Economies of scale in ICT: how to balance infrastructure and applications for economies of scale in ICT and business

Woudstra, U.A.

ECONOMIES OF SCALE IN ICT

HOW TO BALANCE INFRASTRUCTURE AND APPLICATIONS FOR ECONOMIES OF SCALE IN ICT AND BUSINESS

This study offers new insight into the economies of scale of ICT departments. Drawing from data on Housing Corporations, Municipalities and Hospitals, evidence was found that particularly infrastructure-related investments leverage a more efficient use of ICT resources. The measured economies between low and high infrastructure spending organizations are on average more than 20% for their operational ICT labour and for their total ICT costs. It was also found that organizations should spend a certain minimum of their ICT expenditure on applications to realize economies of scale in their business processes.

The author, Ulco Woudstra, has occupied various ICT management positions in different organizations, among which Philips Electronics, Delft Hydraulics, and Getronics. Currently he works as an information manager at the Amphia hospital.

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ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Universiteit van Amsterdam
op gezag van de Rector Magnificus
prof. dr. D.C. van den Boom
ten overstaan van een door het college voor promoties
ingestelde commissie,
in het openbaar te verdedigen in de Aula der Universiteit
op vrijdag 3 december 2010, te 13:00 uur

door

ULCO ANNE WOUDSTRA

geboren te Sneek

Promotiecommissie

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Faculteit Economie en Bedrijfskunde

Printed and bound by Ridderprint BV
ISBN: 978-90-5335-321-9

There is much pleasure to be gained from useless knowledge

Bertrand Russell

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LIST OF ABBREVIATIONS

Abs prod	Absolute productivity
Comb	Combined scale for measurement of ICT assets
CS	Combined scale for measurement of ICT assets
DEA	Data Envelopment Analysis
DEA prod	Productivity according to DEA
FTE	Full Time Equivalents
FTE op	FTE Operations ICT
HC	Housing Corporations
HIR	Human Information Resources
HW	Hardware
Hosp	Hospital
ICT Cost	Total ICT cost
IF	Infrastructure Factor (infrastructure part (including labour) of total ICT cost)
IF av	Average IF
M	Municipalities
MF	Maturity Factor ICT organization
Mun	Municipalities
SW	Software
TIR	Technical Information Resources (HW/SW (excluding labour) cost)
WS	Workstations (number of)

ACKNOWLEDGEMENTS

The idea to write a thesis was born around the year 2000, in the time that I was manager operations at DIV, an application service provider for 10 hospitals and other healthcare organizations. I noticed there were important economies of scale compared with hospitals that managed their own ICT operations. I talked about this idea with Maarten Looijen, who published at that time an article about the relation between the complexity of the ICT and the therefore required ICT management. His article brought me to the concepts of the first hypothesis in this thesis. As Maarten Looijen was about to leave as emeritus professor, I started my research in 2003 with professor Jan Dietz and Marcel Spruit at Delft University, who helped me with the first steps of my scientific research journey. In 2004 I continued this journey at the University of Amsterdam with professor Rik Maes and professor Guido Dedene. I allowed myself lucky that Guido Dedene was my teacher, as his control of my knowledge creation process was just what I needed: focus on the big picture and adjustment on the important aspects. In 2006 I got the opportunity to obtain empirical data concerning housing corporations, municipalities and hospitals via Patrick van Eekeren, partner of M&I/Partners. These data form the base of the empirical verification of my hypotheses. Besides I met Egon Berghout, professor at Groningen University and associate partner of M&I/Partners, with whom I wrote an article about my research. His ideas have inspired me to extend the scope of the research from ICT productivity to business productivity.

Besides the persons and organizations I already mentioned, I want to thank a number of people that contributed to this research. First of all Cock Schipper and Eric Polman who created the opportunity to combine a job of information manager at the ICT department of the Amphia hospital with my research activities. I want to thank the other colleagues of the Amphia ICT department, especially Anneke van Praet for the tips and tricks in Word. I want to mention my children: Raúl and Leonie for being paranimph and Saskia for the methodological discussions. And above all my wife Emmy, who convinced me to start this research and who shared this scientific journey with me during these inspiring years.

Ulco Woudstra
Roosendaal, juli 2010

PREFACE

Nowadays information and communication technology (ICT) plays a more and more important role in organizations. This requires an increasing availability of a complex system of hardware/software and an ICT organization with human resources that have the right knowledge. The complexity of the hardware/software system is a result of the way in which standardized components are assembled into an organization-specific ICT system. The more complex the hardware/software system, the higher the ICT expenditure, not only for hardware/software, but also for ICT human resources. In this thesis I will demonstrate why standardization of hardware/software is the key to limit ICT complexity and therefore ICT expenditure. The complexity of the ICT organization can be limited by the structuring and standardization of the organizational processes. It is in general assumed that a higher level of standardization of ICT processes will lead to a more efficient ICT organization and therefore lower expenditure for ICT human resources. In this thesis I will investigate how the complexity of hardware/software and the complexity of the ICT organization can be limited by standardization in hardware/software and by standardization of organizational processes. This is the first research as I know in which the relation between scale and complexity in ICT is explicitly defined and measured. Economies and diseconomies of scale are conceptualized as a result of the relation between scale and complexity.

The technological development in ICT provides a continuous supply of new products that must be integrated in the hardware/software system of an organization. Thanks to Moore's law the technical and economic lifetime of existing products is relatively short and the ICT organization is permanently faced with the dilemma of integration versus replacement. Very often new applications have overlapping functionality with existing applications and use another infrastructure platform, which makes this dilemma more difficult. There is often a disagreement between the ICT organization and the user organization about the desirability of these applications: users emphasize the importance for the business and ICT people underline the complexity and the cost of ICT management. The users think in terms of business yield and expenditure, while ICT people in general think in terms of ICT yield and expenditure. Users want to optimize applications and ICT people want to optimize infrastructure, which leads to less ICT complexity. In organizations with low ICT budgets there is always a tension between the spending on applications and on infrastructure. If the infrastructure is neglected, then high ICT complexity and corresponding expenditure for ICT human resources will be the consequence. On the other hand, too low spending on applications leads to insufficient business support by applications. Therefore the balance of infrastructure and applications is important for economies of scale in ICT and business.

A more fundamental way to reduce the ICT complexity is standardization of business processes and standardization of data. If business processes are redesigned according to the possibilities of standardized applications (like SAP), then the number of applications can be reduced. If interfaces between applications can be standardized (for example according to the rules of an international standardization organization), then the number of interfaces between applications can be reduced. An example is the initiative of the IHE (2010) which aims to reduce complexity integrating the healthcare enterprise. This approach to reduce complexity lies however outside the scope of this research.

In chapter 1.5 an overview is given of this thesis.

SUMMARY

For ICT management economies of scale are becoming increasingly important, because as the technology matures, particularly its cost-efficient application becomes crucial. This study offers new insight into the economies of scale of ICT departments. We found evidence that particularly infrastructure related investments leverage more efficient use of ICT resources. In this research, the relationships between *ICT management policies*, *ICT assets, and ICT expenditure* have been analyzed. Drawing from data on Housing Corporations, Municipalities and Hospitals, we found evidence that in these relatively low ICT spending organizations, ICT infrastructure expenditure appears to be the most important ICT management policies criterion. The measured economies between low and high infrastructure spending organizations are on average more than 20% for their operational ICT labour and for their total ICT costs. A second ICT management policies criterion investigated in this research was the maturity of the ICT organization, as measured according to COBIT 4.0. A positive relation between ICT expenditure and the maturity of the ICT organization could, however, hardly be validated.

We have also analyzed the relation between *ICT management policies*, *ICT assets, and Organization performance,* and concluded that Housing Corporations should spend a certain minimum of their ICT expenditure on applications, to realize economies of scale in their Business processes. Practically, it is suggested that Housing Corporations should spend as a minimum 42% of their ICT expenditure on infrastructure (costs defined as the sum of hardware, software and human resources). Besides, a minimum of 47% should be spent on applications. For Hospitals a comparable advice is to spend as a minimum 54% on infrastructure and as a minimum 42% on applications. In this research we could not determine percentages for Municipalities, as the available data did not permit us to draw a conclusion. The theoretical contribution of this research lies in the formulation of a definition of the Efficacy of ICT management policies and the measurement of this construct. The analysis of the ICT and business productivity is based upon theories about systems, cybernetics and complexity. We introduce a new method to measure the relationship between the Efficacy of ICT management policies and cost savings in ICT and business processes by economies of scale.

1 INTRODUCTION

1.1 Introduction

ICT infrastructure has become more and more ‘commoditized’, and even application software, once largely custom-developed, is nowadays increasingly being offered as a package or service. As the technology matures, particularly its cost-efficient application becomes crucial. The question then arises whether more could be done with less. If all organizations had access to the same technology, would they offer similar services at similar cost levels? Is it possible to conduct smarter management approaches to outrun the competition, even if the technology applied is similar? Should organizations cooperate, merge or outsource to increase scale? And at which point will the coordination costs become counterproductive? In order to answer these questions the issue of ICT economies of scale should be addressed. For ICT management economies of scale are becoming increasingly important, because as the technology matures, particularly its cost-efficient application becomes crucial (Carr 2003). This study offers new insight into the economies of scale of ICT departments. We found evidence that particularly infrastructure-related investments leverage a more efficient use of ICT resources. In this research, the relationships between *the efficacy of ICT management policies*, *ICT expenditure,* and *the scale of ICT assets* will be analyzed. Although there are several publications about economies of scale in software development, for example, Boehm and Sullivan (1999) and Kitchenham (2002), only a few publications are available about economies of scale effects in ICT management. Barron (1992) is one of the exceptions in this area. The scope of this research focuses on the ability of ICT management to attain economies of scale by converting ICT expenditure into ICT assets.

In this study the definition of ICT assets as presented by Soh and Markus (1995) is used: the whole of applications, ICT infrastructure, and user knowledge and skills within an organization. The efficacy of ICT management policies is defined as the ability of ICT management to govern an efficient and effective conversion from operational ICT expenditure to ICT assets. This implies that effective policies create the conditions for an efficient and effective ICT conversion process. Our basic hypothesis is that economies of scale in ICT can only be realized if the investments in ICT infrastructure are above a certain level. Infrastructures are shared by many applications and have long time spans, which requires a long-term strategic view of the ICT management (Weill and Broadbent 1998). Organizations with a “utility view” on ICT (with lower levels of ICT spending) should invest in infrastructure and transactional applications (Weill and Broadbent 1998). We would expect that organizations with lower levels of ICT spending can only realize economies of scale in ICT if their ICT infrastructure spending is sufficient. If their infrastructure expenditures are insufficient, diseconomies of scale might be the result. There is however an upper limit on the infrastructure share of ICT spending: if the investment in applications is insufficient, there is insufficient support of business processes. The necessity of investments in applications can be determined via an Information Systems Health Grid (Weill and Broadbent 1998; Weill and Vitale 1999). Therefore the ICT management must find an optimal balance between investments in infrastructure and in applications.

