate level of aggregation for representing functions and components of form.

COIReM was created with the objective of gaining a method that could aid in the process of research through representation of the architecture of a CLIOS System and integrate the strengths of the CLIOS Process and OPM, while offsetting their individual limitations. COIReM, however, has its own limitations:

1. COIReM was conceived as a research method to study *the architecture* of CLIOS Systems and, as such, it only addressed the Representation Stage of the CLIOS Process. It has not been tested or applied to the later stage of Design, Evaluation, and Selection or the final stage of Implementation.
2. It has been used to represent a CLIOS System in which the architecture of subsystems of the physical domain *is the major focus* of analysis. In cases where the subject of analysis is a less structured subsystem, such as the Economic Activity subsystem, COIReM would probably add complexity without adding more value or providing better insights.
3. The *process of representing the system* was critical to learning more about it. In the case of our work, the process of representing the system enabled the researcher to learn about the evolution process, and make observations about the reasons and process of architectural change. Representation in itself provides limited value for other purposes.
4. COIReM analysis needs to be used along with case study research methods not only to verify the validity of the model and hypotheses, but also to complement findings about system structure and behavior, with findings about the process of evolution that cannot be fully captured by COIReM.
5. Finally, COIReM representation does not answer all relevant questions. The representation was partially made under the assumption that adoption of IP-enabled communication infrastructure enhances the efficiency of the operations of the Electric Power subsystem, and that deployment of external broadband have a positive impact on local economic development. The representation does not, however, provide proof.

The fourth point above is deeply quantitative. Chapter 5 deals with this question examining the economic effect of this architectural evolution on the internal efficiency of MEUs and on the local economy.

# Chapter 5: Measuring the Economic Effects: What difference does it make?

The previous chapter identified and explained the architectural evolution of MEUs from the adoption of next-generation communication technologies for internal operations to the deployment of additional infrastructure and offering of external broadband services. Qualitative analysis, however, left open some important questions that can be answered only by quantitative means: (i) What is the effect of adopting new technology on the operational efficiency of MEUs? (ii) Do MEUs subsidize their broadband operations with funds from their electric power business?, and (iii) What is the effect of an MEU becoming a broadband provider on the local economy?.

We answer these questions by testing three associated hypotheses: n: (i) the "Internal Efficiency Hypothesis"(IEH), which states that deployment of IT-based solutions for system control and monitoring have a positive effect on an MEU's internal efficiency; (ii) the "Cross-Subsidy Hypothesis" (CSH) which states that, everything else being equal, if MEUs subsidize their external broadband services with funds from their electric power operations, they should exhibit higher electricity prices and costs than MEUs that do not offer external broadband services; and (iii) the "Local Economic Development Hypothesis" (LEDH), stating that deployment of external broadband services by MEUs leads to positive effects on local economic development.

Testing these hypotheses helps to explain some opportunities and identify challenges presented by the deployment of advanced telecommunication services by MEUs, and to inform a policy debate that has been mostly based on anecdotal evidence, limited analysis, and advocacy perspectives. The hypotheses were tested using matched sample estimators (MSE), a recently developed method that can be used to calculate the average effect of technology deployments (Abadie, Drukker et al. 2001). Section 5.1 explains the rationale for applying MSE in more detail.

Testing the IEH shows that MEUs that have adopted new generation IT-based systems for internal control and monitoring operations exhibit lower prices and costs for customer service, and sales and information per unit of output, but higher general expenses and administrative cost. Testing the CSH reveals no evidence of the existence of cross-subsidies from electric power to broadband operations. Finally, our analysis of LEDH indicates that deployment of MEU-based broadband by 2000 is associated with an increase in the growth rate of the number of local business establishments between 2000 and 2002.

## *5.1 Research Design: Research Questions, Hypotheses and Method*

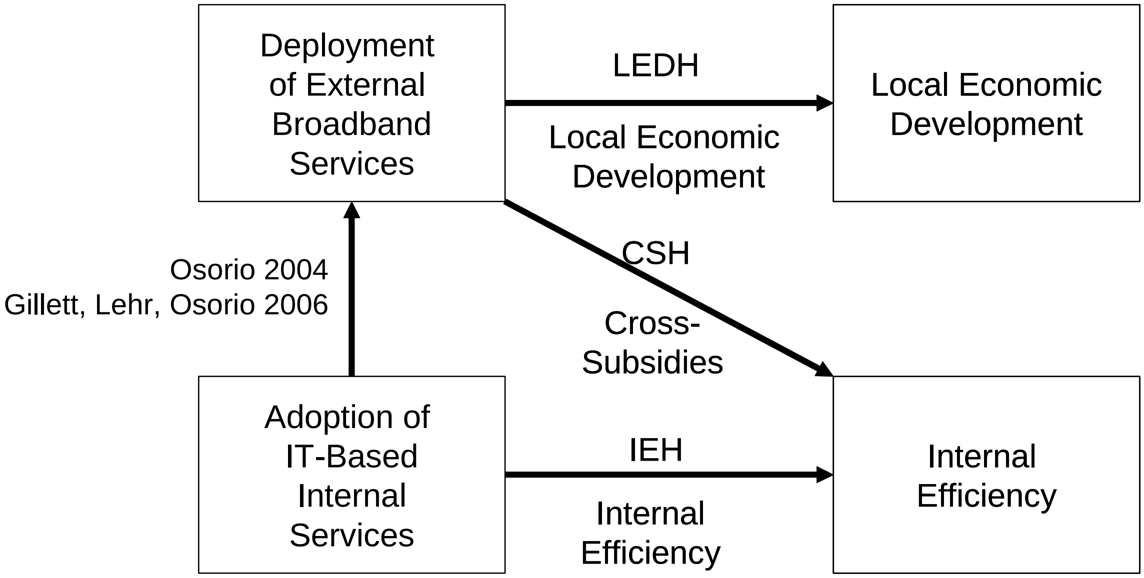
In this section we explain the research questions with their respective hypotheses, and the methods we use to answer those questions.

### 5.1.1 Research Questions and Hypotheses

Previous research has established the relationship between deploying network infrastructure for operating MEUs' internal control systems, and offering external telecommunication services. To do this, investigators studied the factors affecting the likelihood of MEUs becoming providers of advanced telecommunications services (Osorio 2004; Gillett, Lehr et al. 2006). The discussion in Chapter 4 explained this relationship.

This section explains each of the three hypotheses presented above, the overarching research question associated with each, and the dependent variables we use to test them. **Figure 5.1** illustrates the relationship among them, and between this study and previous research.

**Figure 5.1**: Relationships among Hypotheses



Source: the author

We present our research questions and hypotheses as follows.

i. *What is the effect of the adoption of new IP-enabled SCADA and AMR on the internal efficiency of MEU*?

   Answering this question helps to demonstrate whether the original motive for the deployment of the new technology—to use public resources more efficiently—was well-founded. Previous work has suggested a relationship between IP-enabled SCADA and AMR and efficiency in electric power operations (IBM Business Consulting Services 2004; Black 2005). One goal of this study is to determine whether the adoption of IP-enabled solutions for monitoring and controlling electric power systems has had positive effects on their internal efficiency.

   The Internal Efficiency Hypothesis (IEH) states that all else being equal, MEUs that have adopted IT-based control and monitoring systems for their electric utility operations exhibit higher levels of ex-post internal efficiency than non-adopter MEUs. The hypothesis is tested using three different *dependent variables*: (i) price per mega watt-hour (MWh), (ii) customer service, sales, and information expenses per MWh, and (iii) administrative costs and general expenses per MWh.

*ii. Do MEUs cross-subsidize their broadband services with revenues from their electric power operations?*

A subsidiary to the study of efficiency gains, this question has important implications for public policy. If MEUs are subsidizing their broadband operations with revenues from their electric power operations, they could offer lower prices for broadband than private providers, driving them out of business.

The Cross-Subsidy Hypothesis (CSH) states that if MEUs subsidize their broadband operations with funds from their electric power business then, everything else being equal, they will exhibit higher prices or costs in electric power operations than MEUs that do not deploy external broadband services. We test this hypothesis by looking for statistically significant variations in price or costs of electric power operations comparing MEUs that become broadband providers and those that did not. We use the same three *dependent variables* used to test the first hypothesis.

*iii. What is the effect of the deployment of external broadband services by MEUs on the local economy*?

Answering this question requires empirical evidence about either positive or negative effects. This analysis builds on the work of Lehr, Gillett, Osorio and Sirbu (2006) that suggested a positive relationship between the deployment of broadband and local economic development.

The Local Economic Development Hypothesis (LEDH) states that everything else being equal, towns where MEUs have deployed external broadband services exhibit higher levels of ex-post local economic development than towns without MEU-based broadband. We examine whether the deployment of external broadband services by MEUs is associated with positive effects on the local economy at two levels. First, we analyze this relationship *independent* of the existence of private broadband providers. Second, we narrow our sample to study the same effect among places *with* private provision of broadband.

We test this hypothesis using four *dependent variables*: (i) growth rate of local business establishments, (ii) share of business establishments in IT-intensive sectors, (iii) growth rate of employment, and (iv) growth rate of average salary, all measured for the period 2000-2002. Each of these dependent variables is associated with different theories and assumptions about the effect of broadband on the economy. These theories are discussed in detail in Section 2.5.

The next section explains the empirical method used to test our hypotheses.

### 5.1.2 Empirical Method: Randomized Control Trials and Matched Panel Estimator

From a methodological perspective, the problem of studying the effect of adopting or deploying a technology is similar to the problem of studying the effect of a medical treatment in a defined population.

In medical research, one first selects a random sample of the universe of interest. A treatment is randomly assigned to one group from the sample, forming a "treatment group". A comparable sample will not receive the treatment, forming a "control group". If the randomization is done properly, both groups are probabilistically similar, with the exception of receiving the treatment (Shadish, Cook et al. 2002). The researcher calculates the effect of the treatment by comparing the outcomes in the treatment and control groups. This is called Randomized Control Trial (RCT), and is considered the most reliable scientific method for analyzing the effect of a "treatment" on a population.

RCT is an *experimental* method. For this research, using RCT to run an experiment with MEUs would require randomly selecting two statistically equivalent groups of MEUs, and proceeding to randomly assign the adoption of IT-based control systems to one of them (the treatment group). To address the first hypothesis we would compare the effect of this on internal efficiency among treatment and control groups. Similarly, for the Local Economic Development hypothesis, it would be necessary to randomly assign a second group to become broadband providers, and analyze the effects on the local economies in which the MEUs are embedded.

This type of experiment-based analysis is impossible to implement practically in engineering systems. For one hand, it is too expensive to make real experiments in a significant number of MEUs with large infrastructure projects. For other, investing in infrastructure is not a random process, but highly endogenous, so we cannot assume that MEUs have randomly decided to invest in IP-enabled technology. We have, however, the option of using a quasi-experimental method.

The alternative is Matched Sample Estimators (MSE), also known as matched sample regression. MSE is a quasi-experimental method that emulates RCT, sharing many of its characteristics, with exception of random assignment (Campbell and Stanley 1963).

Abadie, Drukker, Herr, and Imbens (2001) developed this method to measure the average effect of a treatment on a population or sample. Two groups of observations form the inputs: (i) one for which the treatment is available (i.e. MEUs that have adopted IT-based control systems), and (ii) another for which the treatment is not available (i.e. MEUs that have not adopted the technology). Each observation includes a vector of data that specifies the outcome (or dependent variable), the treatment, and a series of variables that will be used in the "matching process". This research implements MSE using the *Nnmatch* command in the statistical software *STATA*[48].

In the "matching process", the method pairs each observation of the treatment group with its closest match from the control group. The method includes an option for correcting for bias when the matching is not exact (Abadie, Drukker et al. 2001). By matching, the algorithm implemented in STATA emulates RCT by measuring the effect of the treatment on the dependent variable among observations that would be identical if they were a perfect match[49]. This "*bias-corrected matching estimator*" adjusts the differences among matches using the differences in their covariates or matching discrepancies. It also allows for estimating heteroskedasticity-consistent standard errors (Kennedy 1998; Abadie, Drukker et al. 2001; Wooldridge 2003). In other words, it creates treatment and control groups that are as similar as possible. **Table 5.1** presents the dependent, treatment, and matching variables used in testing each hypothesis.

**Table 5.1**: Hypotheses, Dependent Variables and Matching Variables

| ***Hypothesis*** | ***Dependent Variables*** | ***Treatment*** | ***Matching Variables*** |
|---|---|---|---|
| *Internal Efficiency* | • *price per mega watt-hour (MWh) 2003*<br>• *customer service, sales and information expenses per MWh 2003* | *adoption of IP-enabled SCADA or AMR* | • *Customer Service, Sales and Information Expenses per MWh 2000*<br>• *Revenue per MWh, 2000*<br>• *Administrative and General Expenses per MWh 2000* |
| *Cross-Subsidies* | • *administrative costs and general expenses per MWh 2003* | Cross-Subsidies*: deployment of external broadband services by 2000* | • *Population 2000*<br>• *% Purchase power 2000*<br>• *% Steam power 2000*<br>• *% Hydro power 2000*<br>• *Income per Capita 2000*<br>• *Medium Rent 2000* |
| *Local Economic Development* | • *growth rate of local business establishments (2000-2002)*<br>• *share of business establishments in IT-intensive sectors 2002*<br>• *growth rate of employment (2000-2002)*<br>• *growth rate of average salary (2000-2002)* | *deployment of external broadband services by 2000* | • *=1 if Private Broadband Providers 2000, 0= otherwise*<br>• *Growth Business Establishments 1994-1998*<br>• *Growth Employment 1994-1998*<br>• *Growth College Grads 90s*<br>• *Growth Average Salary 1994-1998*<br>• *% Pop. Bachelor Graduate in 2000*<br>• *% Establishments in IT-Intensive sectors 1998*<br>• *Growth of IT-Intensive establishments 1998-2000*<br>• *Growth Local Employment 1990-2000*<br>• *Population 2000*<br>• *Urban-Rural Influence Code* |

Source: the author

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[48] See http://www.stata-journal.com/software/sj4-3/st0072/ for accessing and downloading Nnmatch.

[49] See Stata help command Nnmatch.

For the internal efficiency and cross-subsidies hypotheses, *o*bservations are matched in terms of the size of the local market; availability of resources for funding the upgrade of electric power infrastructure; basic characteristics of the utility; and lagged variables for the historical baseline of each dependent variable. For the local economic development hypothesis, the matching process considers the size of the towns; their Urban-Rural Influence Code[50]; percentage of educated workforce; wealth; and lagged variables for the historical baseline of each dependent variable.

The use of MSE also helps correcting the typical endogeneity problem associated with the deployment of infrastructure and the measurement of its economic effects (Holtz-Eaking and Schwartz 1994; Haltiwanger and Jarmin 2000). In our case, this means that the decision to deploy broadband is inevitably associated with the economic characteristics of the target market (Gabel and Kwan 2000; Prieger 2003; Flamm 2004; Grubesic 2004). MSE also corrects for this problem, and allows the estimation of robust standard errors.

Our choice for matched sample estimators is useful to policy makers because it enables comparison with previous results about the economic impact of broadband at a national level.

### 5.1.3 Functional Form for Measuring Growth Rates

Recent work using MSE has addressed the local economic impact of broadband in the United States at the zip code level (Lehr, Gillett et al. 2006). Based on their work, this analysis is performed using the following equation to study the external effect of the deployments by MEUs:

$$Y(t)=Y(0)^{\alpha}e^{rt}, \qquad [1]$$

$$\text{where } r=r^{*}+\gamma \text{ treatment } +\mathbf{X}\boldsymbol{\beta}+e, \qquad [2]$$

$$\text{thus } \ln(Y(t)/Y(0))=g(t)=a+\gamma \text{ treatment } +\mathbf{X}\boldsymbol{\beta}+e, \qquad [3]$$

Where $a=\ln A+r^{*}=r^{*}$ if $A=1$, $\mathbf{X}$ is a vector of control variables and $\boldsymbol{\beta}$ their estimators. Here, treatment represents whether the MEUs deployed external broadband. In the case of internal IT-based services we will use a typical linear regression model. Here, $\gamma$

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[50] The Urban-Rural Influence code is developed by the Economic Research Service of the U.S. Department of Agriculture to proxy for the effect of population and proximity to large metropolitan areas as sources of economic opportunity of a locality.

represents the estimated effect of the treatment on the dependent variable in period [0,t], and e represents the error term.

## *5.2 Building the Database*

For this study we have built a *unique* dataset which aggregates data about the type of internal and external IT-based services by MEUs; characteristics of their electric power operations; and economic, social and demographic data about the geographical areas where they are located, among others. This section presents the data sources. We also explain the process of building the dataset, with special emphasis on the solution of the problems of merging and aggregating data.

### 5.2.1 Data Sources

The most important data for this research was provided by the American Public Power Association (APPA). The dataset is drawn from the APPA annual member survey and includes information for all types of internal and external deployment of telecommunication services, including IT-based internal services and external broadband (**Table 5.2** summarizes the data sources). The APPA data provides the information required to construct the treatment variables for the analysis of the three hypotheses.

There are over 1,800 MEUs in the APPA dataset. The analyses, however, are performed over two sub-samples for which all data is available thus making possible a higher quality of matching. The first sub-sample, used to test the Internal Efficiency and Cross-Subsidy hypotheses, includes 421 cases; they constitute a representative sample of publicly-owned electric utilities as described by the Energy Information Administration (EIA)[51].

The dependent variables are taken from the Energy Information Administration's (EIA) Annual Electric Industry Financial Report, and the U.S. Census Bureau's Zip Code Business Patterns. The quality of EIA data is widely recognized. It has been called "*the primary source of financial and expense data for the public power sector, as well as plant cost data and transmission line information for all sectors except investor-owned utilities.*"[52]

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[51] http://www.eia.doe.gov/

[52] Comments of the American Public Power Association to FERC and Electric Energy Market Competition Interagency Taskforce, AD05-17-000, November 18, 2005. Last visited on March 21, 2006, see url at http://www.appanet.org/files/PDFs/APPACmtsAD05-17.pdf

**Table 5.2.**: Data Sources

| Type of Data | Description | Availability | Source |
|---|---|---|---|
| Broadband and IT-based Internal Services | Internal and external telecommunication services by MEUs. | Collected once a year | American Public Power Association, 2000-2004 |
| Private Broadband Providers | Providers of Digital Subscriber Line (DSL) and Cable Modem | Collected once a year | Warren (2004) and DSL data used in Gabel and Huang (2003) |
| Business Activity Indicators | Used to determine place level data on employment, business establishments, wages (payroll), industry sector and size mix. | Collected on annual basis. Most recent data from 2002. Coded by industry sectors using SIC (1994-7) and NAICS (1998-2002). | U.S. Census Bureau -ZIP Code Business Patterns (ZCBP)[53] |
| Indicators of Internal Efficiency | Cost of operation and maintenance, cost of distribution, revenue and profits per MWh sold | Collected annually, from 1990 up to 2004. | Energy Information Administration forms 861[54], and 412[55]. |
| Demographic Indicators | Place-level data for income, rent, educational attainment, and # of households. | Collected every 10 years; most recent data from 2000. | (1) U.S. Census Bureau - 2000 Decennial Census<br>(2) GeoLytics – CensusCD ("1990 Long form in 2000 boundaries")[56] |
| Geographic Indicators | Used to indicate how urban or rural a county is, based on its population and proximity to metropolitan areas. | Computed every 10 years; most recent coding from 2003. | Economic Research Service, U.S. Department of Agriculture - Urban Influence Code (UIC)[57] |

As mentioned above, the matching sample estimators assess the effect of the "treatment" by comparing entities that are otherwise similar. The similarity is established by a matching process where the method pairs each treatment observation with the observation of the control group that is the closest match according to a series of "matching" variables. The criteria for matching used in this research are explained in the following sections, and **Tables 5.3** (see section 5.3) and **5.5** (see section 5.4) exhibit all matching variables and summary statistics.

### 5.2.2 Merging Datasets and Aggregating Data

As our analysis is done at the MEU and town level, we faced the problem of merging databases at different levels of aggregation. Before performing the analysis we needed

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[53] See http://www.census.gov/epcd/www/zbp_base.html

[54] See http://www.eia.doe.gov/cneaf/electricity/page/eia861.html

[55] See http://www.eia.doe.gov/cneaf/electricity/page/eia412.html

[56] See http://www.census.gov/main/www/cen2000.html for data from the US Census Bureau, and for GeoLytics http://www.geolytics.com/USCensus,Census-1990-Long-Form-2000-Boundaries,Products.asp.

[57] See http://www.ers.usda.gov/Data/UrbanInfluenceCodes/

to merge various datasets, and clean and prepare the data. The 8,663 lines of code that clean the original data, rename variables, merge the different datasets, and prepare the data for regression analysis are included on the CD attached to this dissertation. This code is built so one can access all datasets in their original state and build the one used to perform the analysis, and be of help to further research.