In this research we will first investigate the relationship between the level of infrastructure investments in ICT and economies of scale. Secondly, we will examine the connection between COBIT 4.0 maturity and economies of scale. Subsequently, we will compare which of the two factors, infrastructure or COBIT 4.0 maturity, currently provides the best opportunities to foster economies of scale in ICT.

1.2 Research Aim and Questions

Soh and Markus (1995) have developed a conceptual framework, which posits that ICT expenditure leads to ICT assets (ICT conversion process), ICT assets to ICT impacts (ICT use process), and ICT impacts to organization performance (competitive process), see Figure 1.1. Our research focuses on the first part of this model, the conversion process of ICT expenditure into ICT assets by ICT management. A more proficient ICT conversion process implies lower ICT expenditure, given similar scales of ICT assets. There may be many inefficiencies in this conversion process, for instance, negative influences of vendors, poor ICT management policies, inconsistent application of good policies, or self-interested behaviour (Soh and Markus 1995).

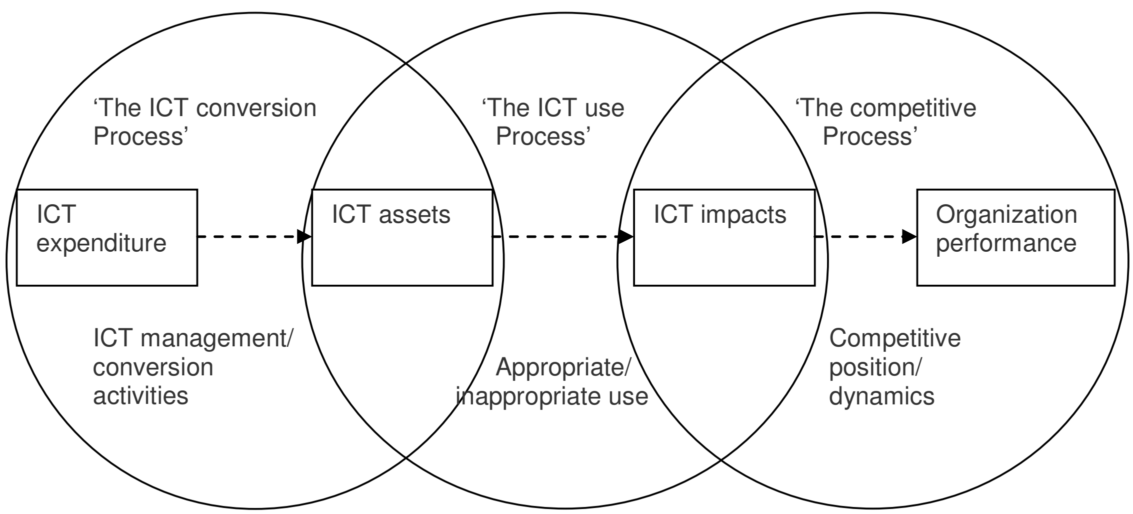


Figure 1.1 How ICT creates Business value: a process theory

In this research the efficacy of ICT management policies is defined as the ability of ICT management to govern an efficient and effective conversion from operational ICT expenditure to ICT assets. This implies that effective policies create the conditions for an efficient and effective ICT conversion process. We will investigate the relationships between ICT expenditure, efficacy of ICT management policies and scale of ICT assets. The model underlying these relations is a reflection of the productivity of the operational ICT conversion process, as represented in Figure 1.2, where:

Productivity = output / input (Chew 1988)

Therefore, the productivity of the ICT conversion process equals: scale of ICT assets / ICT expenditure. The ICT conversion process is governed by the ICT management policies in the sense that a higher efficacy of ICT management policies results in a higher productivity of the operational ICT conversion process. A higher efficacy of ICT management policies should thus result in a certain scale of ICT assets at lower ICT expenditure, or vice versa in a higher scale of ICT assets at the same ICT expenditure. This 'economies of scale' effect is an important tool for the optimal use of resources. The relations of these concepts are illustrated in Figure 1.2: the influence of the efficacy of ICT management policies, concerning technology and ICT organization, on (dis)economies of scale is represented by arrows: more effective ICT management policies have positive (+) effects on economies of scale and negative (-) effects on diseconomies of scale.

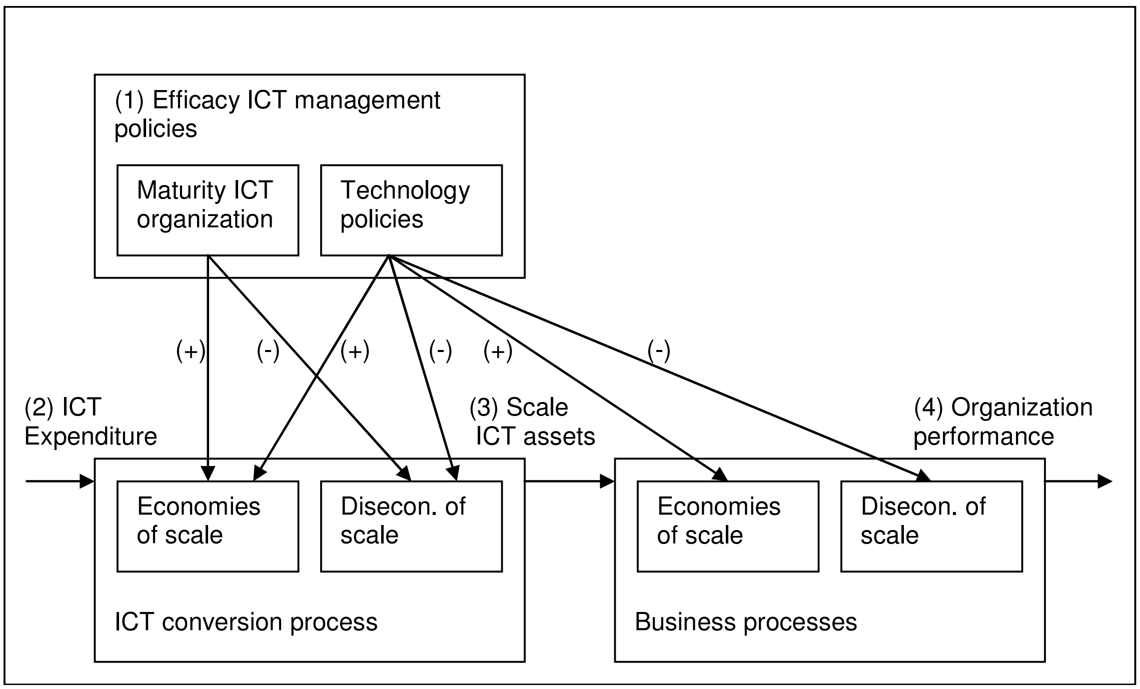


Figure 1.2 Relations among constructs

In our research we do not measure the ICT impacts and define "Business processes" as the conversion from ICT assets (input) to Organization performance (output), see Figure 1.2. We define the productivity of the Business processes as the quotient: organization performance / scale ICT assets. The business productivity is also influenced by ICT management policies, in the sense that different ICT management policies lead to a different composition of ICT assets, which leads to a different support of business processes, which leads to different organization performance. If the technological policy is primarily focused at the ICT infrastructure, then the productivity of the ICT conversion process will be optimized. However, if the policy is focused at the ICT applications, then the productivity of the business processes will benefit (Bharadwaj 2000; Kim 2004; Karimi et al 2007). This research is directed primarily at the productivity of the ICT conversion process and secondarily at the productivity of the business processes. The validity of the research is however improved when ICT assets as the *output* of the ICT conversion process are simultaneously considered as the *input* of the business processes, as will be explained in chapter 4.

1.2.1 Research aim

This PhD research aims at enhancing our understanding of the efficacy of ICT management policies, concerning technology and ICT organization, primarily in relation to the productivity of the ICT conversion process and secondarily in relation to the productivity of the business processes.

1.2.2 Research questions

To adequately fulfill this research aim, a number of research questions have been formulated concerning the basic constructs as represented in Figure 1.2: (1) efficacy of ICT management policies, (2) ICT expenditure and (3) scale of ICT assets. Furthermore we define a theoretical construct, complexity of ICT assets, that will be used to translate the (3) scale of ICT assets to (2) ICT expenditure. Finally (4) organization performance is defined in order to determine the productivity of the business processes.

The research questions are defined as follows:

1) How can the productivity of the ICT conversion process be defined and measured?
2) How can efficacy of ICT management policies be defined and measured?
    a. Concerning ICT infrastructure.
    b. Concerning ICT organization.
3) How can the scale of ICT assets be defined and measured?
4) How can the complexity of ICT assets be defined and measured?
5) How can ICT expenditure be defined and measured?
6) What is the relation between the scale and the complexity of ICT assets?
7) What is the relation between the complexity of ICT assets and ICT expenditure?
8) What is the influence of the efficacy of ICT management policies on the productivity of the ICT conversion process?
9) How can organization performance be defined and measured?
10) How can the productivity of Business processes be defined and measured?
11) What is the influence of the efficacy of ICT management policies on the productivity of the Business processes?

1.3 Research contributions

1.3.1 Theoretical relevance

By developing and testing a theory on the relationships between *the efficacy of ICT management policies, ICT expenditure,* and *the scale of the ICT assets* this PhD research contributes to existing literatures in several ways. First, previous literatures have highlighted economies of scale in software development (e.g. Banker and Kemerer 1989; Kitchenham 2002). Very few studies, however, have actually investigated economies of scale effects in ICT management. The theoretical contribution of this research can be found in the definition and measurement of the efficacy of ICT management policies. In addition, a new methodology has been introduced to analyze the relation between the efficacy of ICT management policies and cost savings in ICT by economies of scale. Secondly, this study confirms the view of Aral and Weill (2007) that organizations with a lower ICT expenditure level should spend relatively more on their ICT infrastructure. This is the first study that applies in-company firm data, which are superior to stock data, to this type of analysis. Using empirical data on Housing Corporations, Municipalities and Hospitals, support has been found to demonstrate economies of scale with respect to ICT assets for (comparable) organizations with a high efficacy of ICT management policies. Furthermore, we have demonstrated diseconomies of scale for organizations with a low efficacy of ICT management policies. Thirdly, our study contradicts Carr's notion of ICT as a commodity, as the effective deployment of ICT is by no means straightforward. In this study the efficacy of ICT management policies appeared to be highly dependent on the percentage of ICT infrastructure investments. In other words, large scale infrastructure investments are a prerequisite for the efficient use of ICT (and not vice versa). The analysis presented in this study has clearly produced new and valuable insights into the realization of effective ICT management policies. Besides, the relation between *the efficacy of ICT management policies*, *the scale of the ICT assets,* and *Organization performance,* is analyzed: organizations have to spend enough on applications, to realize economies of scale in their Business processes. In this research we have used a number of different methods to analyse the data, in order to realize an internal validity as high as possible. In the methodology we distinguish between a global and a detailed analysis (see Figure 4.4). The *global* analysis consists of Partial Least Square (PLS) regression (Gefen et al 2002) and linear regression to obtain a global view regarding the validity of the hypotheses. The detailed methodology uses power regression and is based upon two ways of determining the productivity: the *absolute* productivity and the *relative* productivity. For the determination of the relative productivity we use Data Envelopment Analysis, a technique that is suitable for benchmarking comparable organizations (Charnes et al 1978).

1.3.2 Practical relevance

Drawing from data on Housing Corporations, Municipalities and Hospitals, we found evidence that in these relatively low ICT spending organizations, ICT infrastructure expenditure appears to be the most important ICT management policies criterion. The measured economies between low and high infrastructure spending organizations are on average more than 20% for their operational ICT labour and for their total ICT costs. A second ICT management policies criterion investigated in this research was the maturity of the ICT organization, as measured according to COBIT 4.0 (2005). A positive relation between ICT expenditure and the maturity of the ICT organization could, however, hardly be validated.

We have also analyzed the relation between *the efficacy of ICT management policies*, *the scale of the ICT assets,* and *Organization performance,* and concluded that organizations should spend a certain minimum of their ICT expenditure on applications, to realize economies of scale in their Business processes. Practically, it is suggested that Housing

Corporations should spend as a minimum 45% of their ICT expenditure on infrastructure and as a minimum 49% on applications, in order to attain economies of scale in both ICT and Business processes. For Hospitals a comparable advice is to spend between 54% and 58% on infrastructure (see Figure 4.2 for definitions of infrastructure and application costs). In this research we could not determine a percentage for Municipalities, as we have not sufficient data. In a situation where ICT is hardly more than just a utility, and where the authority of the ICT manager is generally only limited, the findings of this study may help the ICT manager convince the other managers in the organization to start focusing on infrastructure and transactional applications. We think that it is hard to generalize the specific findings of this research to all organizations with relatively low ICT spending: we can only state that neglecting sufficient investments in ICT infrastructure will probably cause diseconomies of scale in ICT processes.

1.4 Research Approach

In this section the research approach is outlined. First the process of data collection is explained, as this is performed by a consultancy firm, M&I/Partners, which gave the opportunity to the PhD researcher to participate in this process and to use the data. Afterwards we elucidate why this research is an example of positive case research. In section 4.4 the methodology is explained and in section 6.3 the limitations concerning the validity of this research are discussed.

1.4.1 Yearly investigation to collect data for research

Since 2002, consultancy firm M&I/Partners has carried out a yearly investigation to review the costs, functionality and maturity of ICT in Housing Corporations (Eekeren et al 2006). Housing Corporations are independent not-for-profit organizations, aimed at building, managing, and renting out affordable living-space. ICT in Housing Corporations concerns all aspects of the life cycle of real estate transactions. The investigation is conducted in about 74 Housing Corporations (see Table 1.1), representing around 45% of this sector in the Netherlands. The research data used cover the years 2002-2007.

A similar investigation has been held since 2004 in Municipalities. Municipalities offer a wide variety of services to their citizens, such as infrastructures, regulations, and social services. The organization of Municipalities generally reflects this variety, consisting of a conglomerate of different departments with specific functions, such as the Department of the Control of Buildings, the Department of Public Affairs, and the Department of Social Affairs. ICT as used by Municipalities is again a reflection of this variety of services and organization. The investigation was conducted in about 22 Municipalities (see Table 1.1), representing around 8% of this sector. The research data used cover the period 2004-2007.

A similar investigation has been held since 2006 to review the costs and maturity of ICT in Hospitals. The organization of a hospital can be considered as a professional bureaucracy (Mintzberg 1979), with relatively much power for the individual medical specialists, organized in partnerships per specialism. The partnerships are legally isolated from the hospital organization, which delivers services to the medical specialists. The hospital organization without the medical specialists can be considered as a machine bureaucracy

(Mintzberg 1979), with a strong hierarchical control. The hospital organization can be considered as a conglomerate of different departments, such as Emergency Medicine, Operating Rooms, Wards, Laboratories, Logistics and Finance. ICT as used by Hospitals is again a reflection of this variety of services and organization. The investigation was conducted in about 36 Hospitals (see Table 1.1), representing around 36% of this sector. The research data used cover the period 2006-2008.

Table 1.1 represents the number of years that Housing Corporations, Municipalities and Hospitals participated in the investigation. About 70% of the organizations have participated more than one year, which give the possibility to perform longitudinal analyses.

Table 1.1 Participation of organizations in the investigation

Number of years	Housing Corporations	Municipalities	Hospitals
1	24	7	11
2	20	3	5
3	8	6	5
4	10	6	
5	4		
6	8		
Total organizations	74	22	36
Median number of years	2	3	1
Average number of organizations per year	33	14	12

1.4.2 Which data is collected and how is it collected?

We will now describe the process of data collection in considerable detail, to be able to explain the research approach. The source data about ICT *costs* were collected using a cost model containing clear definitions of the ICT objects. Appendix 1 contains a more detailed description of the investigation. The data about the *maturity* of the ICT organisation are based on a self-assessment of the most relevant COBIT and ITIL processes, see Figure 4.3. Each process can be scored on a scale from 0 (the process is not organized) to 5 (the process is completely optimized). The *application availability* for the users is quantified by the number of application types, in accordance with the relevant business processes, that are supported by these application types. The weighted number of application types is determined by the product of two factors:

a) The availability of the application type: 0 (no applications), 1 (application in development) or 2 (applications operational).
b) The importance of the application type for the concerning business process: 1 (not critical for the business, can be unavailable for eventually a few weeks), 2 (important for the business, but can be unavailable for maximum one day) or 3 (critical for the business, must always be available).

These application availability data are only available for Housing Corporations: factor “a” is unique for every Housing Corporation and factor “b” is the same for all Housing Corporations.

The source data about ICT *costs* are collected by the accounting department of the concerning organization. The source data were validated by consultants of M&I/Partners in communication with the employees responsible for their management. For the measurement of the *maturity* of the ICT organization, the participants of the investigation had as a requirement that this could be executed with little effort. The self-assessment was done by three persons in every organization, which gave the scores independently of each other. Afterwards in a meeting with a consultant of M&I/Partners a definitive score was determined. The idea behind this process is that the consultant is monitoring a certain norm, and is able to redirect scores that are not comparable with other organizations. The determination of the *application availability* is relatively straightforward, provided that the concerning organization has a registration which applications are used for the different business processes.

1.4.3 Positivist versus interpretive understanding

The collection of the data about *costs* is based upon the scientific discipline of accountancy which can be positioned as a positive science (Popper 1934; Watts and Zimmerman 1990; Christenson 1983). Moreover, Housing Corporations, Municipalities and Hospitals follow the accounting rules that are mandatory for these kinds of organizations in the Netherlands. So the interpretation of these cost data should be identical for all organizations of the same type. According to Lee (1991) this kind of modelling can be considered as "positive understanding", see Figure 1.3. The determination of the level of *maturity* is subjective, as it is based on a self assessment by the participants of the investigation. This is at the level of subjective understanding in Figure 1.3 (Lee 1991). The consultants interpret the answers of the participants to apply the maturity model as good as possible. This can be placed at the level of interpretive understanding in Figure 1.3 (Lee 1991). The determination of the *application availability* is subjective, as it is based on a subjective model, determined by the consultants and the participants of the investigation type (Housing Corporations). The application availability data of Housing Corporations in year n however cannot be compared with application availability data of year n+1. This is at the level of subjective understanding in Figure 1.3. The consultants interpret the answers of the participants to apply the application availability model. This can be placed at the level of interpretive understanding in Figure 1.3.

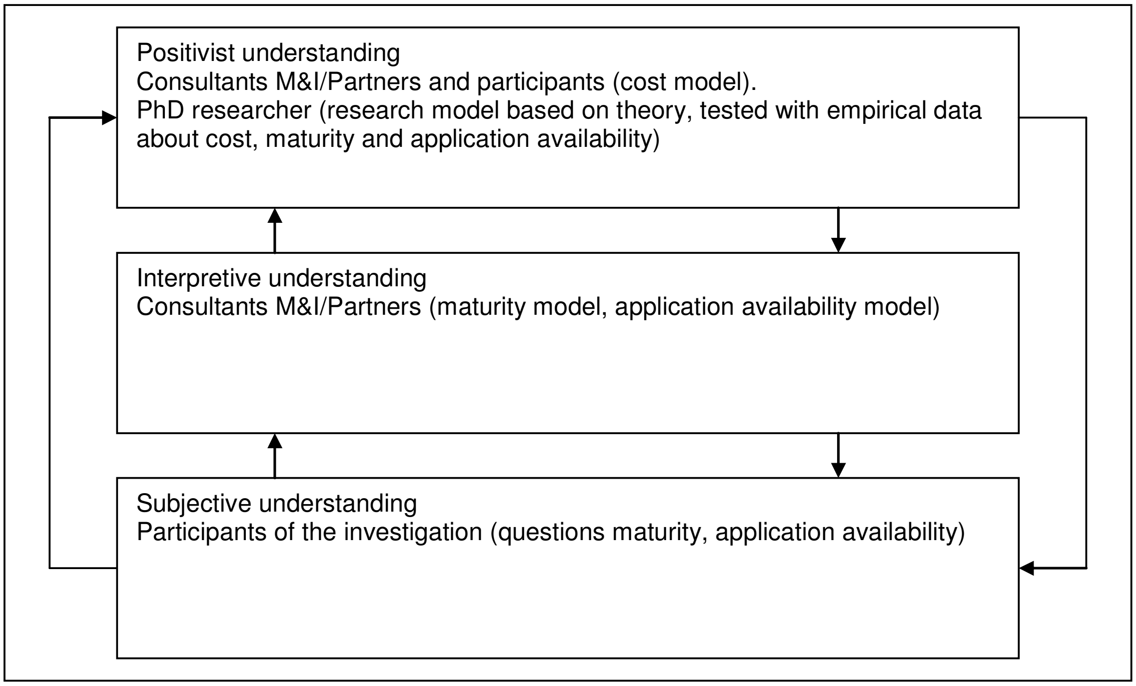


Figure 1.3 Levels of understanding

The research model of this PhD research can be positioned at the level of positivist understanding: it is based on theories about productivity; this is tested with empirical data about cost, maturity and application availability. The collection process of cost data is also at the level of positivist understanding as the interpretation and measurement of these cost data should be identical for every organization. However, the collection process of maturity data and application availability data is at the level of subjective and interpretive understanding; therefore we expect a lower level of hypothesis validation than with cost data. We will explain this by examining in more detail the three levels of understanding.