In the case of MEUs, the data was merged using datasets from the Energy Information Administration using the "Utility Code", which is an unique identifier for all electric utilities. Each MEU is also associated with a town or city. Here, we use the term "place" to denote towns and cities following the description of the U.S. Census Bureau. Besides merging the APPA data with information from EIA, we merged datasets from the 1990 and 2000 Decennial Population Census. We used an unique identifier--AreaKey--to merge the census data across places, and then the name of the place to merge the 1990 and 2000 census data with the utility data. In some cases, the matching between MEUs and places required individual revision and correction. In such cases, these corrections are included in the code individually.

The analysis about the effect of broadband deployment on local economic development required the aggregation of raw data from the U.S. Census Zip Code Business Patterns to the place level. Aggregating data from zip code to place level, however, first required the aggregation of data from enclosed to enclosing zip codes. An enclosing zip code is a regular zip code with a defined geographical area, such as 02139 for Cambridge, MA. An enclosed zip code is also referred as a "point" zip code, or one assigned to a large firm or specific building.

The problem arises because, while enclosed zip codes are physically located in areas represented by enclosing zip codes, their business statistics are presented separately. Failure to aggregate them would underestimate the count of business establishments, employment, and average salary, especially in dense urban areas where they are more common.

Thus, we first aggregated the data rolling up zip codes to represent business pattern statistics at the level of enclosing zip codes. Then, we aggregated data from zip code to place level. We did this by using the Census 2000 U.S. Gazetteer files[58], which present subdivisions for states, counties, places, and Zip Code Tabulation Areas (ZCTAs). Aggregating the Zip Code Business Patterns with data at the place level required us to resolve an additional issue: while Zip Code Business Patterns are presented using U.S. Postal Service (USPS) zip codes, the Gazetteer files use "ZCTAs".

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[58] For more information see http://www.census.gov/geo/www/gazetteer/gazette.html

ZCTAs are a variation of the USPS zip codes created by the U.S. Census Bureau for the purposes of the decennial census. While, in most cases a ZCTA will coincide with a zip code, there are exceptions. Some of these exceptions are the enclosed zip codes mentioned above. Once we had the aggregation between enclosed and enclosing zip codes, it was possible to match USPS zip codes with ZCTAs. When the dataset was indexed by ZCTAs[59], we then aggregated the data to the place level, adding it up by ZCTAs.

As we merged and aggregated all data, we needed to confirm the names of places, counties, states, and add variables such as Rural Urban Influence Code. In many cases, these changes required writing extensive code for verifying and changing names. It should be noted that the process of matching entries for building the database is different from the process used in Matched Sample Estimators.

Section 5.3, 5.4 and 5.5 present the results from matched sample regression and discuss the shortcomings of the analyses, and present further directions for research.

## *5.3 Economic Effect of IP-Enabled SCADA and AMR on MEU Internal Efficiency*

We test the Internal Efficiency hypothesis by studying the effect of the new internal IP-enabled services on various measures of internal efficiency: (i) price; (ii) customer service, support, and information cost; and (iii) administrative costs and general expenses. All price and cost variables are measured by unit of output in megawatt hours (MWh). The latest available data is for year 2003[60].

For the purpose of this research, an MEU is considered to have internal IT-based, or IP-enabled, services if it had deployed technology for running either System Control and Data Acquisition (SCADA) or Automatic Meter Reading (AMR) by 2000. Some MEUs have also deployed two additional internal services: internal voice services and municipal data networks. However, only three out of the 421 cases offered internal voice and municipal data networks without running SCADA and AMR, and none by 2000. **Table 5.3** presents description and summary statistics for the dependent variables and variables used for matching among MEUs.

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[59] For more information see http://www.census.gov/geo/ZCTA/zcta.html

[60] See http://www.eia.doe.gov/cneaf/electricity/page/eia412.html. The EIA has temporarily suspended the collection of this information.

**Table 5.3**: Summary Statistics: variables for testing Internal Efficiency Hypothesis

| **Variables** | | | **MEUs** | |
|---|---|---|---|---|
| | | **Sub Sample** | **IT-based Internal Service** | **No IT-based Internal Service** |
| ***Description*** | ***Name*** | N=421 | N=82 | N=339 |
| Price ($) per MWh, 2003 | PMwh03 | 66.58<br>(16.91) | 67.14<br>(15.60) | 66.45<br>(17.23) |
| Customer Service, Sales and Information Expenses ($) per MWh 2003 | CSSIe03 | 0.33<br>(0.73) | 0.35<br>(0.55) | 0.33<br>(0.77) |
| Administrative and General Expenses ($) per MWh 2003 | S_Adm03 | 9.65<br>(102.77) | 30.91<br>(232.55) | 4.51<br>(5.43) |
| **Treatment**: =1 if IT-Based internal service, 2000 | MEU_Int2K | 19.43<br>(36.61) | 1<br>(0) | 0<br>(0) |
| **Variables for Matching** | | | | |
| Customer Service, Sales and Information Expenses ($) per MWh 2000 | CSSIe2K | 0.18<br>(3.57) | 0.33<br>(0.50) | 0.14<br>(3.97) |
| Price ($) per MWh, 2000 | RMwh2K | 64.35<br>(16.69) | 65.76<br>(16.46) | 64.01<br>(16.75) |
| Administrative and General Expenses ($) per MWh 2000 | S_Adm2K | 4.03<br>(4.49) | 4.62<br>(3.98) | 3.89<br>(4.61) |
| Population 2000 | Pop2K | 59,833<br>(21,625) | 58,793<br>(90,533) | 60,077<br>(23,637) |
| % Purchase power 2000 | Purpower2K | 87.11<br>(24.67) | 78.22<br>(31.48) | 89.28<br>(22.23) |
| % Steam power 2000 | Steam2K | 9.07<br>(21.52) | 17.58<br>(29.60) | 7.00<br>(18.51) |
| % Hydro power 2000 | Hydro2K | 0.50<br>(5.11) | 0.49<br>(2.01) | 0.51<br>(5.61) |
| Income per Capita 2000 | IncPC2K | 18,929<br>(4,887) | 19,576<br>(5,361) | 18,777<br>(4,765) |
| Medium Rent 2000 | Rent2K | 509<br>(138) | 541<br>(131) | 501<br>(139) |

Note: Standard errors in parenthesis

For testing the internal efficiency hypothesis, we matched the MEUs in three dimensions for the year 2000:

(i) *size of the local market*: The proxy for "size" is the local population.

(ii) *availability of resources for funding the upgrade of infrastructure*: Income per capita and median housing rent are used as proxies to measure community wealth, the source of tax-based funds available to a municipal government. This is relevant because municipal electric utilities' investment decisions are often approved by the municipal council.

(iii) *basic characteristics of the utility*. Utilities are considered similar based on the percentage of their power that is purchased or generated through steam or hydroelectric power. The underlying assumption is that similarities in the technology will be associated with similarities in their human capital.

Results from our matched sample estimators analysis show evidence that investing in new generation SCADA and AMR by 2000 is associated with increasing efficiency in MEUs' internal operations by 2003 (See **Table 5.4**, column A). The analysis tests this relationship by considering various dimensions: (i) effect on cost of producing electric power, and (ii) effect on price of electric power by 2003.

**Table 5.4**: Internal Efficiency: Summary Results

| Dependent Variable (2003) | Treatment: Adoption of IT-Based Internal Services by 2000 (A) Estimated Magnitude | Treatment: Adoption of IT-Based Internal Services, given that broadband provider by 2000 (B) Estimated Magnitude | Treatment: External Broadband by 2000, given that Adopted IT-Based Internal Services (C) Estimated Magnitude |
|---|---|---|---|
| Price ($) per MWh | -1.5420* | -3.6748** | 0.9424 |
| Customer Service, Sales and Info Expenses ($) per MWh | -0.3573*** | -1.4411*** | -0.0080 |
| Administrative costs and general expenses ($) per MWh | 19.9357** | 0.9967* | -28.064 |
| No. of Observations | 421 | 44 | 76 |

Source: the author. *: Statistically significant at 10% confidence level, **: Statistically significant at 5% confidence level, ***: Statistically significant at 1% confidence level.

Gains in efficiency--lower price and lower costs for information, and customer service and support--are accompanied by higher administration costs and general expenditures (ACGE). The analysis of matched sample estimation results suggests that investment in these solutions is associated with costs for customer service, support, and information management (CSSI) that are 30% lower than those of non-adopter MEUs (As calculated using the average CSSI cost for MEUs that adopted, and did not adopt, IT-based internal services by 2000, as shown in Appendix 5.1). Furthermore, our analysis of the effect of such technologies on the price of electric power suggests that MEUs that have adopted IP-enabled systems exhibit lower prices than non-adopters.

Sections 5.3.1 and 5.3.2 show more detailed analysis.[61] Evidence from field research suggests that this increase in cost resulted from the hiring of more experienced and expensive senior management and technical managers with experience in telecommunications.

### 5.3.1 Cost Efficiency per Unit of Output (MWh)

Municipal electric utilities were matched according to the size of local markets (population in 2000), income per capita, average rent values, the percentage of purchased power, and percentage of generation from steam and hydroelectric power in 2000.

The association of IT-based internal systems with lower costs for information, customer service and support makes perfect sense from the perspective of the objectives of SCADA and AMR solutions: they are designed to diminish the costs of acquiring information, remote monitoring of substations and customer premises, and electric power consumption. Also, they require lower maintenance costs, extend the lifetime of the electric power infrastructure, and lower costs due to failures. The small size of the average MEU town in some cases make it possible to deploy Passive Optical Networks (PON), creating more robust and less expensive networks.

The average reduction of almost $0.36 per MWh (5.1 [A] [62]) represents annual average savings of more than $77,000 for these MEUs. This value represents a 1.44% reduction from costs not directly related to the purchase of fuel, power, and major capital expenses.

However, our results show that the adoption of new generation SCADA and AMR by MEUs before 2000 is associated with administrative costs and general expenses (ACGE) in 2003 that, on average, are $19.9 per MWh higher than for MEUs that have not adopted such solutions (5.2[A]). Between 2000 and 2003, the average ACGE per employee increased by around 21% for MEUs without internal IT-based systems, but by approximately 33% for MEUs with internal IT-based services. Detailed results are presented in **Appendix 5.2**.

There are two reasons for this finding: more expensive senior management and costs associated with the learning process. Additional analysis shows that (i) this increase in

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[61] Increases in overall efficiency are consistent with the literature on the effect of IP-enabled SCADA and AMR electric power (Tamarkin 1992, Johnston 2003, IBM Business Consulting Services 2004, Black 2005) and on the effect of information technology on productivity (Brynjolfsson, Hitt, et al. 2002, Stiroh 2002).

[62] These references point to the respective table in the Appendices in the following way: 5.1(A) means Table A at Appendix 5.1.

cost is associated with the deployment of IP-enabled communications infrastructure, not from the deployment of broadband services, and (ii) this increase in cost represents an opportunity for additional economies of scope.

Evidence from fieldwork research and the COIReM analysis has shown that the first-adopter MEUs have been able to retain their linemen and technical staff and train them in very complicated tasks, but have had to hire new, and in some cases a different type of, executives and department heads. These have been executives and technical professionals who bring experience in telecommunications, networks deployments, or fiber optics networks and new leadership as well. These employees command higher salaries than their predecessors, who typically have less experience and working knowledge on digital technologies.

These MEUs may also have invested in some capital expenditures as well as higher administrative costs. This alone, however, would not be enough to explain a cost increase of such magnitude.

### 5.3.2 Price per Unit of Output (MWh)

Our MSE analysis shows that MEUs that have deployed IT-based systems for control, monitoring, and automatic meter reading exhibit lower prices for electric power than MEUs that have not made the investments. According to our results, the deployment of IT-based systems by MEUs is associated with $1.54 lower price per MWh by 2003 (5.3[A]). Detailed results are shown in **Appendix 5.3**.

According to the EIA, the average retail price of electricity for 2003 was $74.2 per MWh (EIA 2006). In comparison, our results suggest that the adoption of IP-enabled SCADA and AMR is associated with prices that are around 2% below the national average for 2003. Our results do not support the concerns that investments in IP-enabled SCADA and AMR would have to be financed by higher electricity prices.

These new IP-enabled solutions allow utilities better monitoring and control of their infrastructure and demand load curves. Benefits include greater efficiency, theft detection, and real-time pricing (Johnston 2003; IBM Business Consulting Services 2004; Black 2005).

Observations from fieldwork suggests that, after deploying IT-based systems, MEUs were able to lower their costs and offer customers better prices. In some cases, MEU officials found that average prices per customer prior to installing the new system were higher than the average after using real-time pricing of electric power.

Why would MEUs lower their prices of electric power? The main answer might be found in differences between the service orientation of MEUs and investor-owned utilities (IOUs). Rent appropriation created through technological innovations might be a source of revenue for IOUs. The story is different for municipally-owned utilities. In all cases studies, utility managers stated that any savings from using the new technologies should be shared with their customers in the form of reduced prices for electricity.

IOUs and MEUs have very different strategic goals. IOUs are responsible to their shareholders, but MEUs are also focused on local economic development and social benefits (externalities). They are, for this reason, closer to their local markets' "changing social demands" as defined by Arcelus and Schaefer (1982). Changing social demands beyond the direct demand for a good (e.g. electric power) are strategic issues (Arcelus and Schaefer 1982) for MEUs, but not for IOUs. MEUs have been conceived, built, and operated in order to promote local economic development (Osorio 2004) by providing electric power at the lowest possible price.

### *5.4 Cross-Subsidies from Electric Power to Communications*

Regulators and private telecommunication operators have been worried that MEUs could subsidize their entry into telecommunications by increasing their electricity prices or costs and then using this income to support their broadband services. The argument is that electric power customers would suffer from higher prices. If so, they should exhibit higher prices and/or costs per electric power than similar MEUs that do not offer broadband services. There are also questions about the existence of economies of scope between IP-enabled SCADA and AMR. So, Do MEUs subsidize their broadband services with funds from their electric power operations? We take two approaches to answering this question:

1. First, we restrict the sample to only those MEUs that became broadband providers and analyzed whether there were any differences associated with the fact that some deployed new generation network technology for internal purposes, and some did not. According to data from APPA, about 10% of the MEUs that deployed broadband services by 2000 had not deployed IP-enabled internal services.

   In **Table 5.4**, column B, we compare the gains in internal efficiency among MEUs that became broadband providers based on the deployment of new generation internal services with the gains in efficiency of MEUs that became broadband providers, but did not deploy IP-enabled SCADA and AMR. Our analysis shows that MEUs that diversified as a result of functional emergence from their internal networks exhibit considerable gains in efficiency including reduction of electric power prices of $3.67 per MWh; cost reductions of $1.44 per MWh for customer service, support and information; and a cost increase of almost $1 for ACGE.

Our results suggest that MEUs that offer external broadband but do not use their network to deploy IP-enabled SCADA and AMR are less efficient than those MEUs that do both. These results are extensions of the Internal Efficiency Hypothesis: among broadband provider MEUs, those that deploy IP-enabled services exhibit higher internal efficiency in everything but ACGE. This could signal the existence of economies of scope in ACGE: **Table 5.4**, Column A shows that these costs increase significantly when MEUs adopt IP-enabled SCADA and AMR. **Table 5.4**, Column B shows the magnitude and significance of the coefficient decrease when we study the same effect only among MEUs that have become broadband providers (i.e. the basic infrastructure is needed for both purposes). **Table 5.4**, Column C shows that the statistical significance of this effect disappears when we study the effect of becoming a broadband provider among MEUs that have adopted IP-enabled services.

2. Second, we examine whether deploying external broadband makes any difference in price and cost among similar MEUs that have deployed their internal IP-based solutions for system control and monitoring. The purpose of this analysis is to identify any differences associated with possible cross-subsidies that resulted from the increased efficiency that comes from adopting new IP-enabled SCADA or AMR. We used matched sample estimators to determine whether there was any statistically significant difference in the price or cost of the electric power business between MEUs that deployed external broadband services and those that did not. We considered only MEUs that have adopted IP-enabled SCADA and AMR. As indicated in **Table 5.4**, column C, the analysis shows no statistically significant difference in either price or cost for electricity between MEUs that have, and have not, deployed external broadband services.

In other words, MEUs that became external broadband providers based on their internal communication networks do not exhibit higher energy prices or costs than those that did not deploy external broadband. We also find evidence to suggest that increases in administration and general expenses reflect economies of scope between IP-enabled SCADA and AMR and broadband services (e.g. the need for only one general manager, one financial manager, one common bill to consumers, etc.)[63]

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[63] Our analysis about economies of scope and cross-subsidies brings interesting results, but they need further examination when more data becomes available in the following years. The results could be affected by sample size, and thus would need further confirmation when better and more data becomes available.

### *5.5 Effect of MEU-based Broadband on Local Economic Development*

In this study, an MEU is considered to offer external broadband if it provides at least one of the following services: high-speed Internet through cable modem or digital subscriber line (DSL); fiber leasing; broadband transport; wireless services; or the function of an Internet Service Provider. To test the Local Economic Development hypothesis, we study the effect of municipal broadband on the growth rate of local business establishments; establishments in IT-intensive sectors; employment; and salary-aggregating data from zip code to place levels. The historical baselines for the dependent variables include the growth rate of business establishments, employment, and salary between 1994 and 1998; the share of business establishments in IT-intensive sectors in 1998; and the growth of labor in the 1990-2000 period. The objective is to test the hypothesis on various fronts and to compare the results to previous research on the local economic impact of broadband at the zip code level in the United States (Lehr, Gillett et al. 2006).

The endogeneity problem between the deployment of technology and its effects requires the consideration of various factors affecting the cost and decision of deployment and the likelihood of adoption and use by people and organizations These factors include cost of deployment, the size of towns and their proximity to large metropolitan areas, and the desire and capacity of the populace to use broadband services.

Cost of deployment, for instance, is strongly affected by household and business density, which affects the fixed cost per subscriber. However, a local network will still need connectivity to the Internet. For this reason, an additional important factor in broadband availability is the cost of connecting a local network to the backbone (backhaul costs). The closer a town is to a large metropolitan area, the lower the backhaul costs will be because it is highly likely there will be a Internet Backbone Provider or a large Internet service provider in the area.

The size of towns and proximity to large metropolitan areas is also an important source of economic opportunities in a locality. These arguments have been widely studied by scholars of growth-pole and central place theories, (Parr 1973; North 1975; Polenske 1988). The Urban-Rural Influence Code (UrbInf03) is a variable that has been designed under these assumptions by the Economic Research Service of the U.S. Dept. of Agriculture[64]. The rest of the data follows the same rationale as Lehr, Gillett et al (2006). Finally, broadband becomes productive insofar as it is adopted by people and organizations. People must have certain skills and knowledge to take advantage of this

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[64] See http://www.ers.usda.gov/briefing/Rurality/UrbanInf/

technology (Bresnahan, Brynjolfsson et al. 2002; Autor, Levy et al. 2003). For this reason, we have included the growth rate of college graduates between 1990 and 2000, and the percentage of the local population that held a bachelor degree by 2000 as matching variables.

We analyze the local economic development hypothesis by studying the effect of MEUs' offer of external broadband services on four dependent variables, as shown in **Table 5.5**.