The level of subjective understanding

According to Lee the understanding at the subjective level in social sciences belongs to the observed human subjects. “This understanding consists of the everyday common sense and everyday meanings with which the human subjects see themselves, and which give rise to the behaviour that they manifest in socially construct settings” (Lee 1991). The processes in an ICT organization can be considered as social processes and the maturity of the ICT organization is a qualification of the maturity of social processes. The self-assessment of the maturity by the participants of the investigation is a subjective understanding of the maturity of social processes. Also the model of the weighting of the application availability in relation to the business processes is based upon a subjective understanding of social processes.

The level of interpretive understanding

The interpretive understanding belongs, according to Lee, to the observing organisational researcher. “This understanding is the researcher’s reading or interpretation of the (first level) common-sense understanding” (Lee 1991). The COBIT maturity model as published by the

ICT Governance Institute has a wealth of tools for the objective (in the sense of reliable) determination of the maturity of an ICT organization. However, as the participants of the investigation of M&I/Partners do not want to spend much time, they have chosen as a group for a quick self-assessment of the maturity level. And the M&I consultants try to interpret their answers as good as possible and redirect the participants if necessary. Also the inter-subjective determination of the importance of certain applications for the business processes by the group of participants has been a process of interpretation by the M&I consultants of the subjective understanding of the participants.

The level of positive understanding

The positivist approach puts into practice a view of science that has its origins in a school of thought within the philosophy of science known as "logical positivism" or "logical empiricism" (Lee 1991). This approach involves the manipulation of theoretical propositions using the rules of logic so that the theoretical propositions satisfy the four requirements of falsifiability, logical consistency, relative explanatory power, and survival (Popper 1934). In this PhD research we will define constructs and hypotheses, based on theory; these hypotheses will be tested using the empirical data of M&I/Partners. There are two falsifiable hypotheses concerning the productivity of (a) the ICT conversion process and (b) the business processes, which are tested multiple ways, based on different measurements of (combinations of) constructs. These "proxies" are concerned with the theoretically best way of these measurements. In the analysis section, using empirical data, we will see that the measurements that are based on maturity data and on application availability data result in the lowest level of validation. The measurements with the highest level of validation are based upon the cost data. We believe that this PhD research is an example of the positivist approach, as we objectively determine validation levels of hypotheses; see further section 6.3.

1.4.4 Case study versus survey research methodology

Although there are numerous definitions, Yin (2003) defines the scope of a *case study* as follows: "A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". Case research is, therefore, useful when a phenomenon is broad and complex, when a holistic, in-depth investigation is needed, and when a phenomenon cannot be studied outside the context in which it occurs (Benbasat et al. 1987; Yin 2003; Dubé and Paré 2003). The case research strategy allows for a great deal of flexibility and individual variation (Cavaye 1996). Case research, in its versatility, can be used with any philosophical perspective, be it positivist, interpretivist, or critical. It typically combines several qualitative data collection methods such as interviews, documentation, and observations, but can also include quantitative data such as questionnaires and time series.
Key characteristics of case study research are (Dubé and Paré 2003):

- a contemporary phenomenon is examined in a real-life context or setting,
- one or few entities (person, group, organization, technology) are examined,
- the complexity of the unit is studied intensively,
- the phenomenon of interest is not isolated from its context, especially at the data analysis stage,
- no controlled observation that involves manipulation is involved.

In summary, case research is particularly appropriate in two situations: (a) where research and theory are at their early, formative stages, and (b) where the experiences of the actors are important and the context of action is critical.

Survey research involves examination of a phenomenon in a wide variety of natural settings. The researcher has very clearly defined independent and dependent variables and a specific model of the expected relationships which is tested against observations of the phenomenon (Pinsonneault and Kraemer 1993). Survey research is most appropriate when:

- The central questions of interest about the phenomena are "what is happening?", and "how and why is it happening?" Survey research is especially well-suited for answering questions about what, how much and how many.
- Control of the independent and dependent variables is not possible or not desirable.

On the other hand, surveys are less appropriate than case studies when detailed understanding of context and history of given computing phenomena is desired.
In summary, survey research is appropriate when quantitative data are gathered and analyzed in isolation from the organizational context.

We believe that the yearly investigation by consultants of M&I/Partners is an example of case study research, as experiences of participants are important and the context of action is critical. The trial-and-error process in which practitioners are engaged is necessary for knowledge to accumulate at the three levels in Figure 1.3. Even the cost model is continuously evaluated and if necessary adjusted. The PhD researcher participated actively in the investigation process in the period 2006-2008 and findings of the PhD research were used to enrich the questionnaires. However, the PhD research as such is an example of survey research, using the data of M&I/Partners as secondary source. This implies that we will use proxies for the measurement of the constructs of our PhD research, to fit the theoretical constructs with the data of M&I/Partners. In the next section will be explained how these proxies can be considered as an extension of the basic hypothesis of this research.

1.5 Overview thesis

In Figure 1.4 an overview is presented of the different steps that are followed in this research, divided over the chapters 1-6 of this thesis. The numbers of the constructs are indicated between brackets.

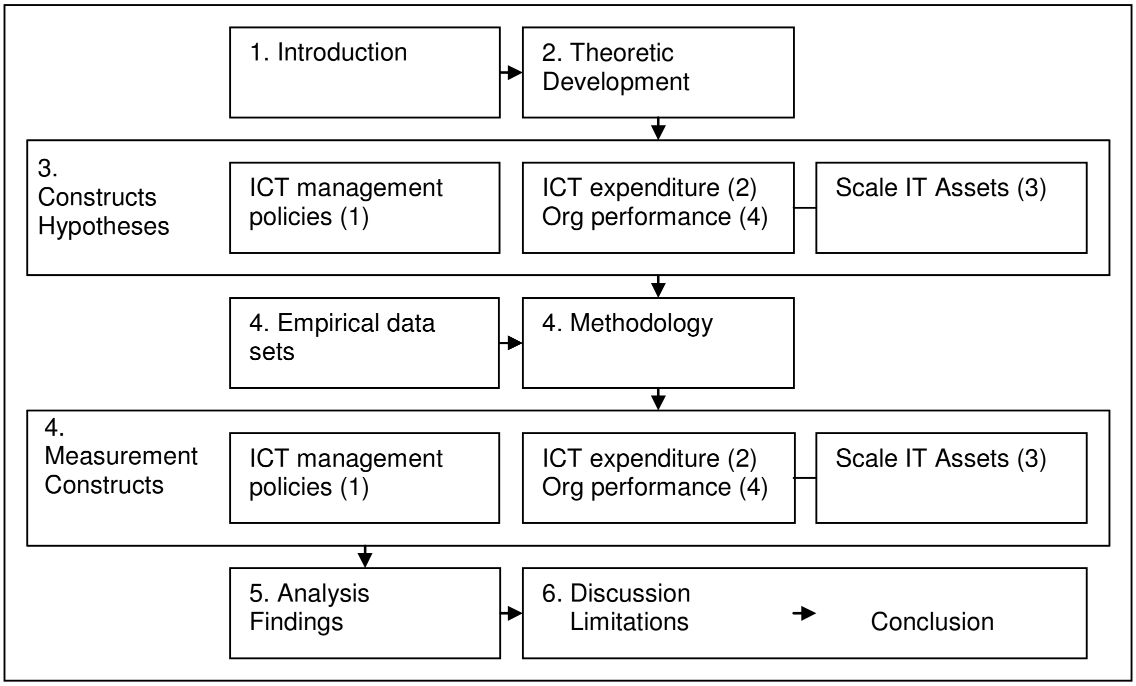


Figure 1.4 Research approach

In chapter 1 we define the constructs (1) efficacy of ICT management policies, (2) ICT expenditure, (3) scale of ICT assets and (4) Organization performance plus their interrelations within scope of this research (see Figure 1.2). The research aim and the research questions are defined, after which the theoretical and practical research contributions are described. Finally the research approach is explicated.

In chapter 2 the theoretic foundation of the constructs in this research is described. This foundation consists of three pillars. Firstly the science of cybernetics and complexity (Heylighen and Joslyn 2001; Edmonds 1999; Edmonds 2000), which is treated extendedly, because this will be used in various parts in this research. The control concept is used in the definition of the basic hypothesis H1 and the complexity concept is used to explain (dis)economies of scale in the conversion of ICT expenditure to ICT assets. Secondly the Resource Based View (Barney 1991) as a fundament for the definition of ICT assets and ICT management. Thirdly the economic theories about economies of scale (Silberston 1972; Bolton 1994). Upon these pillars we have built the theories that are construct specific. In chapter 2 we also treat the theoretical foundations of ICT management policies, concerning ICT infrastructure (Weill and Broadbent 1998) and ICT organization (COBIT 4.0 2005). Finally we develop a cybernetic view on ICT management policies to explain why there is a delicate balance between infrastructure and applications in organizations with low levels of ICT spending.

In chapter 3 the constructs are defined in more detail and the basic hypothesis H1 concerning the relation between the constructs (1)-(3) is formulated. For every construct an additional proxy (P1-P3) is formulated, to fit the theoretical constructs with the secondary dataset. The quantity of ICT expenditure is approached from the Total Cost of Ownership (TCO) view (Maanen and Berghout 2001). The complexity of the ICT assets is defined as a theoretical construct, to translate the scale of ICT assets to ICT expenditure (in the sense of effort of ICT personnel). The efficacy of ICT management policies is approached from two different views: based on the maturity of the ICT organization and on the other hand based on the infrastructure policy. Finally hypothesis H2 is formulated concerning the relation between Organization performance, the scale of ICT assets and the efficacy of ICT management policies. The research model is explained in Figure 3.10.

In chapter 4 the empirical data sets are presented, the research methodology is explained and constructs are made measurable. The data sets consist of data of Housing Corporations, Municipalities and Hospitals over the period 2002-2008. In the methodology we distinguish between a global and a detailed analysis (see Figure 4.4). The *global* analysis consists of Partial Least Square (PLS) regression (Gefen et al 2002) and linear regression to obtain a global view regarding the validity of the hypotheses. The detailed methodology uses power regression and is based upon two ways of determining the productivity: the *absolute* productivity and the *relative* productivity. For the determination of the relative productivity we use Data Envelopment Analysis (Charnes et al 1978), a technique that is suitable for benchmarking comparable organizations. We operationalize the hypotheses and proxies and define an additional proxy P2a concerning the measurement of the scale of ICT assets.

In chapter 5 the data of Housing Corporations, Municipalities and Hospitals are analyzed according to the methodology. The basic hypothesis H1 is tested in the detailed analysis in 20 different ways, as there are different measurements used for the three constructs and two ways to determine productivity. The results of the calculations are represented graphically in Appendix 3. The hypothesis H2 concerning Organization performance is tested in the detailed analysis in 4 different ways. Afterwards we analyze H1 and H2 again, but now simultaneous, according to the methodology (see Figure 4.4). Finally we give an overview of the validity of the hypotheses.

In chapter 6 we discuss the research findings. Then the limitations of this research are analyzed in terms of different validity aspects. Finally we address the implications of the research findings in a concluding section.

2 THEORETIC DEVELOPMENT

2.1 Introduction

The relation between ICT management policies and operational ICT management activities can be considered as a control relation: ICT management activities are controlled by ICT management policies. The "control" concept is theoretically underpinned together with the concepts "system" and "model". The control relation between policies and activities is further elaborated using the Information Management Framework (Maes 1999). As "complexity" plays a pivotal role, not only in the control concept, but also as a source of diseconomies of scale, the next sections are devoted to the definitions and measurement of complexity.

ICT assets and ICT management can both be considered as ICT resources within the framework of the resource-based view (RBV). Grant (1991) and Makadok (2001) emphasize that although resources in themselves can serve as basic units of analysis, firms create competitive advantage by assembling these resources to create organizational capabilities. We describe the theoretical background of the RBV and the role of ICT infrastructure as an important ICT asset. The principles of economies of scale in the conversion of ICT expenditure to ICT assets and in the conversion from ICT assets to Organization performance are then explained.

Finally the theoretical foundations of ICT management policies will be treated, concerning ICT infrastructure and ICT organization. The infrastructure policy is based upon the theories of Weill and Broadbent (1998). The maturity of the ICT organization will be determined using the concepts of COBIT 4.0 (2005). Finally we develop a cybernetic view on ICT management policies to explain why there is a delicate balance between infrastructure and applications in organizations with low levels of ICT spending.

2.2 Definitions of 'system', 'control' and 'model'

The concepts of systems and cybernetics (Joslin 2000) form the basic language in terms of 'system', 'control' and 'model'. Based on theories of Cybernetics I and II the concepts of system, model and control are united in a general paradigm of control (De Leeuw and Volberda 1996).

2.2.1 Definitions of 'System'

Within the systems literature (Joslyn 2000; Heylighen and Joslyn 2001; Checkland 1981) we can recognize two broad families of systems definitions. The standard view, which we will call *structural*, is perhaps best exemplified by Webster's definition of "a group of units so combined as to form a whole and to operate in unison (Webster 1989)". We call this view structural because it focuses on the specific given types of relations among specific types of entities. It entails an entering into relation of multiple entities, called parts, to form the new whole entity with new properties at a level hierarchically distinct from those parts. These new properties do not follow from considering the parts simply together as a collection, rather they must enter into a particular relation so that the whole is formed, resulting both from the parts as entities *and* from the particular way in which they are arranged, that is from their mutual interrelation and organization.

The other view of systems, which we will call "*constructivist*", is more recent. It avoids concepts of existing entities with objective attributes, instead defining a system as a bounded region of some (perhaps abstract) space which functionally and uniquely distinguishes it. It thus emphasizes the perceptions, and most significantly the *distinctions*, drawn by people. 'Certainly, [the making of distinctions] is the most fundamental act of systems theory, the very act of defining the system presently of interest, of distinguishing it from its environment' (Goguen and Varela 1979). This sense can be traced in the systems theory literature too (Ashby 1956) and it resonates with post-modernism, constructivist epistemology, and "second order cybernetics". Movement towards a synthetic sense of system, capturing both the structural and constructivist traditions, is both possible and desirable. Previously Joslyn (1995) has approached this within a more fundamental language of distinction, variety, and constraint, and on the distinction between cardinal (token) and dimensional (type) distinctions and variety. It is sufficient here to note that both the structural and the constructivist view both entail the presence of a distinction, or boundary, between any system and its environment.

In this research we will use the following definitions in the *structural* view on systems (Aken 1978; Leeuw 1980; Leeuw and Volberda 1996; Veld 1984):
Element / attribute / relation: an element is the smallest entity considered; elements have various properties or attributes; a special class of attributes comprises the relations between an element and other elements.
System: a system is a collection of elements with a collection of relations between the elements, whereas all elements are directly or indirectly related.
Black box: a black box is an entity the behavior of which is not described in terms of its internal structure, but in terms of input and output.
Environment: the environment of a system consists of all elements outside the system.
Structure: the structure of a system is the collection of relations of its elements with other elements. The internal structure is the collection of relations between internal elements. The external structure is the collection of relations between internal elements and external elements.
Partsystem: consists of a part of the original system, three types of partsystems are considered:

- Subsystem takes some of the elements from the original system.
- Aspectsystem concentrates on some of the relations of the original system.
- Phase-system takes only part of the original time-slice into consideration.

State / event / process: the state of a system at a given moment of time is the set of values of the attributes of its elements at that time; an event is the change in the state of the system; a process is a sequence of related events over time; the structure of a process is comprised of the relations between its elementary events.

2.2.2 Definitions of 'Control'

A closure can be defined (Joslyn 2000) as an aspectsystem that concentrates only on the internal structure of the original system. (The absence of external relations explains the name 'closure'). Semiotic closures are hypothesized as equivalent to control systems. Such systems form semiotic closures with their environments, and entrain cyclic processes of measurement, interpretation, decision, and action (Figure 2.1). Thus issues arise here concerning the use and interpretation of symbols, representations, and/or internal models (whether explicit or implicit) by the system; and the syntactic, semantic, and pragmatic relations among the sign tokens, their interpretations, and their use or function for the systems in question.

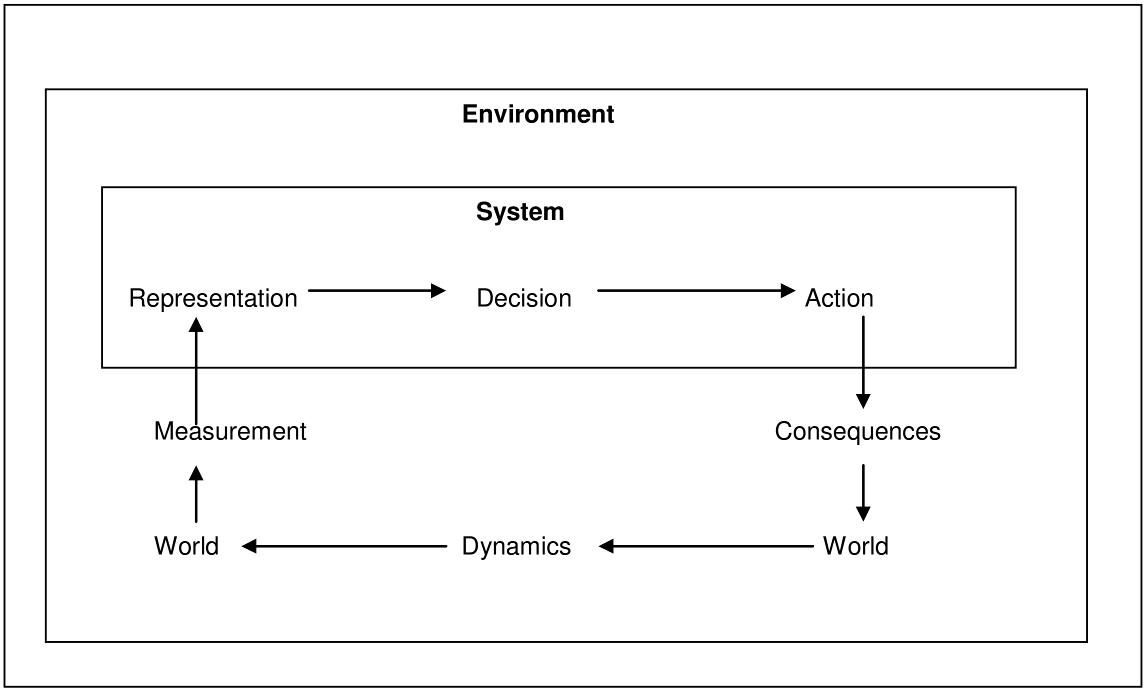


Figure 2.1 Control system as semiotic closure

The relation between system and environment is defined by Leeuw and Volberda (1996) from two points of view (Figure 2.2):

1. Organization as controlled system
   From the viewpoint of Cybernetics I, organizations are seen as open systems (in the structural view), which is a result of attempts to make sense of such systems from the standpoint of an external observer. These open systems are in constant interaction with their environment, transforming inputs into outputs as a means of creating the conditions necessary for survival. Fluctuations in their environment are viewed as challenges to which the organization must respond. This is the classical idea of adapting.
2. Environment as controlled system
   An observer may choose to focus on the internal structure of the system, viewing the environment as background; e.g. as a source of perturbations of the system's behaviour. From this viewpoint, sometimes called Cybernetics II, the properties of the system emerge from the interactions of its components. In other words, environmental influences (in the constructivist view) become perturbations which are compensated for through the underlying recursive interdependence of the system's components.