**Table 5.5**: Summary Statistics: variables for testing Economic Development Hypothesis

| | | **MEUs in SubSample** | **MEUs 2000** | | **MEUs 2004** | |
|---|---|---|---|---|---|---|
| **Dependent Variables** | | | **BB** | **No BB** | **BB** | **No BB** |
| ***Description*** | ***Name*** | N=1314 | N=47 | N=1267 | N=145 | N=1169 |
| Growth Rate in number B. Establishments 2000-2002 | LnrEst | 0.008<br>(0.092) | 0.010<br>(0.054) | 0.008<br>(0.093) | 0.014<br>(0.067) | 0.007<br>(0.094) |
| Growth Rate of Employment 2000-2002 | LnrEmplo | -0.033<br>(0.248) | -0.065<br>(0.174) | -0.032<br>(0.250) | -0.025<br>(0.221) | -0.034<br>(0.251) |
| Growth Rate of Salary 2000-2002 | LnSalary | 0.076<br>(0.146) | 0.057<br>(0.063) | 0.077<br>(0.148) | 0.066<br>(0.077) | 0.078<br>(0.152) |
| % Establishments in IT-Intensive sectors 2002 | ptotIT02 | 0.223<br>(0.063) | 0.255<br>(0.058) | 0.222<br>(0.062) | 0.242<br>(0.047) | 0.220<br>(0.064) |
| **Treatment**: Municipal Broadband in 2000 | MEU_BB2K | 0.036<br>(0.186) | .. | .. | .. | .. |
| | | | **Variables for Matching** | | | |
| =1 if Private Broadband Providers 2000, 0= otherwise | Private | 0.874<br>(0.331) | 0.936<br>(0.247) | 0.872<br>(0.334) | 0.937<br>(0.242) | 0.866<br>(0.340) |
| Growth Business Establishments 1994-1998 | grEst9498 | 0.067<br>(0.152) | 0.062<br>(0.141) | 0.068<br>(0.152) | 0.058<br>(0.105) | 0.068<br>(0.156) |
| Growth Employment 1994-1998 | grEmp9498 | 0.142<br>(1.041) | 0.078<br>(0.271) | 0.145<br>(1.059) | 0.076<br>(0.206) | 0.151<br>(1.102) |
| Growth College Grads 90s | grColl90s | 0.371<br>(0.719) | 0.313<br>(0.256) | 0.373<br>(0.730) | 0.393<br>(0.374) | 0.369<br>(0.751) |
| Growth Average Salary 1994-1998 | grSalary9498 | 0.174<br>(0.199) | 0.158<br>(0.161) | 0.174<br>(0.200) | 0.158<br>(0.118) | 0.176<br>(0.207) |
| % Pop. Bachelor Graduate in 2000 | BachGrad2K | 16.557<br>(8.969) | 25.206<br>(12.618) | 16.236<br>(8.646) | 20.817<br>(9.985) | 16.028<br>(8.695) |
| % Establishments in IT-Intensive sectors 1998 | ptotIT98 | 0.223<br>(0.058) | 0.255<br>(0.057) | 0.222<br>(0.058) | 0.243<br>(0.044) | 0.221<br>(0.059) |
| Growth of IT-Intensive establishments 1998-2000 | grIT9800 | 0.012<br>(0.171) | 0.051<br>(0.297) | 0.010<br>(0.165) | 0.025<br>(0.181) | 0.010<br>(0.170) |
| Growth Local Employment 1990-2000 | grLabor90s | 0.095<br>(0.227) | 0.102<br>(0.154) | 0.095<br>(0.229) | 0.109<br>(0.165) | 0.094<br>(0.233) |
| Population 2000 | Pop2K | 15,186<br>(113,585) | 54,001<br>(101,663) | 13,746<br>(113,785) | 51,040<br>(307,149) | 10,739<br>(51,893) |
| Urban-Rural Influence Code | URinfl03 | 5.336<br>(3.357) | 3.574<br>(2.756) | 5.402<br>(3.361) | 4.248<br>(3.088) | 5.471<br>(3.366) |

Note: standard errors in parenthesis

These results show that towns where MEUs deployed external broadband services exhibited higher growth rates in local business establishments (See **Table 5.6**, column A).

**Table 5.6**: Local Economic Development: Summary Results

| Dependent Variable (2000-2002) | Treatment: Deployment of External Broadband Services by 2000<br>(A) Full Sample<br>Estimated Magnitude from effect of MEU-based broadband | (B) Subset – Places with Private Providers of Broadband by 2000<br>Estimated Magnitude from effect of MEU-based broadband |
|---|---|---|
| Growth Rate in number of Business Establishments† | 0.01534*** | 0.01269** |
| Share of Business Establishments in IT-Intensive Sectors (2002) | -0.0030 | -0.0028 |
| Growth Rate of Employment† | 0.0185 | 0.02370 |
| Growth Rate of Salaries† | 0.00168 | 0.00263 |
| No. of Observations | 1,314 | 1,149 |

Source: *: Statistically significant at 10% confidence level, **: Statistically significant at 5% confidence level, ***: Statistically significant at 1% confidence level. †: The coefficient represents the estimated magnitude for the additional growth produced by the deployment of MEU-based broadband.

We do not find a statistically significant relationship between the deployment of broadband by MEUs and the share of IT-intensive business establishments in 2002, the growth rate of employment, or average salaries in the 2000-2002 period. These results are consistent with findings from qualitative research (see previous chapter) and not surprising. Still, however, they are still not fully conclusive for reasons that are explained in Sections 5.5.2, 5.5.3, and 5.5.4, respectively.

An additional question is whether these results are affected by the presence of private broadband providers. Some might argue that the introduction of a public broadband provider into a market already served by private providers will not necessarily add economic benefits (Bast 2002; Bast 2005). Others assume that private broadband providers tend to underserve a market because they are not able to appropriate all the benefits from investing in infrastructure (BEA 1999, Ford and Koutsky 2005, Vaishnav forthcoming). Our results support the latter, by finding an additional positive effect associated with the presence of MEU-based broadband, while applying MSE only among towns with private broadband providers. (See Column B in **Table 5.6.**)

We have analyzed the effect of MEU-based broadband in two scenarios: (i) regardless of the presence or absence of private providers, and (ii) in places where there is also a private provider. The small number of places (10) in which MEUs had deployed broadband by 2000 without private competition provides upward biased results, and are not further considered in our analysis. For instance, these results state that MEU-based broadband contributes an additional 21.1% to the growth of local business establishments. It is very likely that these results overestimate the effect of broadband availability on the growth rate of businesses, based on a bias produced from sample size.

### 5.5.1 Growth Rate of Local Business Establishments

**Table 5.6**, Column A shows that the deployment of broadband by MEUs by 2000 added an additional 1.53% to the growth rate of local business establishments between 2000 and 2002 in their towns. To determine this we applied Matched Sample Estimator analysis to the growth rate of local business establishments, as calculated by using the functional form explained in Section 5.1.3. In this case the “treatment” is the deployment of external broadband services by an MEU. We matched towns on the basis of the local population in 2000, growth of business establishments in the period 1994-1998, and the Urban Influence Code. (See **Appendix 5.4** for detailed results.)

These results are consistent with previous work (Lehr, Gillett et al. 2006) which found that the effect of broadband deployment in the United States on the growth rate of local business establishments between 1998 and 2000 was 1.23%[65]. Our results are also consistent with findings from field and qualitative research. Together, these results suggest that the main impact on the local economy from the deployment of broadband by MEUs is the adoption of Internet and information technology by local people and businesses. Broadband opportunities have led to telecommuting, the adoption of new practices by local businesses, and the creation of new traditional ventures that, while not profitable based only on local sales, have been successful based on sales generated through the Internet. These results are particularly interesting, considering that there was a recession in the period 2000-2002.

We also wanted to understand the extent to which the deployment of external broadband services by an MEU is good for the local economy in the presence of private

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[65] This work, however, did not make the distinction between the nature of the broadband provider.

broadband providers. More specifically, we wanted to understand the extent to which having a public broadband provider lent additional benefits to a community.

This is based on the assumption that a private provider would be motivated to invest only in the part of an entire broadband infrastructure that could produce profits for it. The argument is that the social optimum deployment of broadband is larger than the private optimum deployment, due to the presence of externalities.

Our results show that the effects are positive and significant for the period 2000-2002. The growth of local businesses in towns where the MEU deployed high-speed Internet services by 2000 in the presence of at least one private broadband provider was 1.26% greater than for similar towns without MEU broadband (5.4[B]).

### 5.5.2 Business Establishments in IT-Intensive Sectors

The deployment of municipal broadband networks in rural and suburban areas has been supported by the assumption that it will attract knowledge-based firms. However, our results indicate that no statistically significant relationship can be established between the deployment of broadband services by MEUs by 2000 and variation in the share of local business establishments in IT-intensive sectors by 2002. (See **Appendix 5.5** for detailed results.) This result, however, is not surprising for many reasons.

MEU venues tend to be slightly more rural and less dense than the average broadband venue. **Table 5.5** shows that places where MEUs have deployed broadband are located in counties that, according to the U.S. Department of Agriculture's Economic Research Service, are defined as either "Micropolitan adjacent to large metro" areas (URinfl03=3); "Noncore adjacent to large metro" areas (URinfl03=4); or "Micropolitan adjacent to small metro" areas (URinfl03=5)[66]. We can define these counties as "sub-urban". Of the 3.141 counties in the United States only 16.43% of them fall into this category; only 7.88% of the nation's population lives in them.

Most zip codes with broadband by the year 2000 in the United States were located in counties in either a "Large Metro Area of 1+ million residents" (URinfl03=1); a "Small Metro Area of less than 1 million residents" (URinfl03=2,) or "Micropolitan adjacent to large metro" areas (URinfl03=3). These cases represent 37.60% of the nation's counties and 84.47% of the United States population.

This is relevant for two reasons. First, analysis of data from the USDA's Economic Research Service indicates a significantly negative correlation between the percentage of

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[66] See http://www.ers.usda.gov/Briefing/Rurality/UrbanInf/ for more detailed information about the Urban Influence Code.

business establishments in IT-intensive sectors and the rural character of a community (See **Table 5.7**). Second, the magnitude of this correlation changed in important ways between 1998 and 2000, and between 2000 and 2002. We cannot say anything about the direction of causality.

**Table 5.7**: Rural/Urban Influence Code and IT-Intensive Business Establishments: Pairwise Correlation, and Varying Percentage

|  | **% Business Establishments in IT-Intensive Sectors** |  |  |
|---|---|---|---|
| **Pairwise Correlation** | 1998 | 2000 | 2002 |
| Urban Rural Influence Code 2003 (URinfl03) | -.1677*** | -.2879*** | -.1879*** |

|  |  |  | **Variation of correlation per year, and level of Urban Rural Influence Code** |  |  |
|---|---|---|---|---|---|
| URinfl03 | % US Counties | % US Population | 1998 | 2000 | 2002 |
| 1 | 13.15% | 53.03% | .2497 | .2543 | .2589 |
| 2 | 21.52% | 29.62% | .2149 | .2190 | .2223 |
| 3 | 2.93% | 1.83% | .1933 | .1934 | .1965 |
| 4 | 3.92% | 0.84% | .2051 | .2038 | .2042 |
| 5 | 9.58% | 5.21% | .1956 | .1982 | .2011 |
| 6 | 11.40% | 2.79% | .1968 | .1977 | .2011 |
| 7 | 5.89% | 0.67% | .1986 | .1996 | .2020 |
| 8 | 8.98% | 3.25% | .1979 | .1994 | .2020 |
| 9 | 6.40% | 1.15% | .2064 | .2068 | .2089 |
| 10 | 6.30% | 0.47% | .2132 | .2160 | .2120 |
| 11 | 4.39% | 0.80% | .2006 | .1985 | .2057 |
| 12 | 5.54% | 0.36% | .2055 | .2075 | .2080 |

Source: the author, based on data from USDA's Economic Research Service. ***: Statistically significant at 1%, **: statistically significant at 5%, *: statistically significant at 10% confidence level

Evidence from field research about the diffusion process of broadband among business establishments supports this result. The deployment of broadband stimulated an increase in the number of home-based business and small firms in the retail sector. Instead of attracting new IT-based or high technology firms, broadband enabled local businesses to reach "external" markets, those outside town boundaries, via the Internet. Ford and Koutsky (2005) also found that municipal broadband stimulates sales in the retail sector. With a few exceptions, MEU broadband did not attract large numbers of new technology-based businesses to towns. This is supported by previous research that states that firms do not make location decisions based on broadband availability (Forman, Goldfarb et al. 2003; Forman, Goldfarb et al. 2005).

In a recent study focused on the effect of broadband in economic development at the zip code level for the United States, Lehr, Gillett et al. (2006) used MSE to find that broadband availability was associated with a small but statistically significant (0.28%) increase in IT-intensive business establishments. This may be attributable to the fact that most business growth in this sector occurred in or near metropolitan areas where the Rural-Urban Influence Code (URinfl03) equals one, two, or three (See **Table 5.7**).

### 5.5.3 Employment

Our analysis suggests that the deployment of MEU-broadband by the year 2000 cannot be associated with growth in employment between 2000 and 2002. (See detailed results in **Appendix 5.6**, **Table A.**) These results are not surprising, and neither support nor contradict theory.

These years were a period of recession in which unemployment in the United States grew from 4% to 5.8%[67]. Additionally, as previously discussed, IT-based applications can either complement or substitute for labor (Bresnahan, Brynjolfsson et al. 2002; Autor, Levy et al. 2003). The presence of both effects could easily offset one another. Based on this evidence, the effect of broadband on employment could vary not only across, but also within, industrial sectors. As a result, one sees "ambiguous changes in the direction of total employment growth" (Lehr, Gillett et al. 2006).

In our sample, towns where MEUs deployed broadband show lower employment growth in 1994-1998 than places without municipal broadband, but a higher rate in the period 2000-2002. This is interesting, albeit statistically insignificant at a 10% confidence level.

### 5.5.4 Salary

Our results show also no statistically significant effect on the growth rate of salaries in 2000-2002 from the deployment of broadband services by MEUs by 2000. (See **Appendix 5.7**, **table 5.7[A]**, for detailed statistics.) These results are similar to those found for the entire United States and the Appalachian region in previous research (Lehr, Gillett et al. 2006). There are at least two reasons for these findings.

First, one might expect to see productivity gains that might spill over to workers in the form of higher wages. During a recession, however, benefits might come in different forms. Fieldwork research suggests that increases in productivity due to broadband deployment by MEUs by business customers may come in the form of improvements to the quality of life--reducing commuting times or creating possibilities to work from home.

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[67] See http://www.bls.gov/cps/cpsaat1.pdf

A second reason could be that the samples are not perfect matches. The inclusion of many variables for matching samples increases the difficulty of finding perfect matches with Nnmatch. The command's bias-corrected matching estimator option (*biasadj(.)*) tries to correct the possible bias, but its effectiveness is limited by the data. In this case, it cannot fully correct the bias of not having perfect matches. As seen in **Appendix 5.7,** Column A, all variables present differences between 5% and 62% among treatment and control groups.

### 5.5.5 Limitations of the Data and our Research

Quality and availability of data impose limitations on our analysis. The most important problems are:

i. *Broadband deployment versus adoption*: The analysis is based on data about the deployment of IP-enabled SCADA and AMR and external broadband services by MEUs. While deployment signals the availability of the infrastructure, adoption suggests its use, and the economic effect of broadband comes from use. We do not have data on broadband penetration by town. Data about broadband adoption could help us to better estimate the economic effect of MEU-based diversification into broadband services.

ii. *Timing of market entry*: We do not have data about the timing of market entry for MEUs and private providers. Therefore, our analysis cannot factor in any response to market entry by MEUs or private providers. This information could allow further analysis of our hypotheses by studying how the local economic impact of MEU broadband is associated with different entry scenarios (i.e. impact of having an MEU enter broadband in a market with private providers compared with the impact of having private providers enter a market already served by an MEU).

iii. *Financial data:* Financial data for MEUs do not perfectly separate costs associated with fuel, operations, and capital investments. The decreases in CSSI and price do not offset the increases in ACGE. We have shown that these costs are associated with deploying IP-based infrastructure and signal the existence of economies of scope between deploying IP-enabled SCADA and AMR and broadband. There is, however, a need for more and better data and further research to fully understand the increase in ACGE.

iv. *Cross-subsidies*: Our analysis has focused only on one type of cross subsidy: the support of broadband operations with funds from electric power services. We have financial data for all MEUs on their electric power businesses, but none about their telecommunications operations. Therefore, it is not possible to test whether broadband operations might be subsidizing electric power services. How would this happen? We have suggested in Chapter 4 that the adoption of IP-enabled SCADA and AMR after 2001 created the option for MEUs to diversify into broadband. Following this observation, other MEUs might have planned to deploy these internal services anticipating future revenue streams from their eventual broadband operations. This, however, cannot be tested until more and better data is available.

## *5.6 Summary and, Conclusions*

This chapter has demonstrated that adopting information technology solutions for monitoring and controlling of electric operations is associated with increased internal efficiency of an electric power business. Additionally, we found no evidence to support the claim that MEUs use resources from their electric power business to subsidize their broadband operations. Finally, our results show that deploying external broadband services is associated with positive effects on local economic development. These results have important implications for policy making.

The deployment of broadband by MEUs presents an interesting case of unexpected diversification and entry into advanced telecommunication services by public actors from a sector not originally designed for communications. Our research has answered pending questions about this phenomenon. We now discuss some opportunities that could be missed and challenges that need to be addressed.

### 5.6.1 Internal Efficiency Hypothesis: information technology does matter for electric power

Our analysis shows that the adoption of new generation communications networks for operating IP-enabled SCADA and advanced AMR has a positive effect on the efficiency of municipal electric utilities for the analysis of energy prices, which confirms recent work on the effect of IT on electric power operations (Black 2005). While AMR solutions allow MEUs to better price load demand, SCADA would translate the resultant lower costs into revenue or customer savings. MEUs found that average pricing before installing the broadband-based systems was higher than after deploying them. In such cases, the MEUs' decision reduced their prices and delivered benefits to customers.

Matched sample regression shows that deploying internal IT-based services is associated with lower costs for information, and for customer service and support, and lower price of electricity (MWh). The effect of internal IT-based services on consumer-related operation costs supports theory about the effect of information technology on transaction and coordination costs in general (Shin 1997; Shapiro and Varian 1998), in the electric power industry (Black 2005), and public organizations (Osorio and Fountain 2001) in particular.

However, administrative costs and general expenses rose—a quantitative finding illuminated by fieldwork research. Modern SCADA and AMR and broadband Internet services proved to be competence-enhancing for both linemen and technical staff, but competence-destroying for senior and some technical managers. An important part of the increased expenses for MEUs that deployed internal IT-based services were for hiring more expensive, experienced managers. This increase was identical for all the MEUs, whether or not they deployed external broadband. The only difference is that, eventually, a broadband provider MEUs could have been able to allocate some of these costs to their broadband division.

We also wanted to know whether deploying IP-enabled internal solutions made any difference among MEUs that have become broadband providers. Studying the existence of gains in efficiency associated with the deployment of internal solutions, while holding constant the deployment of external broadband, allow us to better understand which effects were the result of becoming a broadband provider, and which came from deploying internal services.

In other words, we tried to measure the existence of economies of scope and possible effect associated with functional emergence. We still needed to test whether MEUs were using funds from their electric power operations to subsidize the operation of their new broadband services, which is presented in the next section.

### 5.6.2 Cross-subsidies: MEU broadband does not appear to be subsidized by electric power price increases

We tried to find evidence of subsidies from the electric power to communication services among MEUs by applying matched sample estimators to measure the possible effect of becoming a broadband provider on the internal efficiency of the electric power business for those that had deployed IP-enabled systems for control and monitoring. Subsidies would be evident if the MEUs external broadband services were accompanied by increased prices or costs for power.

The policy implications of our results are very relevant. On one hand, regulators of the electric power industry have been asking electric utilities to invest in command-and-control technologies that would enhance the reliability of the grid. On the other hand, they worry that such diversification might be financed by increasing rates for electric power.

Our results show that investing in the creation of an intelligent local grid is associated with lower prices and operation costs as supported by the literature (Johnston 2003; IBM Business Consulting Services 2004; Black 2005). Furthermore, there are no grounds to support the hypothesis that later diversification into broadband services is subsidized by the electric power operations of these MEUs, as there are no statistically significant differences among MEUs that diversified and those that did not.

### 5.6.3 Local Economic Development Hypothesis: broadband deployed by MEUs matter to the economy

This study is the first attempt to measure the economic effects of municipal broadband in general, and of municipal electric utilities in particular, using municipal utility data for the entire continental United States[68]. Our positive results confirm previous findings about the economic impact of broadband in the United States, and on the Appalachian region (Lehr, Gillett et al. 2006).

Furthermore, this apparent effect of municipal broadband on the local economy holds in the presence of private broadband providers. MEU broadband creates social value that private broadband might not. Our analysis show that, even among towns with private providers of high-speed Internet services, those places where MEUs started offering broadband services by 2000 exhibit an additional contribution of 1.27% to the growth rate of local business establishments between 2000 and 2002. This additional effect is not seen in similar towns that only count with private broadband providers. We argue that this additional effect maximizes the social benefits derived from broadband.

As expected, our analysis found no statistically significant relationship between broadband deployed by MEUs and share of either business establishments in IT-intensive sectors, the growth rate of employment, or average salary between 2000 and 2002. This finding confirms our conclusion from field research. Instead, new "brick and mortar" businesses have either been founded or attracted from neighboring towns without broadband.

The lack of a statistically significant effect from broadband on employment can be explained by both theory and results from qualitative research. It is highly likely that the recession of 2000 influenced employment rates in the towns studied.

Theory states that information technology can either complement or substitute for labor (Bresnahan, Brynjolfsson et al. 2002; Autor, Levy et al. 2003). These mixed effects can be perceived across and within industries. Qualitative research does not show

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[68] Ford and Koutsky (2005) studied the effect of municipal broadband on retail sales Florida.

evidence of massive immigration of out-of-town workers. It does, however, show that broadband availability has been affecting the local economy and quality of life by means others than increasing salaries: (i) saving commuting times, (ii) allowing local businesses to reach other markets, (iii) creating more productive and less stressful jobs, and (iv) improving quality of life at work.