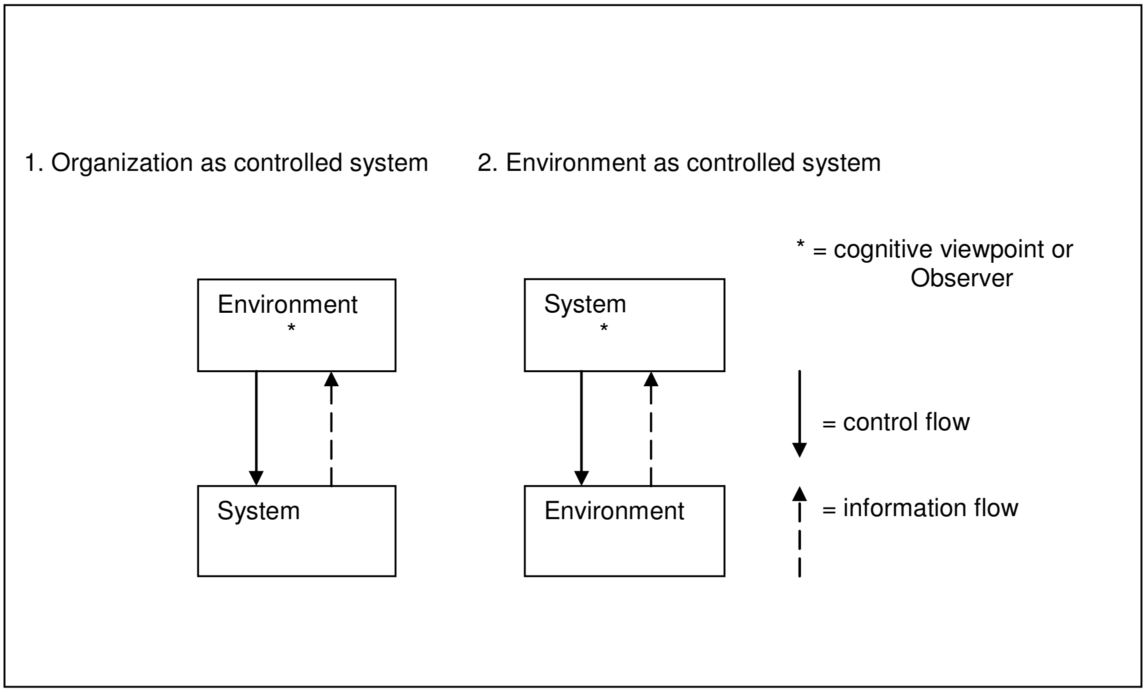


Figure 2.2 Two views on controlled system

Some researchers, however, in particular (Maturana and Varela 1980), offer a new perspective for understanding the logic through which living systems change, which is the foundation of Cybernetics II. In this theory, all living systems are organizationally autonomous systems of interaction that make reference only to themselves. Maturana and Varela have coined the term autopoiesis to refer to this capacity for self-production through a closed system of relations. Morgan (1986) remarks that, used as a metaphor, the theory of autopoiesis has intriguing implications for our understanding of organizations. Von Foerster (1984) gives an explanation from a neurophysiologic point of view: 'The nervous system is organized (or organizes itself) so that it computes a stable reality'.

Leeuw (1980) combines cybernetics 1 and 2 in a general control paradigm that unites both ways of control in Figure 2.2. A system is considered as a process that transforms an input from the environment into an output to the environment, see Figure 2.3. Within the system there is a Controlling Organ (CO) and a Target System (TS). The CO is exercising control over the TS and if possible also over the environment E. CO has a model of TS and E that is fed with information about TS and E.

CO has a set of goals (norms) that forms the base for control. According to Leeuw (1980) there are three levels of internal and external control:

- Operational: control of the transformation of input to output without the possibility to change elements or relations.
- Structural: changing elements or relations to improve the performance of the system with respect to the realisation of the norm.
- Strategic: changing the norm by influencing the part of the environment that is responsible for the norm.

The Goal of the system can be expressed as a relation between Intended Output (for example in terms of services of TS) and Intended Input (for example in terms of the cost of the system).

The “controllability of the TS” is concerned with the possibility of directing the TS from some arbitrary state to a desired state. The “control capability of the CO” is the ability of a CO to get the maximum of a TS; i.e. really using a TS to its full controllability potential (Leeuw and Volberda 1996). “Flexibility” corresponds with high controllability and large or at least sufficient control capability. Therefore, the resulting flexibility of a CO-TS configuration is the minimum of controllability and control capability (Leeuw and Volberda 1996).

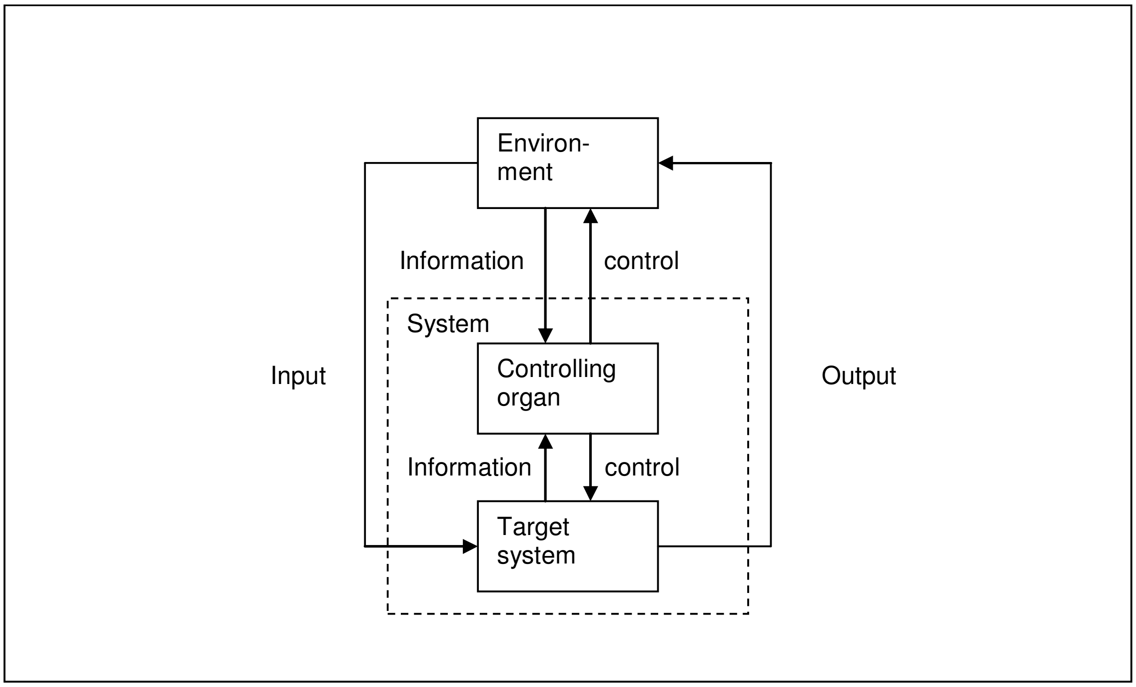


Figure 2.3 Process model of a system with control

2.2.3 Definitions of ‘Model’

Definition model (Apostel 1960): (a model is)… any subject using a system A that is neither directly nor indirectly interacting with a system B, to obtain information about the system B, is using A as a model for B. Leeuw (1980) states: a model is a system A that is representation of system B. Generally there is an isomorphic representation: one-to-many representation of elements A to elements B and a one-to-many representation of relations A to relations B.
In Figure 2.4 a system is represented as a model for prediction (Joslyn 2000). The function of the model is to make a good prediction of the world’ that is changed by a certain dynamics. By measurement’ of the world’ can be concluded whether the prediction is correct.

The relation between "world" and "model" is also a central concept in the process of science and in the complexity theories that will be treated later.

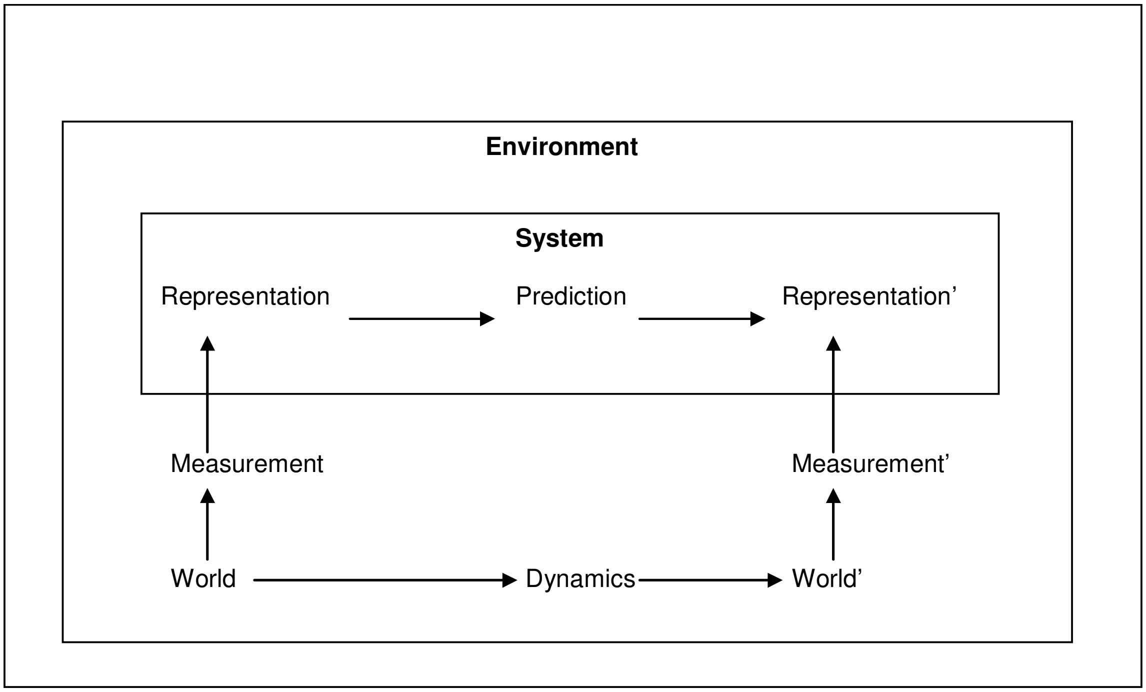


Figure 2.4 System as a model for prediction

2.3 Information Management Framework

In this research we compare organizations of the same type, which operate within comparable environments and have comparable business processes. Melville et al (2004) present a model about the positioning of the ICT system (comparable with the ICT conversion process (Soh and Markus 1995)) in the organization and the positioning of the organization in the environment. In Figure 2.5 the resources for an ICT system are (Melville et al 2004):

TIR (Technical ICT resources): applications and infrastructure
HIR (Human ICT resources): people, organization and procedures

The scope of this research is limited to the following (terms of Figure 2.5):
TIR: technical resources that together deliver application and infrastructure services (TIR services in Figure 2.6)

Infrastructure: hardware and software for workstations, servers and communication facilities (in more detail defined in Appendix 1):

- Workstations
- Peripherals
- Infrastructure data communications
- Servers and storage
- Communications speech and video
- Facilities

- Infrastructure software (server operating systems and middleware)

Applications:

- Software and software services, including interfaces between applications

HIR: human resources that together deliver ICT services (HIR services in Figure 2.6), based on the following types of skills:

Technical skills to create and maintain application and infrastructure services.