### 5.6.4 Opportunities

These positive impacts suggest that we might be in the presence of a sustainable model for facilities-based competition in telecommunications. As local governments face pressure to increase their efficiency, it makes sense to exploit an existing pool of available bandwidth and Internet connectivity. The decreasing cost of fiber optic and network elements makes it more likely that an important number of network industries in general, and electric utilities in particular, will adopt them. As the deployment of networks services running IP-enabled solutions increases, the players offering broadband are more likely to diversify their services. The economies of scope exhibited by the network infrastructure and availability of spare bandwidth could trigger entry from non-traditional actors.

This could further challenge incumbents, and hasten what has been called the death of the core of the telecommunications industry (Vaishnav forthcoming). From the perspective of the qualitative analysis in Chapter 4, this disruptive effect on telecommunications is consistent with the effects of architectural innovations proposed by Henderson and Clark (1990).

Thus, as technology changes and becomes less expensive, it creates a new type of convergence among network services that has the potential to be far more disruptive than the convergence of telephone and cable television. Further investments, which appear inevitable, will give more MEUs the ability to become telecommunications providers. Tomorrow, different types of organizations intensive in the use of bandwidth and information technology could follow.

### 5.6.5 Challenges

The potential of this convergence to increase the efficiency of electric utilities and enhance the economic development of suburban and rural America could be limited by public policies designed to regulate technology that is obsolete. There are two policy challenges: (i) state prohibitions to municipal involvement in telecommunications, and (ii) policy making based on unsubstantiated assumptions.

#### i. *State Prohibitions to Municipal Involvement in Telecommunications*

The ambiguity of the Telecommunications Act of 1996 (TA96) and the policies and position of the Federal Communications Commission about TA96's Section 253(a) led the Supreme Court to rule that the states must decide whether local governments can deploy telecommunication services. As of 2006, 14 states are prohibiting municipal entry in telecommunications.

These policies create several problems. While the United States has lost the leadership in broadband penetration and, despite FCC figures for broadband deployment, suburban and rural areas are still lagging. In this context, broadband availability becomes an increasingly important problem that has a feasible solution, but cannot be implemented.

Furthermore, policies have been very confusing. As previously mentioned, the Governor of Pennsylvania awarded Kutzown's Hometown Utilicom the 2003 Governor's Award for Local Economic Excellence in the category of Information Technology in recognition for their deployment of local broadband services[69]. However, soon after, Pennsylvania passed a law prohibiting any local government or other political subdivision of the state from providing advanced telecommunication services unless no private company either exists or states an "intention" to provide them within 14 months. Verizon, a private broadband provider, was a major proponent of the bill.

John de Figueiredo shows that telecommunication companies have been able to influence the regulatory process directly at the FCC or by litigation, and have been able to use the "ideological distance" between the FCC and the courts in their favor (Figueiredo 1998; Figueiredo and Tiller 2001). Pennsylvania's precipitous reversal of support for MEU broadband is an example of this phenomenon.

State restriction of the entry of MEUs into telecommunications has two deleterious effects. First, MEUs that deploy internal IP-enabled SCADA and AMR are forced to be inefficient in that they are unable to use their spare bandwidth capacity. Second, people living in rural and suburban areas are forcibly underserved, as private providers have little incentives to deploy infrastructure to serve all types of customers. The potential for MEU-based broadband to enhance local economic growth will be lost. State policies restricting MEU entry into broadband will not only limit the potential of MEUs to serve local markets but also dampen economic potential growth within the state.

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[69] Letter from Dennis Yablonsky, Secretary Desingee, Department of Community and Economic Development, Commonwealth of Pennsylvania, to Frank Caruso, Director of Information Technology, Hometown Utilicom, dated February 14, 2003.

### *ii. Policy Making Based on Unsubstantiated Assumptions*

Private telecommunications operators have argued that MEUs could subsidize their telecommunication operations by increasing their electric power rates, a process that would both restrain competition and harm electric power customers. This study found nothing to support this hypothesis. It has also been assumed that MEUs take unnecessary risks by deploying technology that is too complex for them to understand and handle. Qualitative research uncovered no information in support of this assumption.

Good regulatory policy needs to protect competition rather than specific competitors. In this context, telecommunication policy makers need to consider how technical change affects the regulatory and competitive landscape if they are to foster innovation and competition for economic growth. Telecommunication policy needs to reflect the new technical reality and the potential of broadband deployment by electric utilities in general, and municipal electric utilities in particular.

The next chapter presents a unified discussion of these results with findings from qualitative research, and outlines directions for further research.

# Chapter 6: A New Theory of Functional Emergence for Socio-Technical Systems

Chapters 4 and 5 presented the reasons, processes, and effects of the architectural evolution of Municipal Electric Utilities (MEUs) as they diversified into broadband services. In this chapter we identify the underlying process of such an evolution, define it as "Functional Emergence" (FE), and propose and describe a theory explaining it. This chapter reviews our findings from Chapters 4 and 5 and put them in perspective of the literature on complexity in general, and the work done in biology, neurology, and artificial intelligence about functional emergence. We then extend the meaning of FE to socio-technical systems.

We suggest that the emergence of a new externally delivered function in socio-technical systems does not just happen. With adequate analysis, one could identify technologies that could trigger functional emergence; thus, an organization could plan its technology adoption considering taking advantage of the opportunities for diversification created by such adoption.

## *6.1 Previous Work on Functional Emergence*

While relatively new, the term Functional Emergence has been used in other disciplines, mostly to represent what complexity theory defines as emergent "behavior" in, for example, sociobiology (Barash 1982).

In neurosciences, recent research has studied the neural processes underlying the emergence of human cognition. In this case, Luciana and Nelson (1998) studied what they call “developmental emergence” of functions. They applied a test[70] to identify and separate the behavioral functions associated with different parts of the brain (the frontal and temporal lobe). In the context of their research, functional emergence refers to the development of new human cognitive functions as humans develop and reach adulthood.

Their definition of functional emergence refers to the physical development of neural networks and their related “perceptual and sensorimotor functions [that culminates] with the physiological maturation of widespread neural networks that integrate complex processing demands inherent to working memory tasks” (Luciana and Nelson 1998). In other words, in this context FE refers to the development of cognitive functions and identification of when they reach adult level.

From the perspective of artificial intelligence, Cariani (1992, 1992b) defines functional emergence as “the deviation of the behavior of a physical system from an observer’s model of it”. His major question is whether “computational devices are capable of fundamentally-creative, truly emergent behavior” (Cariani 1992). In other words, Cariani is concerned with the capacity of systems to over-perform the specifications of its designer, based on the study of evolution of biological systems.

Brown (1998) defines functional emergence in the context of an emergent *event* during a design process as “an identifiable function in a design which has not been explicitly anticipated or explicitly represented in the current…design” (Brown 1998). In a simple example, he states that putting three squares together in order to create a triangle do not create emergence if one is not able to recognize the new figure as a triangle. Here, knowledge enters into play (See **Figure 6.1**).

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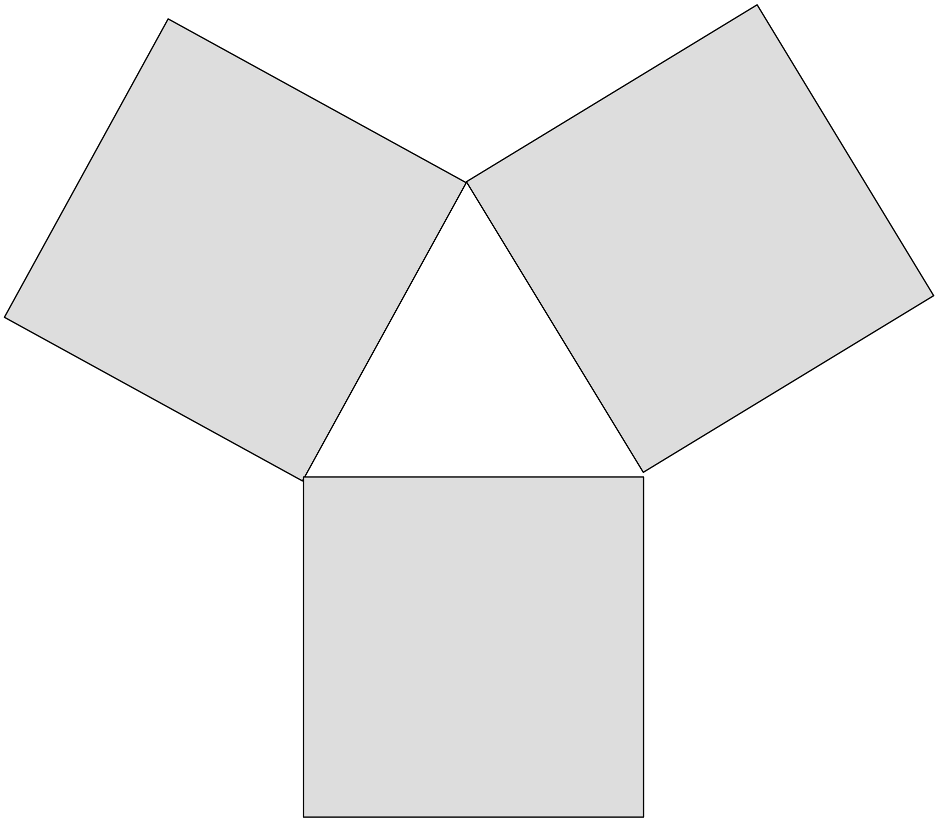
[70] The Cambridge Neuropsychological Test Automated Battery.

**Figure 6.1**: Emergence of a Triangle out of three Squares



Source: the author, based on Brown (1998)

Brown notes that if a designer notices that an object leaves a *mark* when used as intended, and that such mark is not necessarily a "bad thing", then the designer "might consider incorporating some of the structural or behavioral characteristics of pens" in order to take advantage of the property of *marking*. In this case, the designer has all the knowledge about the object and some related objects (pen).

But, what if there is no *single* designer, but instead, *many* designers along the object's lifetime so that some information about the object has been lost? What if the *object* is a *system* of such complexity that the ability to notice emergence is bounded by the rationality of the observer? Moreover, what if –when used as intended-- the object leaves marks that are internal or not *visible*[71] to the observer, so he or she cannot infer

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[71] By visible, we also want to represent two things: (i) the mark is hidden by the external structure of the system, and (ii), following Brown (1998), the observer has to *know* what the mark is in order to be able to identify it.

about its potential use as a pen? Our research provides an initial answer to these questions for socio-technical systems.

Luc Steels propose the concept of emergent functionality (Steels 1990) as different from hierarchical functionality. We say a system exhibits hierarchical functionality if its externally delivered function results from, and can be decomposed into, its internal sub functions, as depicted in **Figure 4.8** (Functional Decomposition for Electric Power Subsystem). From Steels perspective, in a system that exhibits emergent functionality "*each component has its own interactions with the environment*", which drives the activation of the functionality of each component. In his view, the functionality of the component is "*not recognizable as subfunction of the global functionality*". Our research extends this work and focuses on subfunctions that, while originally being designed and recognized as performed by hierarchical components of a system, emerge from within to become global, or externally delivered, functions on their own merit.

## 6.2 A New Theory of Functional Emergence for Socio-Technical Systems

In our work, functional emergence represents the process by which a *new externally delivered function* emerges from the internal functions of an engineering system. We define the new function as the *Emerged* Externally Delivered Function (E-EDF). The *designed* objective for these internal functions is to sustain the system's originally *Designed* Externally Delivered Function (D-EDF). In the case of our research, this D-EDF was the supply of electric power, and the E-EDF corresponded to the supply of external broadband services[72].

The COIReM analysis in chapter 4 demonstrated how and why MEUs became broadband providers, and described it as a four-stage process. In this section we dissect the process and identify general principles that would make it possible to identify possibilities for functional emergence across different socio-technical systems.

In the initial stages of the evolution, major technical changes affected internal components, between two and three hierarchical levels down in our CLIOS System: the SCADA/AMR system and its related IP-based communications network. The changes were not only upgrading the technology, but also connecting components in new ways. The concept and EDF of the electric power subsystem, however, did not change[73].

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[72] Dodder (2006) provides an interesting example of cities that have used their intelligent transportation systems for affecting air quality.

[73] This would be characterized as an architectural innovation under Henderson and Clark (1990)

The two years following the investment and deployment of this network, however, were marked by various social and organizational changes within the MEUs.

These changes affected the concept of the new internal communication infrastructure. We can make an analogy with Brown's (1998) example about the emergent triangle created by connecting three squares: MEUs learned about triangles, about how they looked, their properties, and what could be done with them. **Table 6.1** summarizes the stages of the emergence of the new function for broadband provision among municipal electric utilities.

**Table 6.1**: Evolution of Functional Emergence among MEUs

| Stages | Case of MEUs |
|---|---|
| **Changes in Critical Components** | • Innovation and technical changes in information technology affected the design of critical components for system command and control.<br>• Some of these changes were new connections among the various components of the system. |
| **Changes in Context** | • Regulatory changes in the electric power industry increased the need for intelligent solutions for those automated solutions, which lead to the decision of adopting these new technologies. |
| **Internal Emergence and Organizational Learning** | • The MEUs have an important endowment of absorptive capacity and dynamic capabilities that allowed them to learn from the new technology, identify its potential for new uses, adapt it, and put this new knowledge to work, increasing the potential to diversify into new services. |
| **External Emergence and Diversification** | • Learning and adaptation processes, and identification of demand led to organizational processes that progressed from using the new infrastructure solely for internal purposes to using those resources for diversification and becoming providers of external broadband. |

Source: the author

We will argue that an organization could increase its possibilities to identify the likelihood of functional emergence and, thus, prepare to take advantage of them. The next sections discuss the changes in critical components, contextual change, internal emergence and organizational learning, and external emergence and diversification.

### 6.2.1 Changes in Critical Components

Long-lived engineering systems need to expand in capacity, or replace components from time to time in order to exhibit sustained performance of their regular operations. The replacement of components can arise from: (i) replacement of used with new components in the same generation of technology), or (ii) replacement of used components with a new generation of technology.

New technology upgrades may be triggered by technical, social, organizational, regulatory, or contextual changes, or some combination of them. For instance, the upgrade can be triggered by the desire to enhance the performance of D-EDF due to innovations and technical changes in some internal components critical to delivering one or more of D-EDF's internal functions.

Another way to understand this is by analyzing the phenomenon of successive technologies. Let assume there is an internal function (IF) that has traditionally been performed by what we define as an *Old Technology* (OT). Thus, $\text{IF}_{\text{OT}}$ represents the internal function operating using the old technology. At some point, OT will reach decreasing marginal effect on performance to the engineering efforts to increase such performance. At some point in time, a *New Technology* (NT) is developed that can deliver superior performance to $\text{IF}_{\text{NT}}$.

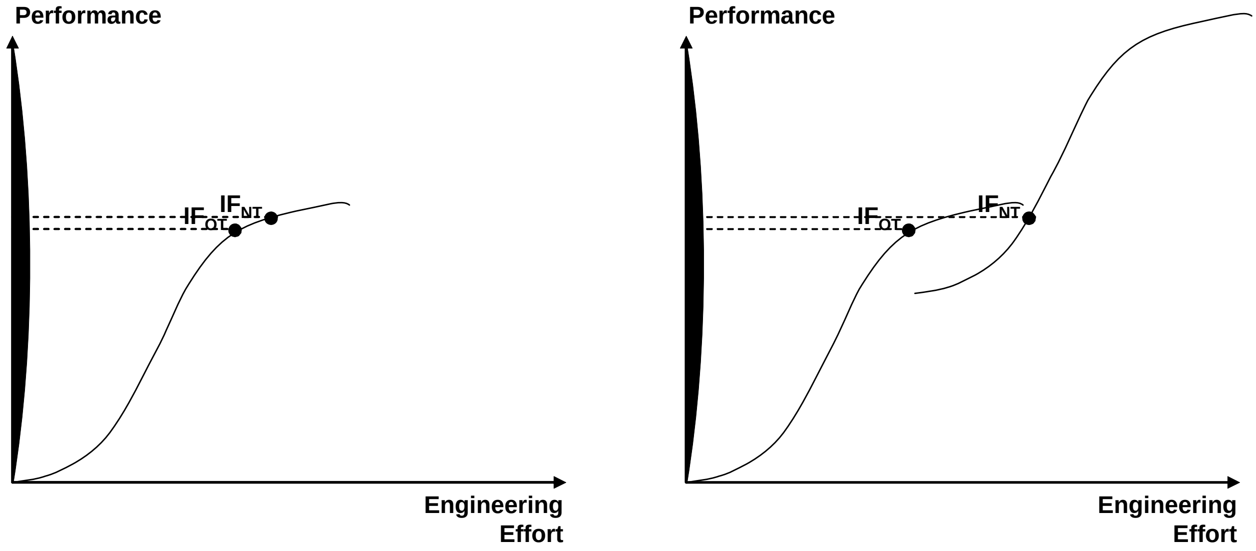
Innovator organizations will switch from the old to the new technology ($\text{IF}_{\text{OT}} \rightarrow \text{IF}_{\text{NT}}$), which could happen along the same, or in different S-curves. In both cases, the performance of $\text{IF}_{\text{NT}}$ is likely to be higher than $\text{IF}_{\text{OT}}$. The differences will be on (i) the magnitude of the gains in performance, and (ii) the obsolescence of the knowledge and capabilities organization. This is briefly explained as follows:

1. Upgrading technologies along a same S-curve, by the nature of incremental innovations, would be competence-enhancing adoption of new technology. By definition, the capabilities of the organization would be more aligned with the required skills of the new technology than with radically different technologies. In consequence, most of the gains from upgrading from the old to the new technology are likely to be predicted and identified ex-ante. The increase in performance due to the upgrade in technology is likely to create flexibility in terms of adding capacity to the system. Also, if technical change has reached decreasing marginal effect on performance along the curve, the potential for future increases in performance are limited (see **Figure 6.2**, A).

2. The upgrade across technologies in different S-curves, however, would not only increase performance of $\text{IF}_{\text{NT}}$ over $\text{IF}_{\text{OT}}$, but also allow possibilities beyond the scope of the organization (emergent functionality). Part of this is created by a potential of future performance that is unknown and goes beyond the potential of the old technology (See **Figure 6.2**, B). Technology developments along different S-curves are associated with disruptions that are often competence-destroying (Christensen 2000), and require organizational learning and adaptation. In some cases, depending on how radical is the new versus the old technology, the increase in performance

can reach beyond the needs of the D-EDF for $IF_{NT}$ (as in the case of switching from an analog system using telephone cables to an IP-enabled system operating over a fiber optic network). The possibilities of emergent functionality might not be evident ex-ante in the absence of basic knowledge about the new technology and dynamic capabilities (in the sense of Teece, Pisano and Shuen 1997).

**Figure 6.2**: Potential in Future Performance from Technical Change along a same and different S-curves



**(A) Technical Change along a Same S-Curve**

**(B) Technical Change along a Different S-Curve**

Source: the author

**Figure 6.2** shows that two technical options could generate a similar effect in present overall performance, but allow for a different potential in future performance. Technical change along a same S-curve could be achieved with lower engineering effort (option A) than change using next generation technology (option B), which might require higher effort and seem unjustifiable ex-ante. The justification of the additional effort, however, is in the potential that the new technology brings for the future.

In the case of MEUs, the technical changes did not affect the original concept of the electric power subsystem. The adoption of the new technology connected the components of the system in new ways creating an architectural innovation, but the difference between analog telephone based and digital fiber optic communication networks also added extra capacity well beyond the needs of the electric power utility.

### 6.2.2 Changes in Context

These architectural innovations, however, were not the result of technical changes alone[74]. Regulatory changes proposed by actors in the institutional sphere were also responsible for triggering the adoption of IP-enabled SCADA and AMR. Also, the process of identifying the potential use of such technology was largely the result of the social processes parallel to the due diligences needed to deploy and fund the initial network infrastructure.

Also, following Steels (1990), contextual changes modify the relationships of a system's components with its environment. If these relationships drive the activation of the functionality of components, as he suggests, then contextual changes could also drive emergent functionality (and independently from technical changes in components).

While technical changes drive functional emergence from *within* a system, contextual changes drive it from *outside*. Changes in context create new problems and needs. In some cases, functional emergence arises to deal with these problems and needs as a result what Thomas Hughes defines as a "reverse salient". When a problem or need is identified as critical (the reverse salient), the organization identifies resources that can be directed towards the goal of solving the problem or fulfilling the need.

Thus, while a system might have had a functionality that has been unnoticed for a long time, its existence might only become relevant as result of its usefulness to respond to a change in the environment.

Thus far we can say that functional emergence could be driven by both technical and contextual changes.

**Figure 6.3** illustrates the points of this and the previous section. The figure is not an attempt to represent the only possible states, but rather to illustrate the extremes of a continuum.