Information skills to assist the users of the application and infrastructure services.

Managerial skills to collaborate with business and external organizations.

Organizational resources:

Cost of ICT downtime and in general cost of time of users (e.g. training) is outside the scope of the research.

Users that spend part of their time executing ICT activities (in general supporting other users and specifying ICT functionality) are supposed to be part of HIR (for the relevant part of their time).

Employees of the organization that use the ICT systems are part of the business processes.

Business processes (performance) and organization performance are part of the scope of this research.

Competitive and macro environment: In this research organizations of the same type are compared, that belong to the same environment.

Empirical research is related to the following organization types: Dutch Housing Corporations, Municipalities and Hospitals.

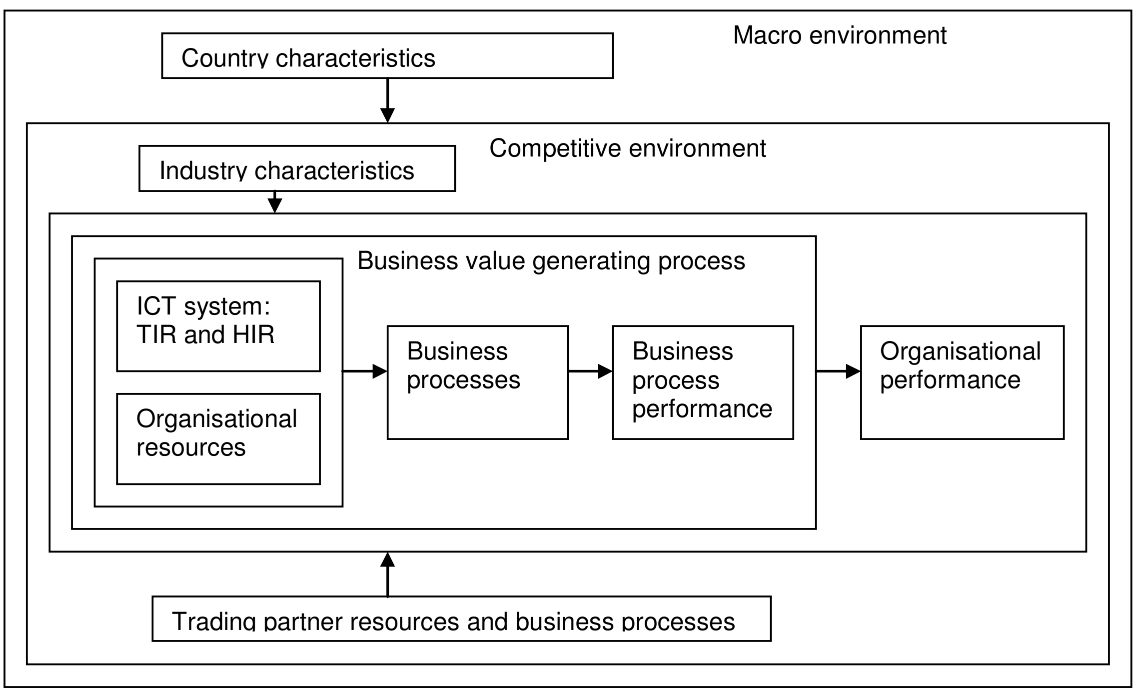


Figure 2.5 ICT business value model (Melville et al 2004)

The ICT system in an organisation consists of HIR processes and TIR processes (Figure 2.6). TIR processes: applications, data, processing and communication facilities delivering TIR services (data services) to users in the business. Inputs are TIR (hardware, software) and TIR services (in case of outsourcing data processing). TIR processes are executed by hardware and software.
HIR processes: people and procedures delivering HIR services (support and advice) to the business. Furthermore the HIR processes are controlling the TIR processes to deliver the services that the business needs. Inputs are HIR (people) and HIR services (support, advice and procedures). HIR processes are executed by people of the ICT organization.
In this research the control of TIR by HIR is defined in the broad sense of ICT management, including all the activities, from strategic to operational levels, to create and maintain TIR processes.

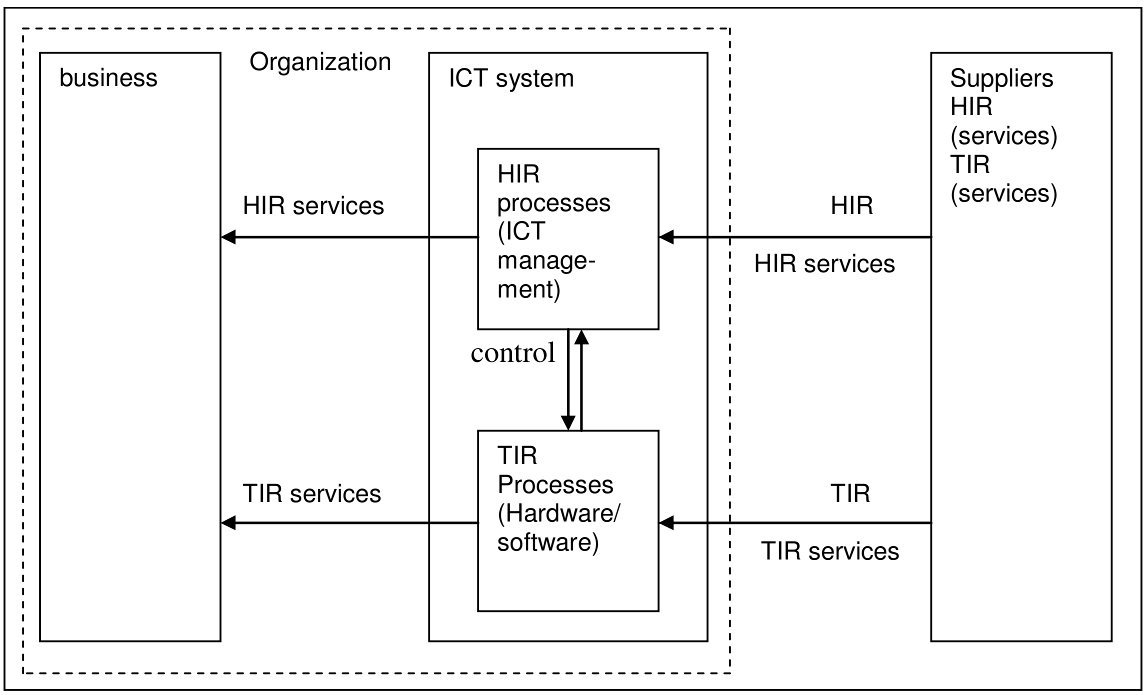


Figure 2.6 Model of HIR and TIR processes in ICT system

We use the Information management framework (Maes 1999) to fill in the HIR processes (see Figure 2.7) at the operational, structural and strategic level with IC (information and communication) and Technology aspects. At the operational level services are delivered to the users in the business by TIR (Technical Information Resources). At all levels HIR (Human Information Resources) are necessary to perform the following activities:

- Strategic level aspects:
  - Scope of IC and Technology
  - Core capabilities of IC and Technology
  - Governance aspects (make or buy and strategic partnership decisions)
- Structure level aspects:
  - Architecture of IC and T

Definition and design of critical IC and T processes and decision on legacy systems
Selection and development of promising IC and T capabilities
Development of an IC and T learning infrastructure
Operations level aspects:
(Re)design, perform and monitor IC and T processes (development and maintenance)
Delivery of IC services and operational Technology management (ITIL)
Acquisition, training and development of skills of IC and T professionals

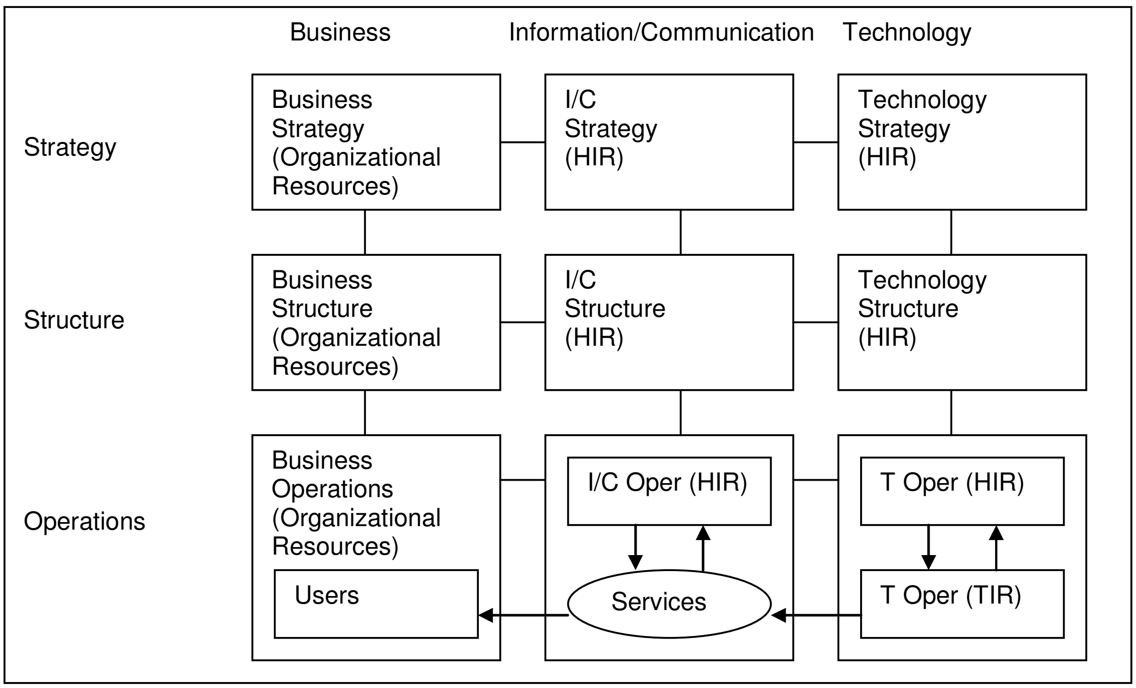


Figure 2.7 Information Management Framework

From a control point of view the organization is divided in 3 subsystems (see Figure 2.8):
The Business Subsystem.
The Information and Communication (I/C) Subsystem.
The Technology Subsystem.
Each of these subsystems is composed of the following components:
Strategic Control Organ.
The sub-subsystem that is composed of the Structural and the Operational Component.
The following control relations are considered:
There is a control relation between the strategic component and the structural component (strategic steering).
There is a control relation between the structural component and the operational component (structural steering).
The following alignment relations are considered:
Strategic alignment between Business Strategy and I/C Strategy.
Strategic alignment between I/C Strategy and Technology Strategy.