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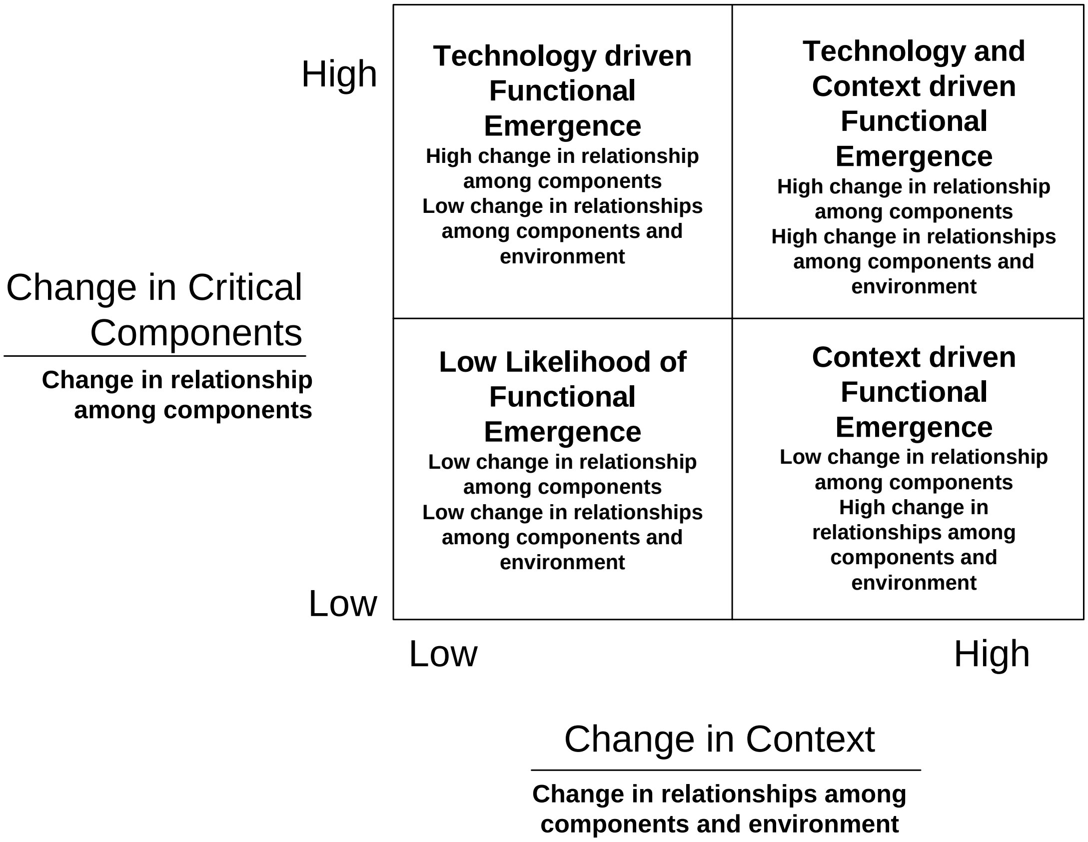
[74] This distinction is an important difference with respect to Henderson and Clark (1990).

**Figure 6.3**: Combined Effect of Technical and Contextual Changes in Functional Emergence



| | Low | High |
|---|---|---|
| High | **Technology driven Functional Emergence**<br>High change in relationship among components<br>Low change in relationships among components and environment | **Technology and Context driven Functional Emergence**<br>High change in relationship among components<br>High change in relationships among components and environment |
| Low | **Low Likelihood of Functional Emergence**<br>Low change in relationship among components<br>Low change in relationships among components and environment | **Context driven Functional Emergence**<br>Low change in relationship among components<br>High change in relationships among components and environment |

Source: the author

However, one thing is to trigger functional emergence; a different idea is the organizational adaptation that leads to creation of value. The next two sections complement the previous two.

### 6.2.3 Internal Emergence and Learning

The organization begins learning about a new technology during its adoption. For the system under study here, this first happened during the deployment of fiber optic networks, and later with technicians working on the SCADA systems, and those with experience and interests in computer networks.

However, one needs to differentiate between learning about $IF_{NT}$ as a necessary condition to sustain the performance of D-EDF, and learning about it as the basis for new type of internal or external services. In our research, the first case allowed increases in the reliability of the supply of electric power, while the second enabled the provision of communication services to other units of the local government and later diversification into external broadband services.

We define as *internal functional emergence* the process by which an organization recognizes that upgrading from $IF_{OT}$ to $IF_{NT}$ has created capacity and resources beyond the internal function's (or functions') original design and place in the architecture of E-EDF.

Existent absorptive capacity and dynamic capabilities within the organization can allow the recognition of value from the new resource; learning about the new technologies; and devising new ways for using it. These processes can trigger the adaptation and evolution of capabilities to find ways to turn excess capacity into a resource that might be used in new ways.

In the case of MEUs, this allowed municipal electric utilities to use the extra capacity to connect municipal buildings and departments, and provide communication and information services. At this point, there was no formal decision to diversify into telecommunication services, but the MEUS and local governments were already using the extra capacity as an emerged function internal to the towns.

The next step is how the organization identifies the opportunity to diversify its operations and develop external services based on the internal emergent functionality.

### 6.2.4 External Emergence and Diversification

The decision to diversify is based on the recognition of the possibility of creating value and the existence of enough demand for the new resource to justify diversification. This process has been widely studied following the first works in resource-based diversification (Rumelt 1982; Wernerfelt 1984). Resource-based diversification is especially easy when the organization has an existing customer base that is likely to exhibit demand for the new resource, as in the case of MEUs and their diversification into broadband services.

In our case, the diversification decision was highly customer-driven; the transparency and accountability of the process of approval by the local government heightened awareness among local residents and businesses. This is a special case of von Hippel's (1988) suggestion that the involvement of leading users and gathering of information can lead to innovations and the identification of new business opportunities.

In the case of MEUs, the broadband infrastructure evolved from being the support network for the SCADA and AMR systems to become the platform for providing broadband Internet communications for the electric utility and the town's business and residential users. Even without major changes in form, the change in concept created the emergence of a new externally delivered function, which was especially relevant for functional emergence, as it allows for diversification into new and possibly unrelated businesses.

For this reason, being aware of the possibility of functional emergence could have important practical implications. Knowing that functional emergence can be triggered by a combination of factors, the next section discusses how organizations could plan in order to (i) recognize sources of functional emergence, and (ii) create value from it.

### *6.3 Planning for Functional Emergence*

The process of emergence and creation of value from it results from four important steps: (i) changes in critical components and the relationships among them; (ii) contextual changes, (iii) identifying the type, quantity, and possible value of resources associated with the new resources; and (iv) deciding whether or not to diversify. The case of diversification of MEUs shows several characteristics that are relevant to functional emergence.

We propose that functional emergence is a general characteristic of many complex socio-technical systems. Furthermore, we propose that if organizations plan technology investments and react to contextual changes having in mind the possibility of functional emergence, they would be able to take advantage of new opportunities for technology-based diversification.

Based on our qualitative research in chapter 4, we know that organizations can identify, learn, and take advantage of functional emergence in at least two ways: (i) *exploration*, and (ii) *copying*.

1. Our analysis of the entry of MEUs into broadband services before the year 2000 is a case of *exploration*. After changes in context and technology, it took between 2 and 3 years for MEUs to (i) figure out that the new infrastructure (IP-enabled communication network) had economies of scope in the use of the new resource (bandwidth) that might be used for offering external communication services, (ii) learn how to use it and identify the existence of local demand and (iii) start offering external services.

2. We mentioned in chapter 4 that the MEUs that entered broadband services after 2001 were *copying* the first adopters of IP-enabled SCADA and AMR. As result, most of the ambiguity, uncertainty and risk associated with the early adoption of these IP-enabled technologies disappeared. Late adopters MEUs knew that deploying an IP-enabled communications network could be used both for running solutions for

> command and control *and* operating a broadband utility. The necessary knowledge was also available in the *Community Broadband Guidebook*, a 324-page document published by the American Public Power Association that is said to include *everything that needs to be known* about how an MEU can become a broadband provider.

Exploring and copying are two extremes of a continuum. In the first, each organization follows what Fleming and Sorenson (2004) call an information search process. This and previous work (Thomke 1998, 2001, Fleming 2001) supports the idea that exploration in the form of experimentation with new components and new combination of components lead to new innovations. While exploration allows an organization to be among the first to discover and take advantage of functional emergence, it takes too much time and might not always lead to diversification.

In the second case, the copiers –or late adopters- leapfrog the exploration process, face less uncertainty and ambiguity, and have access to better information. From the perspective of functional emergence, the copiers face the technology and contextual changes knowing that functional emergence exist, and they can profit from it. Copying uses information and knowledge that has been made explicit, and will probably take less time to accomplish the same end. However, the second generation may have to cope with competitive, regulatory, and legal barriers to entry raised in response to the first generation of MEU broadband providers. This is exactly what happened to all MEUs that did not diversify before their states prohibited municipal entry in telecommunications.

This leads us to a third alternative: to plan for functional emergence. In between the previous alternatives, there is a stream of research that can add great value to this discussion, but has been left for further research: real options analysis. There is significantly relevant work on investments as real options in information technology (Schwartz and Zozaya-Gotostiza 2000) and telecommunications (Gaynor 2001). In the case of the *acquisition* of new technology, as opposed to its *development*, the real options approach states that an organization makes an investment for new technology expecting an uncertain stream of future cash flows.

A firm is planning to upgrade components to new generation equivalents based in new technology. Planning for functional emergence could give it the opportunity for ex-ante analysis of the investment alternatives that could stimulate emergent functionalities, alternatives for diversification, and options for planning the deployment of the new technology. In other words, the organization could consider an array of possible investment not as a mere technology upgrades, but as options that could lead to different streams of future cash flows and could lead to diversification into new services. This line of analysis, however, is left for further research.

An organization's reasons for adopting a new technology can sometimes be not clear if considered only within the cognitive domain of its current line of business. That alone is a reason for analysis, because it could expand the context of the organizations decision making.

Thus, a useful approach to plan for functional emergence would be to combine exploration, copying (when possible) and options analysis. In terms of Brown's analogy about the emergence of the triangle, a combined approach like this would enable an organization to consider various alternatives in order to examine the implications of new functionalities by complementary processes of information searching about (i) what the is the likelihood and nature of the new functionality, (ii) whether it has useful properties, and (iii) how useful could it be.

By planning technology upgrades partly in terms of their ex-ante potential for functional emergence, and taking advantage of existing economies of scope, an organization could decrease the time between adopting the new technologies and diversifying into new services. This requires, however, that an organization is able to:

i. Identify and estimate the increase in resources associated with the new technology;

ii. Identify and evaluate alternative uses of such resources outside the current services and industries covered by the organization;

iii. Assess how the organization's knowledge base could be used to take advantage of such resources;

iv. Estimate the potential demand for such resources or value-added services; and

v. Develop a business plan to adopt the new technology, and a road map for deploying the new external services.

## *6.4 Conclusions*

We have identified functional emergence as the process by which one or more internal functions of a system enable the creation of a new externally delivered function. We call it *Emerged* Externally Delivered Function (E-EDF), and differentiate it from the system's originally *Designed* Externally Delivered Function (D-EDF).

We proposed that functional emergence is a property of many complex socio-technical systems, and suggested that the possibilities for functional emergence can be detected with the right type of analysis. We suggest that, if investments in upgrading system components from old to new generation technologies are analyzed as options, then organizations would be more likely and able to identify the probabilities of diversification based on FE.

The existence of functional emergence has important policy and management implications:

i. From a policy perspective, the existence of technology-based economies of scope and related diversification opens the possibility for convergence across different industries, or segments within an industry. This is relevant from the perspective of regulatory approaches that have treated some industries as clearly delimited silos, and enacted rules that limit entry and operation.

ii. From a management perspective, being aware of FE and being able to identify its likelihood allows managers to take advantage of opportunities for diversification, and increase the competitive position of organizations.

Chapter 7 expands on these issues, and presents the various aspects that remain open for further research.

# Chapter 7: Conclusions, Policy Recommendations, and Suggestions for Future Research

Municipal Electric Utilities (MEUs) have become active participants in the broadband market. In this research, we have provided a first answer to the questions of (i) why and how has this happened, (ii) what the economic effect of MEU entry into broadband has been, (iii) what was the underlying phenomenon behind this change in the architecture of MEUs, and (iv) what methods can be used to study these changes.

We developed a new qualitative method, COIReM, for testing our hypotheses about the first question. From our application of this method in Chapter 4 we confirm that the diversification of MEUs into broadband resulted from the emergence of broadband capabilities out of the adoption of IP-enabled solutions for Supervisory Control and Data Acquisition (SCADA) and Automatic Meter Reading (AMR). We proceeded to provide evidence about the economic impacts of these changes in chapter 5, demonstrating quantitatively that the adoption of IP-enabled SCADA and AMR enhances the efficiency of electric power operations. We also showed that the deployment of external broadband has positive effects on the local economy. Finally, we provided evidence that MEUs do not, as often asserted by those opposing MEU-based broadband, subsidize their broadband operations with revenues from their electric power business. Based on these findings, we suggest that MEUs should not be prohibited from deploying broadband services as they are in some states at present.

This chapter integrates the conclusions from our qualitative and quantitative analysis. Based on this, we present recommendations for policy about how to consider the involvement of MEUs in broadband services. We conclude by presenting our directions for further research on the study of the diversification of municipal electric utilities in broadband, the advancement of COIReM, and advancement of the theory of system architecture.

## *7.1 Conclusions from Qualitative and Quantitative Research*

In this section we present our conclusions about the four major research questions: (i) the reasons for and effects of the architectural evolution of MEUs, (ii) the magnitude of its economic effects, (iii) the underlying phenomenon behind such evolution, and (iv) the methods that can be used for studying architectural evolution. We explore our findings in the next sections.

### 7.1.1 Evolution and Diversification of MEUs into Broadband Services

Chapters 4 and 5 tell us part of the story about the motives behind, the evolution of, and the effect of the architectural change of MEUs, and their diversification into broadband services. In this section we consider jointly our results from qualitative and quantitative analysis to reach a full understanding of what happened

1. The Adoption of IP-Enabled Solutions for System Command and Control

   Our qualitative analysis revealed that the adoption of IP-enabled SCADA and AMR by MEUs was triggered by many converging factors. Part of the reason lies in the fact that the electric power sector in the United States was experiencing deregulation at the time. Many MEUs needed to increase the reliability of their systems and improve their efficiency to meet possible competition.

   MEUs that adopted analog-based SCADA and/or AMR during the 1970s and 1980s found that by the beginning of the 21st century that this infrastructure had already reached and passed its operational life. The case studies revealed this aging infrastructure was presenting problems.

   Seeking to upgrade their systems, MEUs adopted solutions for command and control enabled by Internet Protocol and operated on fiber optics networks. The goals were twofold: (i) to increase the reliability of the electric power operations by using real-time solutions for command and control , and (ii) to increase efficiency of electric power operations by increasing the life expectancy of network assets, better load management, and real-time pricing.

   Many questioned the rationale of these investments because these technologies were supposed to be expensive and complex. Such doubts, however, arose from a “telecom mindset”. Fiber optic network technology was pervasive among telecommunication and cable television operators who paid a high price for laying out fiber optics, expected short-term return on investment, and had experienced low returns on investments made during the mid-1990s.

Electric utilities have a quite different perspective. They calculate return on investment over a much longer term. Research shows (CIGRE 2000) they are accustomed to invest in assets with an average operational life of over 24 years. Furthermore, MEUs were adopting fiber optics at a much lower price than telecommunications had half a decade before. At the point of MEU adoption, the price of a meter of low-end fiber was not only below that of high-end copper, but also had higher functionality.

Many expected that changes like this would be so expensive that they would raise MEUs operational costs and require financing via raises in rates for electric power (IBM Business Consulting Services 2004). Chapter 5 and Section 7.1.2 tells us that the evidence shows otherwise.

The next question was *how* MEUs became broadband providers.

2. Adapting the New Technology and Learning within the Organization

The adoption of IP-enabled services by MEUs was marked by fast learning by their personnel, and a gradual adaptation of internal practices and capabilities.

In some cases the adoption of IP-enabled services by MEUs was accompanied by the signing of no-layoff agreements that required MEU managers to try using their in-house capacity. They thought that, with appropriate training, the linemen would probably be able to learn how to handle fiber optic. Reality showed that the linemen learned not only to handle, but also to splice and deploy fiber in very short time. From the linemen's perspective, the type of work was not much different from working with power lines, and far less risky. Also, personnel interested, or with experience, in computer networks started to become involved in the deployment of the new technology, and easily learned how to operate the new IP-enabled infrastructure.

This high degree of absorptive capacity within MEUs can be partially explained by (i) the disciplinary closeness between electrical engineering and computer science, and (ii) the fact that electric power and broadband services are both in the "*network business*".

The existence of capacities to absorb new knowledge, however, is not enough. We also identified the existence of dynamic capabilities in MEUs: the ability to put that knowledge into action in order to take advantage of the opportunities in rapidly changing environments.

Learning and adaptation within MEUs was also triggered by the effects of openness and transparency of the processes to select, approve, and deploy the new technologies, and the drive among municipal officials to create public value. The processes of approving and adopting the new technologies required open, public hearings and voting. Users asked why the same fiber optic network developed for MEU's internal use could not be used for other internal and external uses. From the perspective of enhancing public value, the first candidates for extended use were other local government departments.

Up to that point, MEUs had been busy deploying their internal network and operating SCADA. When MEUs started connecting with and providing service and informal training to other municipal departments, they enhanced their learning experience. They began to behave as informal broadband providers for local government.

3. Diversifying into Broadband Services

The openness of these processes allowed information to be shared with the local population as well as with other governmental groups. Increased awareness about the availability of a local fiber optic network and the success of providing broadband Internet services to some municipal units were two important factors in the gradual progression to public broadband. The realization among public officials that the MEUs had excess capacity began to converge with the public's concern about inadequate broadband access, in terms of price and quality. The joint impact of these factors combined with the fundamental mission of MEUs to create public value. The move into broadband services was a logical outcome of these three phenomena acting together. There were two important considerations:

i. The technology already has been deployed and was being used to operate SCADA and AMR. When one understands bandwidth as a valuable resource, and has efficiency as a driver, it is hard to argue against taking advantage of it.

ii. Local government and businesses assumed that that deployment of broadband would foster local economic development by attracting technology-based businesses and stimulating the local economy.

This analysis represents only the evolution of the first group of MEUs that diversified into broadband. Since 2001, the number of MEUs providing external broadband services has grown in almost five times (4.53), reaching 260 by the end of 2005[75]. Based on theory and fieldwork research, we can state that the motives, reasons, and processes

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[75] Data from the 2005 Community Broadband Survey from the American Public Power Association.

characterizing these *late-adopter* MEUs were different from the process just described, and responded to a copying process.

Finally, we conclude that the diversification of MEUs into broadband has more to do with the fact that MEUs are electric utilities than with their municipal nature, and that they can be an example of a sustainable model for facilities-based broadband provider.

### 7.1.2 Economic Effects of the Architectural Evolution of MEUs

The entry of MEUs into telecommunications has raised many policy-related questions. (i) Does the adoption of new IP-enabled technologies have a positive economic impact on the internal operations of MEUs? (ii) Were MEUs subsidizing the deployment of their broadband operations with revenues from their electric power business? And (iii) Does the broadband deployed by MEUs have a positive effect on the local economy? The last two questions had remained unanswered until now.

i. We found that MEUs that adopted IP-enabled SCADA and AMR by 2000 were able to reduce the price of electric power per MWh by about \$1.54, representing a 2% reduction as compared to the US average for 2003. Our results also show that these MEUs also show a decrease on their Customer Service, Sales, and Information Expenses per MWh.

ii. The analysis in chapter 5 demonstrates that no statistically significant differences in MEUs' prices or costs by MWh are associated with their deployment of external broadband services. This evidence refutes the assertion MEUs subsidize their broadband division with funds from their electric power operations.

iii. In terms of the effect of MEU-based broadband on the local economy, our results indicate that the deployment of external broadband services by municipal electric utilities by 2000 contributed *an additional* 1.5% to the growth rate in the number of local business establishments between 2000 and 2002. Our analysis of the effect of MEU-based broadband on the share of IT-intensive business establishments confirms previous results that companies do not base their location decisions on the availability of information infrastructure (Forman, Goldfarb et al. 2003b; Forman, Goldfarb et al. 2005).

Our quantitative results complemented our qualitative research by adding evidence about the effects of adopting the new technologies for system command and control, and the economic impact of using such infrastructure to diversify into external broadband services. Our results support the general idea that broadband has a positive effect on the local economy, but for reasons other than those commonly assumed. Case study research shows that much of the new business stimulated by broadband comes from small brick-and-mortar firms that have used the Internet to reach distant markets and sell online, bringing income from other towns.

### 7.1.3 CLIOSP-OPM Integrated Representation Method

We developed a new method for carrying out this qualitative analysis by integrating the Representation Stage of the Complex Large Interconnected Open Socio-Technical (CLIOS) Process and Object Process Methodology (OPM). We called the resulting approach by CLIOSP-OPM Integrated Representation Method (COIReM).

The development and use of COIReM proved to be useful for testing our hypotheses about the architectural evolution of MEUs. We find that COIReM analysis needed fieldwork research to validate some hypotheses and assumptions, and to explain some of the underlying processes of organizational change. The qualitative analysis also needed to be complemented with empirical quantitative analysis in order to quantify the impact of the evolution.

Architectural evolution results from the interaction between dominant influences and the need for change, but also within the constraints on change imposed by the system's architectural legacy. As such, the detailed study of the Electric Power Subsystem proved to be useful to identify and understand the major sources of that legacy. For this reason, historical analysis was critical to understanding path dependence and some aspects of architectural legacy.

The approach in this study was developed as a research method, integrating the CLIOS Process and OPM into COIReM. Also, it was purposely adapted to analyze the evolution of the architecture of systems. We are not claiming that it could be used for other purposes (although some other functionalities could emerge). For this reason, we suggest COIReM be used for problems in which the architecture of technology-based subsystems of the physical domain is the main focus of analysis.

In the case of our research, the validation of the representation and testing of the hypotheses was fairly direct. Some cases, however, would require more rework and analysis. This investigation suggests to the following:

i. Always keep in mind the hypotheses that need to be tested, and finish each step of COIReM Analysis with a brief assessment of whether the analysis performed in each step provides learning, information and knowledge to validate or reject the hypotheses.

ii. We propose literature and case study analysis to be used separately for testing the hypotheses. The literature can be wrong, biased or based in assumptions or paradigms that are no longer valid. It is useful to test the model using this information, and use data from field research as final step to validate. This approach enables the investigator to identify counterintuitive behavior, facts and, possibly the opportunity to redefine or create theory.

iii. The use of both qualitative and quantitative methods improves the investigator's capacity to test assumptions about architectural change. If the necessary data is available or can be obtained, integrating the adequate qualitative and quantitative methods can provide better and more complete answers to the research questions.

Our understanding of the system was greatly advanced by integrating the strengths of CLIOS Process (nested complexity and institutional sphere) and OPM (hierarchical decomposition and representation of functions). The use of this integrated method has demonstrated useful results. Its application in a wide variety of problems and by other researchers will provide a more definitive assessment of COIReM's value.

### 7.1.4 Functional Emergence

The analysis of MEU expansion into broadband allowed us to identify an interesting phenomenon in socio-technical systems that we have defined as "Functional Emergence": the emergence of a new externally delivered function (EDF) that results from technical changes in at least one internal function, and the cognitive evolution of the organization toward the value of the internal function in the form of a new EDF (e.g. broadband services) in addition to its original EDF (e.g. electric power services).

Complex systems are said to exhibit emergent behavior (Simon 1962; Simon 1997; Sussman 2003; Whitney, Crawley et al. 2004). Our definition of emergent functionality, however, is not necessarily associated with the behavior but with the purpose of the system as expressed by its externally delivered functions. Based on the analysis of our MEU case, in chapter 6 we developed a theory about the way in which functional emergence might occur in socio-technical systems. This theory explains the phenomenon in four stages:

(i) Once in a while, the components of a system are upgraded in order to incorporate the benefits of technical changes. The upgrade usually leads to an improvement in the performance of the functions performed by those components. We define such functions as internal to the system. By definition, in COIReM, they are classified at a lower hierarchical level than the system's *designed* externally delivered function (D-EDF).

(ii) Independently from changes in technology or components, socio-technical systems are often subject to contextual changes. Contextual changes affect the relationship between some of the system's components and the environment, which affect the system's performance by having direct or indirect effects on its concept, form or function.

(iii) As the organization adopts the new components of the system and starts operating with the new technology, organizational learning and adaptation begin. The outcome of the process will depend on the endowment of the in-house knowledge base about the new technologies, the extent to which the new technologies are competence-enhancing or -destroying, and the organization's dynamic capabilities and absorptive capacity. If the managers of the organization perceive the creation of valuable resources beyond those needed for performing D-EDF, and start using the new functionality for internal purposes, we say there is *internal functional emergence*.

(iv) Finally, the function can emerge externally if the managers of the organization recognize the existence of demand for the resource outside its institutional boundaries. If so, and they decide to take advantage of the resources, we say the function has become an emerged externally delivered function (E-EDF) the source of diversification. Here we say there is *external functional emergence*.

The relevance of functional emergence is that, by knowing the potential for it exists, one could plan technology investments with awareness that the possibility exists; analyze its likelihood; value it; and anticipate possibilities for diversification.

### *7.2 Policy Recommendations*

Reactions to the entry of municipal electric utilities into telecommunications have been marked by arguments containing at least as much ideology as fact. We have provided the first analytical evidence about some questions that, up to this point, had remained unanswered. Based on our qualitative and quantitative results, we present some recommendations for policy.

- **Allow Convergence Among Network-Based Utilities**. We have concluded that MEU entry into telecommunications resulted more from their nature as electric utilities than as municipal entities. New-generation information technologies have become ubiquitous and the specific knowledge once associated with highly technical tasks for managing and operating IP-enabled networks has become the common knowledge needed to operate the general-purpose basic infrastructure required complicated systems for command and control. These systems are being adopted in water, electric, and gas utilities as well as by transportation companies. From a theoretical perspective, this type of convergence is the next step following the convergence between media and telecommunications.

If one believes that public policy should enhance competition rather than protect specific competitors, then it should allow competition when it comes from technical change and technological innovation. This means allowing competition from non-traditional actors in telecommunications.

- **Lift State Prohibitions for the Entry of MEUs into Broadband Services**.. Fourteen states have enacted legislation prohibiting or limiting municipalities from deploying telecommunication services. The arguments are various: (i) unfair competition from local governments, (ii) harm to local residents and business by raising taxes to finance unprofitable businesses, (iii) inefficiency in the management of resources, etc. We have argued that MEU-based broadband is a different phenomenon than regular municipal broadband, and shown that:

  (i) Their deployment of broadband networks respond to the adoption of IP-enabled services for operating command and control systems, which have enhanced the internal efficiency of their electric power operations,

  (ii) There are economies of scope between operating such systems, and offering external broadband services,

  (iii) There is no evidence that MEUs are subsidizing the deployment of broadband operations with revenues or costs from their electric power business, and

  (iv) The deployment of broadband services by MEUs has a statistically significant and positive effect on the local economy, even in the presence of private broadband providers.

Many of the arguments for forbidding municipal broadband do not hold for the MEU case. However, MEUs fall within the *Municipal Broadband* class that is forbidden for entering into telecommunications in many states.

These restrictions are not protecting telecommunications competition; they only protect certain competitors. Furthermore, these restrictions are forcing MEUs to be inefficient by not allowing them to take advantage of their extra-capacity bandwidth thus restricting the potential for creating public value. These restrictions are also slowing down the potential for local economic growth of towns with MEUs. We suggest excluding MEUs from these state prohibitions, and allow them to compete in the broadband market.

- **Policy Making: From Policy for Technology, to Technology for Policy**. The existent state legislation prohibiting or limiting municipal broadband followed active lobbying from telecommunications and cable modem operators in state legislatures. John de Figueiredo has shown the relationship between these activities and the outcome of legislative activity in telecommunications (Figueiredo 1998; de Figueiredo and Tiller 2001).

  Most of the positions taken in this context have been based on *policy for technology* arguments: policy making applied to technology problems, without major consideration of the complexity and dynamics of the technology under regulation, and based on unsubstantiated assumptions. We suggest that policy making needs to follow a *technology for policy* and *fact-based* approach: explicit consideration about the particularities of the technologies being regulated, updates based on their evolution, and policy design based on tested hypotheses, rather than unproven assumptions.

Our results provide enough evidence to suggest that the inclusion of MEUs in state legislation prohibiting local governments for offering broadband services needs to be revisited, reconsidered and, ideally, changed.

## *7.3 Directions for Future Research*

Our study suggests opportunities for future research in many areas. In this section, we present various questions for further research related to (i) the diversification of municipal electric utilities in broadband, (ii) the use and refinement of COIReM, (iii) advancement of theory about understanding of the architectural evolution of long-lived socio-technical systems, (iv) functional emergence and its applications for technology policy and management, and (v) architectural innovations.

### 7.3.1 Municipal Electric Utilities

Our research focused on innovator MEUs, leaving open the need to answer similar questions and test the same hypotheses for all MEUs that have adopted IP-enabled SCADA and AMR since 2001. As we have discussed, while the process of diversification and architectural evolution of innovator MEUs was one of discovery, the diversification of follower MEUs resulted from copying the leading MEUs and following the suggestions of the Community Broadband Guidebook, and led by adopting processes first tested elsewhere.

Until now, there has been no analysis of how successful this second generation of initiatives has been. How can we explain the adoption of IP-enabled service and diversification after 2001? Our hypothesis is that it can be explained by institutional isomorphism (DiMaggio and Powell 1983), which states that organizations tend to model themselves after others perceived to be successful, but often without any evidence of such success.

Being an innovator has given some MEUs a special advantage over those who have not deployed external broadband. One example is that some states have prohibited the future development of similar projects for other MEUs, but grandfathered those already deployed. A relevant question is, besides the regulatory landscape, whether the market and competitive conditions have also changed. How different is the economic impact of broadband deployed by follower MEUs? One could argue that, based on the dynamics of the broadband industry, the need for MEU-based broadband, and thus its economic impact, might have decreased between 2001 and 2005. More data and analysis is needed to answer these questions.

An important question in our research was whether MEUs were subsidizing their broadband business with funds from their electric power operations. We provided results, but more research is needed to give a definitive answer. Waiting a few years for more data would reduce any possible bias associated with sample size in our results.

In chapters 4 and 6 we proposed that, based on our analysis, the MEU phenomenon was more related to their nature as electric utilities than to the fact they are municipal agencies. This leads naturally to the following questions: how different are the structures and impacts on local economies of MEU initiatives from municipally-based broadband in general? Based on the existence of economies of scope and funding structure, we should not expect to see similar results and cannot extrapolate results from MEU-based broadband to general municipally-based broadband.

Thus, this research can be continued by (i) incorporating the MEUs that have diversified into broadband after 2001, and analyze the differences among the two groups (early adopters and followers) by qualitative and quantitative methods, and (ii) studying the evolution of private electric utilities that have started experimenting and offering advanced telecommunication services, in order to identify the differences in impact and adoption process. This last line of research would help us to advance our understanding about the relevance of the public-private nature of these systems on their architectural evolution towards becoming a broadband provider.

### 7.3.2 COIReM

While the development and application of COIReM were helpful in answering our research questions, there is still a long way to go to test its usefulness as a research method. More research is needed to refine it through application to other systems. Two questions are especially relevant:

(i) Are other qualitative and quantitative methods needed to strengthen the quality of the results from applying COIReM? If so, why and which are these methods?

(ii) What are the limitations of the method? Do the twelve steps make sense for other systems?

### 7.3.3 Architectural Evolution of Long-Lived Engineering Systems

An issue of major interest is a better understanding of the factors affecting the architectural evolution of engineering systems, especially long-lived systems. A major question for further research motivated from our research is: How can one better manage the evolution of the architecture of these systems? This question has three subsidiary questions of high interest from the perspective of flexibility of a system facing architectural evolution or the possibilities for architectural innovation:

(i) How can we learn from history and avoid losing information throughout the system's life that might be useful in planning its evolution?

(ii) How can we design long-lived systems for maximum flexibility? Here, an interesting perspective to further research is designing flexibility from the perspectives of engineering and finance.

(iii) How can we minimize constraints on future evolution in designing system architecture?

### 7.3.4 Functional Emergence

We have defined functional emergence, and suggested it is a property of many complex socio-technical systems. The next step is to finish building a theory of functional emergence that (i) proposes its properties and how they are related to other properties of complex systems, and (ii) develops an analytical representation of emergent functionality and relates it to decision making. Once these ideas are established, we can move toward a more detailed framework and tools for planning for functional emergence. There are three major questions for further research:

(i) What is the extent to which Functional Emergence is a characteristic of *some* or *all* types of socio-technical systems? How generalizable is the framework presented in Section 6.2?

(ii) How does Functional Emergence relate to other properties of complex socio-technical systems?

(iii) What would be an adequate analytical framework to represent and model Functional Emergence? If we can find such framework, Can we integrate it with others, such as real options analysis, to provide better answers to decision makers?

This effort would require deepening our understanding about the phenomenon with the study of a larger number of cases in varied areas, and further explore the relationship between technical and contextual changes as sources of Functional Emergence.

### 7.3.5 Architectural Innovation

As follow up from the previous point, and building on the work of Henderson and Clark (1990), we argued that architectural innovations can be triggered not only by technical but also by social and regulatory changes. From this respect, it is also necessary to better establish the theoretical relationship between Functional Emergence and architectural innovation.

This is an important issue, and needs serious consideration and development. The theory of architectural innovations would greatly benefit from including aspects from theory of system architecture. The author plans to connect them, and provide a new framework for analyzing architectural innovations in future work.

We hope this dissertation will prove to be of value, by contributing to the advancement of the theory of system architecture and the discipline of engineering system, by providing new tools for practitioners and policy makers, and by providing useful advice for policymakers, managers and investors working in the MEU broadband provision domain.

# Appendix 1 : Interview Questionnaire

## Introduction:

*Thank you for participating in this interview. It is part of a research project which is being conducted by the Massachusetts Institute of Technology's Communication Futures Program. Your participation in this interview is voluntary. You are free to do not answer a question you feel uncomfortable with, and you are free to stop at any time your participation on this interview. Our main focus is on the processes of, and reasons for, designing and implementing the municipal broadband service, and the evolution of its impact on the local economy. We have a series of general questions, some of which ask for more specific details.*

1. **Describe the local government's broadband initiative(s). What do they consist of and what target markets are they intended to serve (e.g. schools, government offices, local businesses, and local citizens)?**
   - *What is the choice of broadband technology? Why was this choices made?*
   - *How were defined the target markets?*

2. **What, if any, was the first type of telecommunication or information technology service deployed by the local municipal electric?**
   - *Why was this first telecommunication service deployed?*

3. **How is the broadband initiative related to the electric power business of the utility?**
   - *Why?*

4. **Why did the local government decided to pursue its broadband project?**
   - *How did the municipal government get the idea?*

5. **What were the initial objectives of the broadband initiative?**
    - *What are its current objectives?*
    - *Why do you think these objectives evolved?*

6. **Describe the process of developing the initiative. What were the stages of decision-making and how long did each last?**
    - *How did the project evolved through them?*
    - *Why do you think the project followed/evolved through these stages?*

7. **What were the most important factors encouraging and discouraging the initiative?**
    - *How have these factors evolved?*

8. **What, if any, are the measures of success of the municipal broadband project?**
    - *How were these measures of success created? (Who set them?, when?)*

9. **What organizations were involved in developing the initiative?**
    - *What have been the roles of public, private, and non-profit organizations?*
    - *What role have other governments (e.g. state, federal, or other communities) played?*

10. **How was/is the initiative funded in each one of its stages? (% Public, % Private, Cost for subscribers).**
    - *How was this funding model selected?*

11. **Describe the effects of the initiative, in particular effects on e-government and local economic development. How has this initiative affected the local economy?**
    - *Please refer to any visible effect on the number of jobs, creation of new companies, attraction of businesses, etc.*

**Thank you for participating in this project.**

# Appendix 2 : Case Study of Braintree Electric and Light Department -- Braintree, MA

### Case Study Information

This case study is the result from a series of five interviews and site visits conducted on March 9th and 15th of 2006 in Braintree, MA, and from access to documentation from Braintree Electric and Light Department (BELD). The subjects of the interviews were BELD's past and current General Manager, the Marketing and Program Director, and two members of the staff (customer service and maintenance).

In total, there were 125 minutes of interview time recorded, transcribed and then coded in order to identify relevant facts and internal processes.

### Town and Utility Basic Information

The town of Braintree is located at Norfolk County, MA, a little less than 10 miles southeast of Boston. In 2000, the town had a population of 33,828 inhabitants living in 12,652 households in an area of 13.4 square miles; per capita income was relatively high income at $28,683. Braintree is mainly a residential town, with some small and medium-size businesses.

The history of Braintree begins in 1625, when Captain Wollaston established a settlement with about 40 colonists in a place named Mount Wollaston, which was later renamed Merry Mount and annexed to Boston in 1634. The town of Braintree was incorporated in 1640, as a result of a petition to separate from Boston[76].

Braintree Electric and Light Department (BELD) was founded in 1891 by Thomas A. Watson, who years before assisted Alexander Graham Bell in the invention of the telephone, and also served on Braintree's special committee on education in the 1890s[77]. BELD first offered street lighting by 1892, and added commercial and domestic services a year later.

**Context**

In 1998, the Massachusetts Department of Telecommunications and Energy decided to deregulate the state's electric power sector, with the objective of creating better services at lower costs through increased competition.

The utility had already started a process of increasing the reliability of its operations by replacing the old twisted-pair telephone line infrastructure for communications between their light department and the power plant. In 1990, BELD completed the construction of a new (Churchill) substation, and conversion of a generation station (Potter II)[78].

While BELD was not directly affected by the new regulatory changes, advisors told BELD's general manager that eventually the utility would have to allow third-party access to their meters. This triggered the idea of adopting new technologies for automated system monitoring and meter reading (BELD 2001).

Thus, BELD projected the adoption of a new information technology infrastructure to replace old infrastructure, and install Supervisory Control and Data Acquisition (SCADA) in the short term. The long-term plan included deployment of automatic meter reading and billing.

The objective of installing SCADA, according to past and current BELD's general managers, was to eliminate interruptions in communications with the power plant, gather more and better data from substations and, by those means, increase the reliability of substations and the whole system.

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[76] See http://www.townofbraintreegov.org/history/index.php

[77] See http://www.beld.com/AboutBeld/Watson.asp?subsection=1890s#timeline

[78] See http://www.beld.com/AboutBeld/History.asp?subsection=1990s#timeline

## Deployment

In 1998, BELD deployed a 750 MHz system of 170 miles of Hybrid Fiber Coaxial (HFC) cable with 34 fiber optic nodes that served almost all homes in town (each node served about 400 homes). This included a communication network deployed in 1995 for its electric power operations that included an Optical Carrier of 51.8 Mbps (OC-1) Synchronous Optical Network (SONET). This network connected the substations, the power plant, and the central office, which was cabled with a fiber optic network.

BELD got support from its board to invest $ 2.8 million in the network infrastructure. As this was an extension of BELD's business, there was no need for additional approvals.

The main reason for choosing HFC and fiber was that fiber and HFC are totally isolated and most of the cable was supposed to go underground. It would not deteriorate like the old telephone cable-based communication system.

About 90% of the fiber could be installed by BELD crews. The electricians learned how to splice and connect fiber, and the engineers were operating the new SCADA system and creating new constructions for the communication infrastructure. In the words of BELD's general manager, it was critical to keeping talented people interested and involved. However, once BELD began to deploy HFC cable, it became necessary to outsource part of the job because of lack of the appropriate equipment.

Meanwhile, local government officials were concerned about the need for a new generation communications network for the town. BELD crews connected town buildings, the police and fire department, and schools. The utility already had a backbone that passed most of the schools and municipal buildings.

The success of the deployment of Internet access for schools and municipal buildings raised the awareness of local government officials about the possibilities for using the new infrastructure. In1999, the utility launched its high-speed Internet access service provider--BELD.net--to residential and business customers. Service included email, web hosting, and remote access. In a few months, BELD had signed up about 1,600 subscribers (BELD 2001), and by 2006 had surpassed 5,000.

The availability of commercial Internet provided by BELD raised awareness among residents that the utility could also provide a competitive alternative for cable television services. There were problems with the quality and cost of services provided by Cablevision, the private provider operating in Braintree. At that time, the town was re-licensing cable television, and there was increasing pressure for the utility to become a local provider.

Entering cable television, however, required a different system of approval. It was not enough to get permission of BELD's board; town approval was required for both funding and a cable television license.

BELD's board approved the deployment of cable television services in December of 1999, and the proposal was presented in Town Hall meeting. By the end of 1999, residents of Braintree voted in a non-binding referendum to grant BELD permission to enter into cable television, obtaining an approval of 82%. Network Engineering Consultants, Inc. (NECI) was hired to conduct a feasibility study. NECI surveyed 500 residents and found that 90% of them would be interested in subscribing to BELD's cable television services (BELD 2001) even if it was more expensive. The sense was that dealing with BELD was better than dealing with Cablevision. These results allowed BELD to go back to Town Hall meeting to ask permission to secure the necessary funding for the investment.

In a May, 2000 vote, BELD obtained dual approval to (i) offer cable television services, and (ii) obtain $3.5 million in non-taxable bonds. Representatives from Cablevision attended the meeting and tried to discourage the Board of Selectmen without luck. At that point, Cablevision was decided to sell its assets; however, its potential buyer, AT&T, was not yet ready to enter the market. BELD was eager to take advantage of this window of opportunity but still faced the additional step of getting the cable television license from the Selectmen.

BELD managers asked the Board of Selectmen to transfer Cablevision's license to them, a decision that was made in August 2000. This approach, bypassing the time-consuming process of getting a new license, saved BELD almost a year in the approval processes. The utility decided to launch its new services by January 2001.

The original SONET ring was, however, in the wrong places for deploying residential services. BELD had to deploy the new fiber and HFC 750MWz network in order to have full town coverage. They had to issue a request for proposal for a new cable headend and equipment.

A major change for the utility, however, was that for the first time it needed to compete for customers. AT&T was coming to town and had begun updating the old Cablevision infrastructure; BELD had a commitment to offer services at the lowest possible prices (See **Tables A2-1** and **A2-2**).

**Table A2-1**: Cable Modem Internet Packages and Prices

| Package | Basic Office Plan | Network Office Plan | Small Office Plan | SO/HO | Residential |
|---|---|---|---|---|---|
| Download Speed | 4 Mbps | 8 Mbps | 6 Mbps | 2 Mbps | 5 Mbps |
| Upload Speed* | 384 Kbps | 384 Kbps | 384 Kbps | 256 Kbps | 386 Kbps |
| Monthly Rate (2006) | $85 | $215 | $135 | $42 | $42 ($38.5 for senior citizen) |

Source: http://www.beld.com/Pricing/Default.asp?BusinessType=Internet. BELD also offers a corporate plan that is tailored to customers specifications and priced accordingly.

**Table A2-2**: Cable Television Packages and Prices

| *Resident Packages* | *Price* | *Channels* |
|---|---|---|
| *Basic* | *$42* | *62 (analog)* |
| *Complete* | *$93.5* | *190 (analog)* |
| *Digital* | *$49.25* | *155 (48 digital)* |
| *HD* | *Extra $10* | *Upgrade to set-top box* |
| *Lifetime* | *$9* | *25 (analog)* |
| *Digital Plus* | *Extra $4* | *Add more channels to BELD digital* |

| *Business Packages* | *Price* | *Channels* |
|---|---|---|
| *Basic Tavern Digital* | *$135.8* | *58 (analog)* |
| *Tavern Complete* | *$220.85* | *65 (8 digital)* |
| *Music* | *$26* | |
| *Standard Business Basic* | *$42* | *62 (analog)* |
| *Standard Business Digital* | *$49.25* | *112 (48 digital)* |

Source: http://www.beld.com/Pricing/Default.asp?BusinessType=Cable

BELD also offered two cable television and broadband Internet bundles for residential customers, and eight for business customers.

During the first months, BELD's manager for support services started managing about 25 installations per day, working six days a week. Two and half years after starting broadband operations, BELD had a 40% of market share with no advertisement and an average of 40 new customers per month.

### Reaction from Incumbents

The incumbent, CableVision, was being sold to MediaOne (owned by AT&T) and did not react; MediaOne was not yet a player, so it did not react either. After some years, Comcast entered the market offering half prices over a 16-month period, which cost BELD about 150 customers. These offers, however, were not made available anywhere else near Braintree. The Comcast strategy included hiring a specialized door-to-door sales force. For a while, BELD fought these strategies in the newspapers and through public relations. An unintended consequence of this campaign was that BELD got unusual publicity, which later increased their customer base. Later, in 2006, Verizon sent out 15 crews to begin deploying fiber in town.

### Funding

The Town first approved an investment of $2.8 million for constructing the HFC network. The network was completed by 1998. Later, in May 2000, BELD received dual approval in Town Meeting for a $3.5 million bond in order to launch the broadband services. There were special reasons for asking for these amounts. The commissioners suggested a lower figure, because they were afraid that such a large request would not be approved. According to BELD's general manager at the time, about $10 million were actually needed. Since then, every year BELD has allocated between $100 and $200 thousand dollars from revenue to expand the system.

### Impact

There has been no study of the impact of BELD's broadband offer on the local economy. Evidence from interviews, however, suggests that two major effects have been broadband Internet access to local schools, and an increase in the number of telecommuters.

# Appendix 3 Case Study of Hometown Utilicom -- Kutztown, PA

### Case Study Information

This case study was written using information from interviews, site visits, documentation from the utility and information from the Internet. The interviews and fieldwork were carried out during site visit during February 23rd and 24th of 2006 to Kutztown, PA.

The interview process included the Mayor of Kutztown, the Town Manager, the Director of Information Technology for Kutztown' utility, the professional in charge of the SCADA system, two members of the council, and the owners or executives from four local businesses (a travel agency, a bookstore, a design company, and a homemade soap store).

There was a total of 325 minutes of interview, which were transcribed and coded. The resulting information, added to field notes, photography, documentation from the utility and information found on the Internet allowed identifying relevant facts and process.

## Town and Utility Basic Information

Kutztown is located in Dutch County, Pennsylvania, 56 miles northwest of Philadelphia. In 2004, the Census Bureau estimated its population at nearly 5,200 inhabitants. With 2,200 households in 1.6 square miles, it has a household density of 1,375 per square mile. The town was founded on June 1755 as "Cootstown", became Kutztown in 1830[79], and was chartered as a city in 1847 (Kutztown Area Historical Society 2005).

In 1902, the borough founded its electric utility, today known as Kutztown Hometown Utilicom (HU)[80]. Hometown Utilicom used to offer three basic utility services: (i) water services, which started as Kutztown Water Company in 1889, (ii) electric power, which started in 1902, and (iii) sewage treatment which was added in 1940.

HU had a SCADA system in place for its electric operations; sewage treatment plant; and water collection, purification and distribution. For the water services, HU had a basic SCADA communication system that was installed in the early 1970s. The system, which worked over telephone lines, remotely started and stopped pumps between the raw water tanks, filter plant, and finished water reservoirs. The system was very unreliable, difficult to maintain, and very susceptible to lightning strikes.

## Context

In 1996, Pennsylvania deregulated its electric power markets, amidst concern about competition from regional investor-owned utilities (IOU). There was special concern about the possibility that McConway & Torley Steel Foundry, known as Kutztown Foundry until 1980[81], could be targeted as potential customer by an entrant IOU. The foundry's focus is on making train couplers; it uses an electric furnace that is a large source of demand. The furnace has contributed one third of all HU electric power revenues since the early 1980s. Losing this business to an IOU would have been had a major financial impact on HU.

Also in 1996, Kutztown borough began a Comprehensive Planning Program with the overall objective of making of Kutztown an "*attractive and desirable community in which people would want to live, work, shop, visit, [and] attend school* "(Kutztown Borough 2000).

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[79] See http://www.kutztownlionsclub.org/history/index.htm

[80] See http://www.davidallen.org/papers/Kutztown%20et%20al.pdf

[81] See http://www.mcconway.com/history.htm

One objective of the planning was "*resolving the community's water and sewage issues*" and decreasing the cost of town services.

From the electric utility side, the objectives for deploying SCADA were to monitor equipment in order to extend its operational life. A SCADA system made it possible to identify and address problems as they were occurring, as opposed to have equipment fail totally and then going out and fixing it. For example, SCADA devices in transformers and breakers could monitor rising heat levels, an indicator that something was wrong in advance of a major failure.

Previously, HU had a system of lights that were supposed to start flashing when something was going wrong with power or water. This, however, required neighbors and police to see those lights and contact HU, which would then activate its on-call service crew to assess causes and damages. HU was looking for an advanced warning system that could directly communicate with the on-call crew through pagers and cell phones. The advantage of SCADA was that it could identify failures in the field before or as they started to occur, and correct them proactively rather than reactively, after major damage had happened.

HU's first step was to upgrade the SCADA system first for the water facilities, and then for the electric utility and sewage services. This would enhance reliability and customer service and, from the perspective of maintenance, eliminate the costs of total replacement of failed components, thus prolonging the life of the infrastructure.

Despite the fact that Kutztown houses Kutztown University, and hosts nearly half of its 10,000 students, no entity offered broadband Internet in town in 1999.

### Deployment

In 1999, HU began implementation of its SCADA system. The system could control, analyze, report, and modify automated processes in real time, using the graphical interfaces of an integrated grid between electric, water, and sewer facilities. The system documents failures as they begin, and alerts the responsible crew by mobile devices enabling quick decision making and deployment of repairs. The SCADA system also allows remote process management through the network. The next goal was to include Automatic Meter Reading.

The original idea for the SCADA system was to use standard phone communications, leasing lines from Verizon. HU was already paying $1,100 per month for leased lines for Internet access. HU officials thought they could "hang the wires [themselves]", and save that money, in addition to upgrading to wires that were not affected by electromagnetic or radiofrequency interference.

At this time, however, Wavelength-Division Multiplexing (WDM) was already being deployed commercially, allowing the channeling of various services along a single wire. HU officials attended a United Telecom Council Conference where people were talking about converged services. As HU was laying out fiber, managers began to think about using the new infrastructure in new ways. The ideas presented at the conference opened the door to options beyond what HU was considering originally.

HU started connecting municipal buildings outside the main Borough's building, creating an internal municipal data network. First, they connected the water and sewer plants, electric substations, and the garage. Second, HU connected the police and fire departments so that they could receive alarms from the SCADA system. Soon, they began to include locks and security cameras on the system, and were able to respond to various requests from Council members, such as placing security cameras in parks and restaurants.

After the UTC Conference, HU decided to become a "pipeline" for telecommunication services using the fiber infrastructure they were building for internal use. This was seen as an additional way to serve the purposes of the Comprehensive Planning Program, obtain additional revenue and *"provide the public works infrastructure and communications and information data network services to enhance the quality of life of the constituents in the Kutztown community in this growing technological society"*(Kutztown Borough 2000).

Along these lines, the Borough was also working on a project to revitalize downtown Kutztown's Main Street, and foster local development by attracting new commercial and industrial businesses as part of the "Route 222 Dev.Com" project.

The original idea was to build a fiber optic network that would reach every home and business, and then lease it to content and service providers who could serve the town with advanced telecommunication services. On December 11t, 2000, HU issued a first request for proposals (RFP) inviting providers to design and build a system that would provide cable television, telephone, Internet, security services, and AMR. Optical Solutions and Atlantic Engineering were selected to design and build the network, respectively. HU choose passive optic network (PON) architecture for three reasons: (i) lower cost, (ii) higher reliability, and (iii) the fact without active components everything could be controlled from the central office.

At the time, there were increasing demands for Internet access in Kutztown as well as concerns over the cost of cable television. The plans for open access, however, failed. According to HU officials, no private company was interested in providing broadband access or cable television if they didn't "own" the last mile. By that time, HU linemen had acquired enough expertise with the fiber-based SCADA system, that HU could leverage their experience and knowledge. HU managers decided that HU could become provider of broadband services and cable television itself, and committed to offering three services—broadband, telephone, and cable television (Vittraino 2003).

Fiber-to-the-premises (FTTP) broadband services were launched in August of 2002. A second RFP was issued on April 9, 2002; Electric Engineering was selected to design and build the network. Telephone communications were outsourced to CEI Communications, and access to the Internet backbone was bought from Adelphia Solutions. Again, no partner was found to build the television headend, which was built later by HU about a quarter of a mile from the central office at a cost of $850,000 (Sirbu, Lehr et al. 2004).

HU started its broadband services in August 2002 with 200 homes. This number increased to nearly 650 by 2004 and reached 800 by the beginning of 2006. Currently, it offers High-Speed Internet services (See **Table A3-1**), cable television (See **Table A3-2**), and telephone for all users, as well as security systems and web hosting. HU offers a two- and three-service bundles:

- 2-Service Bundle: 2.5% discount on any telephone or television service contracted jointly with broadband Internet access.
- 3-Service Bundle: 2.5% discount on both telephone and television service, if contracted jointly with broadband Internet access.

**Table A3-1**: Broadband Internet Access

| *Download Speed* | *64 Kbps* | *128 Kbps* | *256 Kbps* | *768 Kbps* | *1 Mb* |
|---|---|---|---|---|---|
| *Upload Speed** | *2 Mbps* | *2 Mbps* | *2 Mbps* | *2 Mbps* | *10 Mbps* |
| *Price Jun 2003** | *$15* | *$20* | *$25* | *$35* | *$40* |
| *Price Jun 2006* | *$20* | *$22* | *$30* | *$35* | *$45* |

*: Upload speed was 1Mbps for all tiers. Source: http://www.hometownutilicom.org/Services/internet.html

**Table A3-2**: Cable Television Services

| *Service* | *Price* | *Description* |
|---|---|---|
| *Basic* | *$16* | *21 Channels from a selection of 32* |
| *Expanded Basic* | *$31.75* | *95 channels (including previous 21)* |
| *Premium 1* | *$16* | *Showtime, Shotoo, Starz, Encore, The Movie Channel, Sundance, & Flix* |
| *Premium 2* | *$16* | *4 HBO channels & 3 Cinemax* |

Source: http://www.hometownutilicom.org/Services/TV.html

Next steps include expanding cable television capabilities for High-Definition Television, and deploying wireless Internet access.

**Reaction from Incumbents**

There was no reaction from Verizon, the incumbent telephone and DSL provider. Before HU deployed cable television services, the incumbent (Cablevision) price for a 70-channel offer reached $33.63, and dropped by 20.25% to $26.82. The services were deployed over a 350 MHz Hybrid-Fiber Coax system. After HU's entry, CableVision ran fiber into town and upgraded its system to 650MHz, thus allowing for more channels, and started offering three-tier services for $25. These prices are not offered in neighboring towns. Additionally, Kutztown's Main Street is currently a hot spot for free wireless Internet access offered by CableVision.

**Funding**

Between August and September 2000, HU started to present its idea to provide broadband to the council and to request permission to raise the US$ 2 million needed for the first stage through a 30-year taxable bond. They decided to use taxable bonds, for two reasons: (i) Non-taxable bonds would have required HU to allow private providers to become service and content providers through the network. (ii) Non-taxable bonds would invite criticism that HU was using its non-tax status to raise capital. The remaining $1.9 million were obtained through a loan from the Borough Electric Fund.

**Impact**

There has been no study about the impact of MEU-provided broadband in Kutztown. HU officials, and Council members, however, have seen an increasing revitalization in terms of the number of new store fronts along Main Street, and increasing revenues. The major benefits have come not from technology-based firms, but from "brick and mortars" such as law firms, travel agencies, bookstores, and bath shops that have started to bring revenues into town by selling online.

A major driver has been the quality of customer service, which has been driven by two factors. First, customers actually know who are responsible for customer service, and ultimately can talk directly to the town manager or HU's director for IT by visiting their offices or homes. Second, customer service can turn into a political issue in Kutztown. If HU fails to meet people's expectations and dissatisfactions, customers will talk about it at town hall meetings every month.

# Appendix 4 : Case Study of Owensboro Municipal Utility -- Owensboro, KY

### Case Study Information

This case study was the result of information gathered through 11 interviews, documentation from the Owensboro and information from the Internet. The interviews and fieldwork were performed during a visit to Owensboro between April 3rd and 5th of 2006.

The persons interviewed included the General Manager of the utility, the Director for Engineering and Operations, the Director for Finance, the Director for Power Production, the Public Relations representative, the Head OMU Online (the broadband provider), and two professionals from the SCADA group. Additionally, managers from four local businesses (the airport, a hospital, an oil company, and a local hotel) were also interviewed.

The total time of interviewing added 401 minutes. Each interview was transcribed and coded, and the resulting information served as input for the analysis and building of the case study. Besides the interviews, the case studies resulted from information on field notes, photography, documentation received from the utility, and from the Internet.

## Town and Utility Basic Information[82]

Owensboro was incorporated in 1817, having grown from a settlement in 1797 known as Yellowbanks. The city is located 109 miles southwest of Louisville, KY. It is the third largest city in Kentucky, registering 54,067 inhabitants in the 2000 National Census in almost 23,000 households.

Owensboro's municipal electric utility started operations at 4:25pm on December 31, 1900, as result of a town voting process held by Owensboro's residents in 1895 that decided, by 1,771 votes to 63, to start a local electric utility. The impetus was dissatisfaction with the service of local private providers. Something similar happened in 1990 when, dissatisfied with the water services, Owensboro residents voted 1,942 to 444 to build a local water utility.

Owensboro Municipal Utilities (OMU) was born in 1940 when the city decided to combine its electric and water systems. Currently, OMU is operated by 235 employees, and is Kentucky's largest municipal utility with power generation capacity, with 15 substations divided into 73 circuits and 345 miles of power lines. Its user base includes 23,963 accounts for water service and 25,423 for electric power.

## Context

Owensboro Municipal Utility owns a coal-based power plant with a total capacity of 425 MW, 15 substations, and a water treatment facility with a capacity of 20 million gallons per day. OMU had a SCADA system running over microwaves among their substations, which also served the water department and two other neighboring water districts.

To update its infrastructure, OMU planned to replace old electromechanical relays in substations with digital relays. They decided to build a fiber optics network because fiber provides a better communication circuit than microwaves and telephone lines.

Kentucky has not yet passed a state law deregulating the electric power market. A report of the Special Task Force on Electricity Restructuring released its Final Report, research report No. 299, stating that "no action should be taken during the 2000 session of the General Assembly to restructure Kentucky's electric utility industry". The Task Force suggested a continuation of the study of options for liberalizing retail competition (Special Task Force on Electricity Restructuring 2000).

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[82] See http://www.owensboro.org/page.php/City%20Information/aboutowensboro.php and http://www.omu.org/AboutOMU/history.htm

OMU's culture is defined as very customer oriented, with a strong focus on getting what customers need.

**Deployment**

OMU deployed 18 miles of fiber optics in a network around the city in 1997 in order to connect its substations with the central office and operate a SCADA system. The utility is separate from the city government. The utility used its own funds for the investment.

During the process, OMU officials thought that because its linemen already knew how to climb poles and handle cable, they could learn how to splice fiber. OMU bought a splicing trailer, originally intending to use it only for installing the SCADA system. As the work progressed, a significant number of the linemen began to express a preference for doing what started to be called "telecom work". There were two reasons for this: (i) the lower levels of risk involved compared to working with power lines, and (ii) personal interest and the excitement about working with new technology.

Workers from the substations and the metering group also became involved in learning about and computer networking. For example, one electronic technician at the power plant, who worked with computers in his spare time, was pleased with opportunity to do "at work" something he really enjoyed and, at the same time, help to build the network and assist customers.

The investments were well received by citizens and public officials, who were excited about OMU's potential to provide fiber optic capabilities. At that time there was no affordable high-speed Internet access in Owensboro. OMU started deploying fiber optics beyond utility operations in order to give broadband access to various government departments and schools. According to OMU officials, the connection of government offices had a significant effect on internal efficiencies. Owensboro has a very active Parks Department, which wanted to take advantage of the new infrastructure to attract more sports events to the city, by offering wireless access over the municipal network. As commercial customers of their water and electric power services became aware about OMU's fiber optic capacity, the provision of broadband services was perceived as a natural extension of utility's other two existing businesses (water and electric power).

As result, OMU began to provide high-speed fiber services to commercial customers, and later started thinking about lower cost options, such as wireless. The idea was to extend the backbone using point-to-point wireless backhaul units. The cost of extending the backbone using fiber to reach a remote water tower would be in the range of

$15,000-$20,000. However, a wireless backhaul unit could perform this task for $1,500 to $2,000.

OMU decided to extend fiber-to-the-premises broadband only to large business customers, and offer wireless high-speed Internet access to small business and residential users. They installed several wireless base stations connected to the OMU network operations center through either fiber or wireless, and then offered point-to-multipoint wireless access (at a cost of $900 per subscriber). The projected subscriber limit per wireless access unit was 85, but actually reached only 70 subscribers each.

As OMU began developing external broadband services, many of its employees interested in computers came forward and said they were very excited about getting into what they called the "telecom group". While OMU officials thought they would need to hire experienced people from outside, many positions came to be filled with OMU employees, plus a few highly trained hires such executive and department heads from outside. One example of the latest was OMUs telecommunications supervisor, who already had founded and sold his share of an ISP before coming to work at the utility.

OMU decided to launch a residential wireless pilot program in 2001. The commission approved the program, which was completed during the second week of August of 2002. While the utility commission took the first two weeks of September to review the plan, OMU employees underwent customer-service training, orientation, and information sessions. The utility commission gave approval to proceed by mid-September, and contractors started installing antennas the third week of September 2002.

By the end of 2002 OMU had 22 customers for fiber-based broadband, and 55 wireless customers[83]. Then, between the third week of September 2002 and mid-March 2003, OMU initiated a marketing plan oriented primarily towards residential and commercial customers located within the OMU electric service territory. At the end of March 2003, OMU started marketing to residential and commercial consumers outside its service area.

The phase of installations for new consumers within OMU's service territory also started by mid-September 2002 and was completed in June 2003. Also, March 2003 marked the beginning of installations to include customers outside its service area.

As result of these efforts, OMU had more than a thousand broadband users by 2003. A year later, the utility counted more than 2,000 wireless residential and small

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[83] OMU's Annual Report 2002, See http://www.omu.org/AboutOMU/AnnualReport2002.pdf

businesses users in an area of about 20 square miles, and about 200 large companies with fiber-based broadband. **Table A4-1** and **A4-2** show the various services offered by OMU.

Gross revenues from broadband operations accounted for $1.2 million in fiscal year 2004, and $1.6 in fiscal year 2005. In May 2005, Owensboro was named a "Broadband Boomtown" by *Business 2.0* magazine.

**Table A4-1**: OMU Wireless Services

| | *Residential Wireless* | *Wireless Commercial Basic* | *Wireless Commercial Premium* | *Wireless Commercial VL* |
|---|---|---|---|---|
| *Download speed* | *512 Kbps* | *512 Kbps* | *512 Kbps* | *1.5 Mbps* |
| *Upload Speed* | *128 Kbps* | *128 Kbps* | *128 Kbps* | *128 Kbps* |
| *Price* | *$29.99* | *$49.99* | *$49.99* | *$84* |
| *Plus* | | | *Static IP address, 50 email addresses and, 100 MB of web space* | |

Sources: http://www.omu.org/Services/index.htm

**Table A4-2**: OMU Fiber Optic Services

| | *Point-to-Point 1* | *Point-to-Point 2* | *Point-to-Point 3* | *Wideband Broadband* | *NarrowBand Broadband* | *Dark Fiber* |
|---|---|---|---|---|---|---|
| *Accessible bandwidth (Ethernet)* | *10 Mbps* | *100 Mbps* | *1 Gbps* | *1.544 Mbps (T1)* | *512 Mbps* | *--* |
| *Price* | *$299* | *$479* | *$779* | *$400* | *$150* | *$500* |
| *Fixed* | *$1000 first circuit, $500 each additional* | | | *$375 first circuit, $149 each additional* | | *$1000 First mile, $250 additional mile* |

Source: http://www.omu.org/OMUOnline/fiber-pricing.htm

## Reaction from Incumbents

Following OMU's initial investment, Adelphia--a local incumbent--made significant capital investments to upgrade their fiber-based services. Bellsouth, the incumbent telephone company, was very aggressive, lowering prices for Digital Subscriber Lines (DSL) and offering six-month low rate packages and bundled services. Additionally, Kentucky's House Bill 337 is written to deregulate telephone services, with exception of basic telephone lines[84]. According to OMU officials, this bill would allow Bellsouth to put all their services out of regulation, with the exception of basic telephone.

### Funding

OMU invested nearly $1.5 million for a SCADA system from its own funds, and an additional $11 million for the deployment of the external broadband services (Gillett 2006). The wireless pilot program cost $50,000.

### Impact

No formal study of impact has been conducted in the town. The deployment of broadband, however, has had important effects on the Owensboro Medical Health System (OMHS) and among schools.

OMHS has capacity of 469 beds. It has deployed wireless intelligent information systems within its premises and created HealthPark, which includes the operation of the TechnoGym Research Center that incorporates innovative software and hardware, using wireless technology for the operation of a personalized training system. Powered by OMU, the hospital installed an internal wireless system that allows doctors and nurses to access all patient information, and as well as managing different stages of a patient's life (scheduling, admitting, charging, etc.). In this context, the city's wireless network allows remote monitoring of patients with chronic conditions. OMHS has also saved considerable amounts of money by converting its telephone system to voice over Internet Protocol (VoIP). From the perspective of education, Owensboro's community network enabled the deployment of online education and training, employment information, and monitoring.

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[84] See http://www.lrc.ky.gov/record/06RS/HB337.htm

# Appendix 5 : Tables from Econometric Analysis

This appendix includes the tables created through quantitative analysis. As stated in Chapter 5, the econometric analysis was performed using Matched Sample Estimators method. This method is coded into the Nnmatch command for the STATA statistical software.

The following tables are the result of using the Nnmatch command with the option of creating an output for the average values for the treatment and control groups.

**Appendix 5.1**: Effect of IT-Based Internal Systems on Customer Service, Support, and Information Costs per MWh, 2003

(A) Effect of IT-Based Internal Services

| | | MEU_Int2K Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=421 | CSSIe03 | -0.3572 | -3.85 | 0.000 |

| | | Treatment MEU_Int2K=1 | | Control MEU_Int2K=0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | CSSIe03 | 0.38 | 0.4737245 | 0.54 | 0.89 |
| Matching Variables | CSSIe2K | 0.38 | 0.4224147 | 0.14 | 4.71 |
| | Pop2K | 48108.62 | 75633.85 | 86924.97 | 288892.60 |
| | PurPower2K | 86.12% | 0.2594776 | 86.44% | 26.12% |
| | Steam2K | 11.58% | 0.2380491 | 10.40% | 23.22% |
| | Hydro2K | 0.15% | 0.0086923 | 0.17% | 0.94% |
| | IncPC2K | 18639.32 | 3250.56 | 18846.20 | 4591.73 |
| | Rent2K | 500.37 | 108.3781 | 502.13 | 141.07 |

(B) Effect of IT-Based Internal Services, computed for the sub-sample that has deployed External Broadband Services

| | | MEU_IntBB Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=44 | CSSIe03 | -1.441055 | -6.73 | 0.000 |

| | | Treatment MEU_IntBB=1 | | Control MEU_IntBB=0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | CSSIe03 | 0.6837 | 0.5719 | 0.7477 | 1.1868 |
| Matching Variables | CSSIe2K | 0.6434 | 0.6057 | -1.0612 | 10.6605 |
| | Pop2K | 77091.64 | 112496.9 | 74284.73 | 65393.47 |
| | PurPower2K | 71.15% | 33.81% | 72.71% | 33.35% |
| | Steam2K | 23.60% | 32.34% | 21.19% | 27.96% |
| | Hydro2K | 0.16% | 0.81% | 0.00% | 0.00% |
| | IncPC2K | 19630.93 | 3872.90 | 19073.68 | 6749.77 |
| | Rent2K | 553.97 | 128.31 | 583.0227 | 157.11 |

MEU_IntBB==0 includes only MEUs without internal IP-enabled services and without MEU-based broadband

### (C) Efficiency Effect of Deploying Broadband Services on MEUs that deployed IT-Based Internal Systems

|  |  | MEU_IntBB Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=76 | CSSIe03 | -0.00801 | -0.04 | 0.964 |

|  |  | Treatment MEU_IntBB=1 |  | Control MEU_IntBB=0 |  |
|---|---|---|---|---|---|
|  | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | CSSIe03 | 0.5895 | 0.5742 | 0.4797 | 0.5244 |
| Matching Variables | CSSIe2K | 0.5527 | 0.5650 | 0.4982 | 0.4673 |
|  | Pop2K | 78682.93 | 114340.4 | 40169.59 | 24078.71 |
|  | PurPower2K | 71.92% | 34.42% | 71.95% | 34.96% |
|  | Steam2K | 22.91% | 32.48% | 27.04% | 35.07% |
|  | Hydro2K | 0.30% | 1.12% | 0.30% | 1.41% |
|  | IncPC2K | 18964.91 | 2981.757 | 19110.11 | 2915.452 |
|  | Rent2K | 533.31 | 119.05 | 533.54 | 99.92 |

**Appendix 5.2**: Effect of IT-Based Internal Systems on Administrative Costs and General Expenses per MWh, 2003

(A) Effect of IT-Based Internal Services

| | | MEU_Int2K Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=421 | s_Adm03 | 19.9357 | 2.48 | 0.013 |

| | | Treatment MEU_Int2K=1 | | Control MEU_Int2K=0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | s_Adm03 | 15.51 | 154.509 | 4.68 | 5.11 |
| Matching Variables | s_Adm2K | 3.93 | 3.419392 | 3.96 | 3.51 |
| | Pop2K | 42043.70 | 57313.35 | 70538.78 | 240297.70 |
| | PurPower2K | 86.79% | 0.2438795 | 86.95% | 24.72% |
| | Steam2K | 10.21% | 0.2260957 | 9.46% | 22.03% |
| | Hydro2K | 0.26% | 0.0154156 | 0.25% | 1.33% |
| | IncPC2K | 18698.77 | 4438.113 | 18911.54 | 4976.94 |
| | Rent2K | 509.00 | 119.7424 | 507.32 | 142.60 |

(B) Effect of IT-Based Internal Services, computed for the sub-sample that deployed External Broadband Services

| | | MEU_IntBB Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=44 | s_Adm03 | -0.967 | 1.89 | 0.058 |

| | | Treatment MEU_IntBB=1 | | Control MEU_IntBB=0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | s_Adm03 | 5.24 | 3.89 | 3.72 | 2.35 |
| Matching Variables | s_Adm2K | 4.99 | 3.56 | 4.02 | 2.74 |
| | Pop2K | 76001 | 100419 | 67844 | 67503 |
| | PurPower2K | 75.2% | 31.8% | 78.3% | 31.2% |
| | Steam2K | 20.0% | 30.2% | 16.9% | 26.0% |
| | Hydro2K | 0.5% | 2.1% | 0.0% | 0.0% |
| | IncPC2K | 19233.53 | 3176.85 | 18965.50 | 5753.78 |
| | Rent2K | 548.27 | 121.97 | 570.82 | 160.37 |

MEU_IntBB==0 includes only MEUs without internal IP-enabled services and without MEU-based broadband

### (C) Efficiency Effect of Deploying Broadband Services for MEUs that deployed IT-Based Internal Services

| | | MEU_IntBB Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=76 | s_Adm03 | -28.06402 | -1.35 | 0.176 |

| | | Treatment MEU_IntBB=1 | | Control MEU_IntBB=0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | s_Adm03 | 5.049 | 3.631 | 34.22 | 248.20 |
| Matching Variables | s_Adm2K | 4.692 | 3.379 | 4.751 | 3.732 |
| | Pop2K | 75452.36 | 97016.78 | 35264.46 | 22227.83 |
| | PurPower2K | 76.24% | 31.74% | 76.53% | 32.49% |
| | Steam2K | 19.62% | 30.29% | 20.13% | 32.89% |
| | Hydro2K | 0.58% | 2.07% | 0.36% | 1.24% |
| | IncPC2K | 19122.92 | 3142.405 | 19591.46 | 5343.159 |
| | Rent2K | 535.00 | 113.90 | 534.55 | 122.17 |

## **Appendix 5.3**: Effect of IT-Based Internal Systems on Price per MWh, 2003

### (A) Effect of IT-Based Internal Services

| | | MEU_Int2K Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=421 | PMwh03 | -1.542 | -1.73 | 0.084 |

| | Variable | Treatment MEU_Int2K=1 Mean | Std. Dev. | Control MEU_Int2K=0 Mean | Std. Dev. |
|---|---|---|---|---|---|
| Dep. Variable | PMwh03 | 65.41 | 13.93386 | 66.12 | 17.17 |
| Matching Variables | PMwh2K | 63.50 | 14.9204 | 63.57 | 16.50 |
| | Pop2K | 40,144 | 56,546 | 62,349 | 221,913 |
| | PurPower2K | 87.67% | 0.2382543 | 87.35% | 24.38% |
| | Steam2K | 9.71% | 0.2217006 | 9.20% | 21.74% |
| | Hydro2K | 0.25% | 0.0151956 | 0.23% | 1.30% |
| | IncPC2K | 18679.77 | 4139.556 | 18863.01 | 4703.07 |
| | Rent2K | 503.44 | 112.662 | 507.78 | 134.61 |

### (B) Effect of IT-Based Internal Services, computed for the sub-sample that deployed External Broadband Services

| | | MEU_IntBB Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=44 | PMwh03 | -3.67486 | -2.23 | 0.026 |

| | Variable | Treatment MEU_IntBB=1 Mean | Std. Dev. | Control MEU_IntBB=0 Mean | Std. Dev. |
|---|---|---|---|---|---|
| Dep. Variable | PMwh03 | 65.57 | 15.58 | 67.20 | 19.26 |
| Matching Variables | PMwh2K | 63.61 | 15.78 | 64.59 | 18.02 |
| | Pop2K | 52936.11 | 84153.96 | 108476.8 | 384373.7 |
| | PurPower2K | 79.06% | 30.31% | 79.69% | 30.48% |
| | Steam2K | 16.68% | 28.93% | 17.41% | 28.60% |
| | Hydro2K | 0.26% | 01.66% | 0.06% | 0.25% |
| | IncPC2K | 19176.62 | 3254.68 | 19384.27 | 5202.53 |
| | Rent2K | 539.37 | 127.00 | 549.37 | 164.88 |

MEU_IntBB==0 includes only MEUs without internal IP-enabled services and without MEU-based broadband

### (C) Efficiency Effect of Deploying Broadband Services on MEUs that deployed IT-Based Internal Systems

| | | MEU_IntBB Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=76 | PMwh03 | 0.94245 | 0.27 | 0.790 |

| | | Treatment MEU_IntBB=1 | | Control MEU_IntBB=0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | PMwh03 | 65.55 | 14.57209 | 66.73 | 15.76846 |
| Matching Variables | PMwh2K | 63.68 | 16.2076 | 66.15 | 15.44682 |
| | Pop2K | 76771.24 | 95635.88 | 32974.28 | 21697.07 |
| | PurPower2K | 76.66% | 31.90% | 78.70% | 33.34% |
| | Steam2K | 18.76% | 29.84% | 19.00% | 33.22% |
| | Hydro2K | 0.51% | 2.01% | 0.29% | 1.18% |
| | IncPC2K | 18950.26 | 3030.881 | 19215.55 | 5371.655 |
| | Rent2K | 530.72 | 105.3828 | 531.90 | 125.7959 |

## **Appendix 5.4**: Effect of Municipal Broadband on Growth of Business Establishments

### (A) Growth Rate of Business Establishments 2000-2002, Unrestricted

|  |  | Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=1,314 | lnrEst | 0.01534 | 2.79 | 0.005 |

|  |  | Treatment BB2K =1 |  | Control BB2K =0 |  |
|---|---|---|---|---|---|
|  | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | lnrEst | 0.0207 | 0.0417 | 0.0070 | 0.0933 |
| Matching Variables | Pop2K | 19391 | 112474 | 12939 | 56976 |
|  | grEst9498 | 0.0593 | 0.1018 | 0.0680 | 0.1509 |
|  | URinfl03 | 5.2291 | 3.2649 | 5.3409 | 3.3543 |

### (B) Growth Rate of Business Establishments 2000-2002, Restricted by Presence of Private Providers

|  |  | Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=1,149 | lnrEst | .0126931 | 2.31 | 0.021 |

|  |  | Treatment BB2K=1 |  | Control BB2K =0 |  |
|---|---|---|---|---|---|
|  | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | lnrEst | 0.0195 | 0.0416 | 0.0085 | 0.0845 |
| Matching Variables | Pop2K | 17883 | 111341 | 13285 | 57170 |
|  | grEst9498 | 0.0616 | 0.0990 | 0.0704 | 0.1489 |
|  | URinfl03 | 5.0661 | 3.231 | 5.1749 | 3.3367 |

## **Appendix 5.5**: Effect of Municipal Broadband on Percentage of Business Establishments in IT-Intensive Sectors

### (A) Percentage of Business Establishments in IT-Intensive Sectors 2000-2002, unrestricted

| | | Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=1,314 | ptotIT02 | -0.00308 | -0.88 | 0.380 |

| | | Treatment BB2K =1 | | Control BB2K =0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | ptotIT02 | 0.2254 | 0.0479 | 0.2225 | 0.0622 |
| Matching Variables | Pop2K | 19894 | 111412.6 | 12499.57 | 55790.24 |
| | pIT98 | 0.2305 | 0.0435 | 0.2233 | 0.0577 |
| | grColl90s | 0.3390 | 0.3068 | 0.3700 | 0.7186 |
| | pcollege2K | 17.3071 | 7.6131 | 16.5374 | 8.9505 |
| | grpIT9800 | 0.0016 | 0.1066 | 0.0108 | 0.1646 |
| | URinfl03 | 5.0556 | 3.1109 | 5.3356 | 3.3591 |

### (B) Percentage of Business Establishments in IT-Intensive Sectors 2000-2002 in Locations where Private Providers were also Present

| | | Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=1,149 | ptotIT02 | -.0028115 | -0.82 | 0.410 |

| | | Treatment BB2K =1 | | Control BB2K =0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | ptotIT02 | 0.2257 | 0.0473 | 0.2225 | 0.0599 |
| Matching Variables | Pop2K | 19462.07 | 111506.7 | 12880.56 | 56622.73 |
| | pIT98 | 0.2306 | 0.0428 | 0.2234 | 0.0550 |
| | grColl90s | 0.3479 | 0.3108 | 0.3820 | 0.7105 |
| | pcollege2K | 17.46 | 7.69 | 16.87 | 9.04 |
| | grpIT9800 | 0.0016 | 0.1071 | 0.0110 | 0.1635 |
| | URinfl03 | 4.87 | 3.08 | 5.16 | 3.34 |

**Appendix 5.6**: Effect of Municipal Broadband on Growth of Employment

(A) Growth Rate of Employment 2000-2002, unrestricted

| | | Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=1,314 | lnrEmplo | 0.0185 | 1.07 | 0.285 |

| | | Treatment BB2K =1 | | Control BB2K =0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | lnrEmplo | -0.0199 | 0.1495 | -0.0292 | 0.2463 |
| Matching Variables | Pop2K | 17127 | 112445 | 13070 | 57018 |
| | gEmp9498 | 0.0869 | 0.1703 | 0.1424 | 1.0411 |
| | URinfl03 | 5.2725 | 3.2736 | 5.3364 | 3.3573 |

(B) Growth Rate of Employment 1998-2002 in Locations where Private Providers were also Present

| | | Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=1,149 | lnrEmplo | .0237065 | 1.38 | 0.168 |

| | | Treatment BB2K =1 | | Control BB2K =0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | lnrEmplo | -0.0153 | 0.1461 | -0.0305 | 0.2310 |
| Matching Variables | Pop2K | 15605.19 | 111240.8 | 13440 | 57234.43 |
| | gEmp9498 | 0.0899 | 0.1655 | 0.1481 | 1.1084 |
| | URinfl03 | 5.1114 | 3.2534 | 5.1697 | 3.3399 |

## **Appendix 5.7**: Effect of Municipal Broadband on Salary Growth

### (A) Growth Rate of Salary 2000-2002, unrestricted

| | | Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=1,314 | LnrSalary | 0.00168 | 0.09 | 0.929 |

| | | Treatment BB99=1 | | Control BB99=0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | LnrSalary | 0.0756 | 0.1044 | 0.0769 | 0.1467 |
| Matching Variables | Pop2K | 20414 | 111123 | 12525 | 55882 |
| | grColl90s | 0.3220 | 0.3078 | 0.3699 | 0.7188 |
| | grSalary9498 | 0.1577 | 0.0955 | 0.1735 | 0.1977 |
| | pcollege2K | 17.6253 | 8.3406 | 16.5283 | 8.9956 |
| | grLabor90s | 0.0831 | 0.1461 | 0.0957 | 0.2266 |
| | URinfl03 | 5.0852 | 3.2035 | 5.3402 | 3.3582 |

### (B) Growth Rate of Salary 1998-200 2in Locations where Private Providers were also Present

| | | Coefficient | z-statistic | P>\|Z\| |
|---|---|---|---|---|
| N=1,149 | LnrSalary | .0026319 | 0.14 | 0.888 |

| | | Treatment BB99=1 | | Control BB99=0 | |
|---|---|---|---|---|---|
| | Variable | Mean | Std. Dev. | Mean | Std. Dev. |
| Dep. Variable | LnrSalary | 0.0779 | 0.1025 | 0.0768 | 0.1368 |
| Matching Variables | Pop2K | 19728.69 | 111331.8 | 12939.82 | 56735.56 |
| | grColl90s | 0.3264 | 0.3152 | 0.3813 | 0.7104 |
| | grSalary9498 | 0.1550 | 0.0971 | 0.1679 | 0.1924 |
| | pcollege2K | 17.8362 | 8.5136 | 16.8678 | 9.1013 |
| | grLabor90s | 0.0854 | 0.1443 | 0.0970 | 0.2265 |
| | URinfl03 | 4.9321 | 3.1985 | 5.1749 | 3.3419 |

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