Structural alignment between Business Structure and I/C Structure.
Structural alignment between I/C Structure and Technology Structure.

The following services are delivered at the operational level:

Technology services from Technology Operations to I/C Operations.
I/C services from I/C Operations to Business Operations.

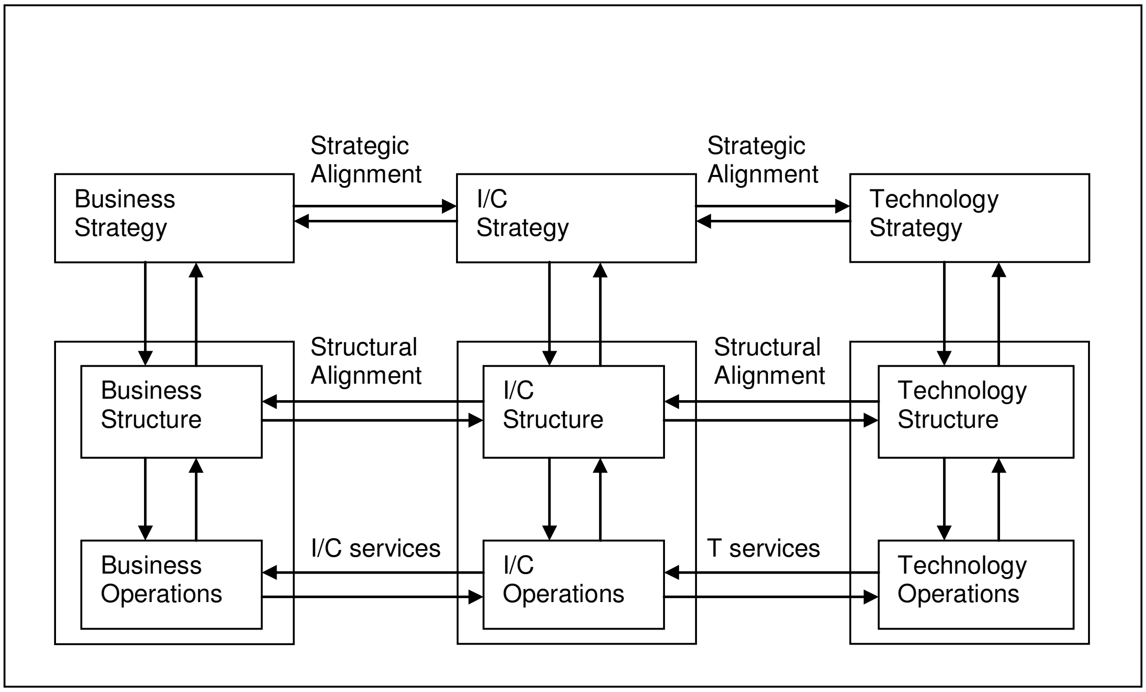


Figure 2.8 Information Management Framework from a control point of view

In Figure 2.9 the *operations level* of I/C and T is divided in a Control Organ (development and maintenance) and a Target System (service delivery). The Business Operations is considered as a black box.

The specification of I/C services is input for the I/C Operations Control Organ to develop and maintain the I/C services of the I/C Target System.
The specification of Technology services is input for the Technology Operations Control Organ to develop and maintain the Technology services of the Technology Target System.
The relations with the structure level of Business, respectively I/C and Technology are the constraints for all the activities at the Operational level.
Technology service delivery is executed by hardware and software (syntactical aspect).
I/C service delivery is executed by people (users), using the applications and translating the data syntax to information and human communication (semantic aspect).
Business Operations are executed by employees of the organization that translate the semantic aspects to organization performance (pragmatic aspect).

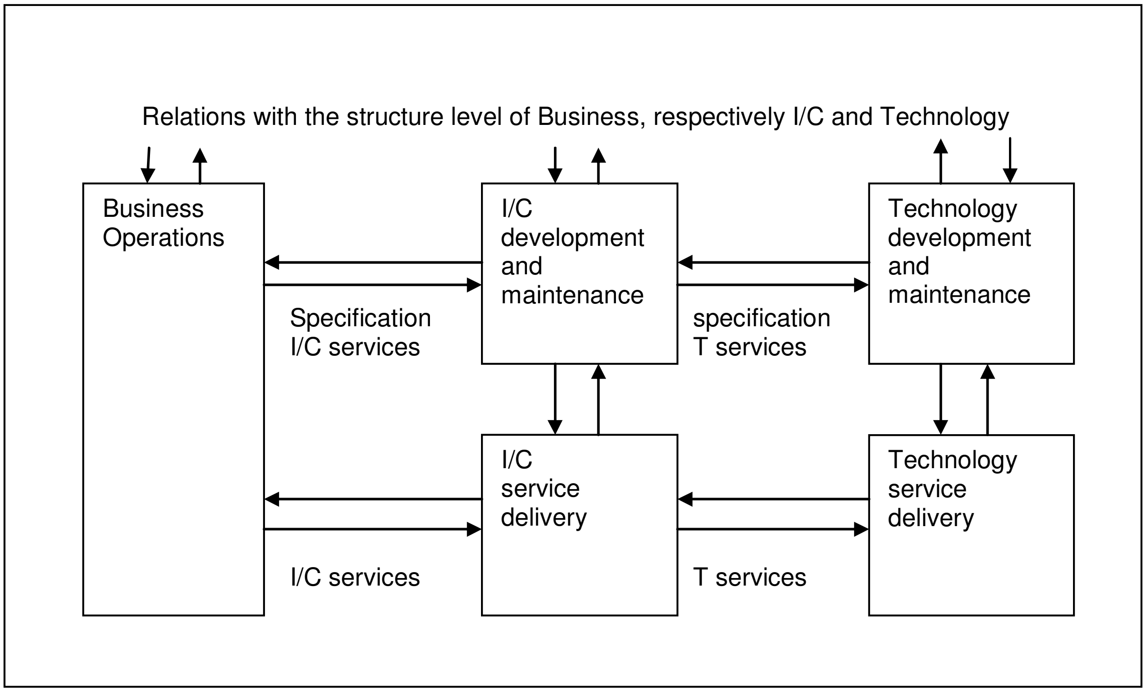


Figure 2.9 Operations level IM framework from control point of view

The operational delivery of services to users can be related to the “ICT assets”, which are defined by Soh and Markus (1995) to consist of infrastructure, applications and users (employees of the organization). Infrastructure is part of Technology; applications can be considered from a technological point of view and can be viewed as I/C services; users consume the information in the I/C service delivery process and use the information in the business operations. Aral and Weill (2007) have a comparable classification: they use the word “ICT assets” for infrastructure and applications and use the word “practices” for the usage of information. Therefore their ICT assets are part of technology and service delivery and their practices are part of the consumption of information and the usage in business operations.

2.4 Definitions of ‘complexity’

Over the last 50 years complexity has become a broad ranging subject, that is appreciated in a variety of ways (Ashby 1958; Simon 1962; Koolhaas 1982; Prigogine and Stengers 1984; Gleick 1987; Anderson *et al* 1988; Kauffman 1993; Kelly 1994; Holland 1998; Edmonds 1999; Xia and Lee 2005). In this research the study of complex systems will be elaborated as part of cybernetics and systems theory. This implicates that the science of complexity as described by a.o. Heylighen et al (2007) belongs outside the scope of this research. Heylighen describes a theory of complexity about how a system, and complexity in general, may emerge out of something which is not yet a system. Such a phenomenon might be understood with the help of concepts developed around the phenomenon of *self-organization*. This field of research is sometimes called “complex adaptive systems” (Gell-Mann 1995), where a lot of research from the perspective of natural science (but also with a growing interest from economics and social science) endeavours to investigate self-organizing systems, co-operative behaviour of agents, and non-linear dynamical systems creating emergent properties during their time evolution (Bar-Yam 1997).

Instead we will use the concept of "complex systems" and ask ourselves whether we are able to measure the complexity as a property of a *system* ("ontological" complexity according to Emmeche (1997)) or as a property of a *model* of the system ("descriptive" complexity (Emmeche (1997)). In the definitions of complexity there are two fundamentally different views:

Complexity of a real world *system*. The definition of complexity tries to describe aspects of reality. We will use the concept of complexity according to Rosen (1996) to explain this. See also Pattee (1973).

Complexity of a *model* of the real world system. In this view of Edmonds (1999) the relation between model and system is outside the scope of the definition of complexity. See also Suppes (1977).

We define the concepts "ignorance" and "validity" to describe the *relation* between model and system.

After this introduction we give an overview of the different lines of research concerning the measurement of complexity. Then we give an example about the measurement of complexity in an artificial, designed system. Finally we describe the measurement of complexity in this research.

2.4.1 Complexity of a real world system according to Rosen

Mikulecky (2001) describes the way how science is done according to Rosen (1996). It is a combination of using our senses to observe the world around us and then to use some mental activity to make sense out of that sensory information. The process is what we will call the *modelling relation* (see Figure 2.10). If we call the world we are observing and/or trying to understand the *Natural System* and the events that make it change as we observe *causality (1),* then that represents our object of study. What we do in our minds is to *encode (2)* the natural system into another system that is of our making or choosing which we can call a *formal system.* Once we have chosen a formal system, we can manipulate it in various ways with the objective of mimicking the causal change in the natural system. These manipulative changes in the formal system we will call *implication (3).* Finally, once we think we have an appropriate formal system and have found an implication that corresponds to the causal event in nature, we must *decode* (4) from the formal system in order to check its success or failure in representing the causal event. Figure 2.10 represents the modelling relation (Hughes 1997) we have just described.

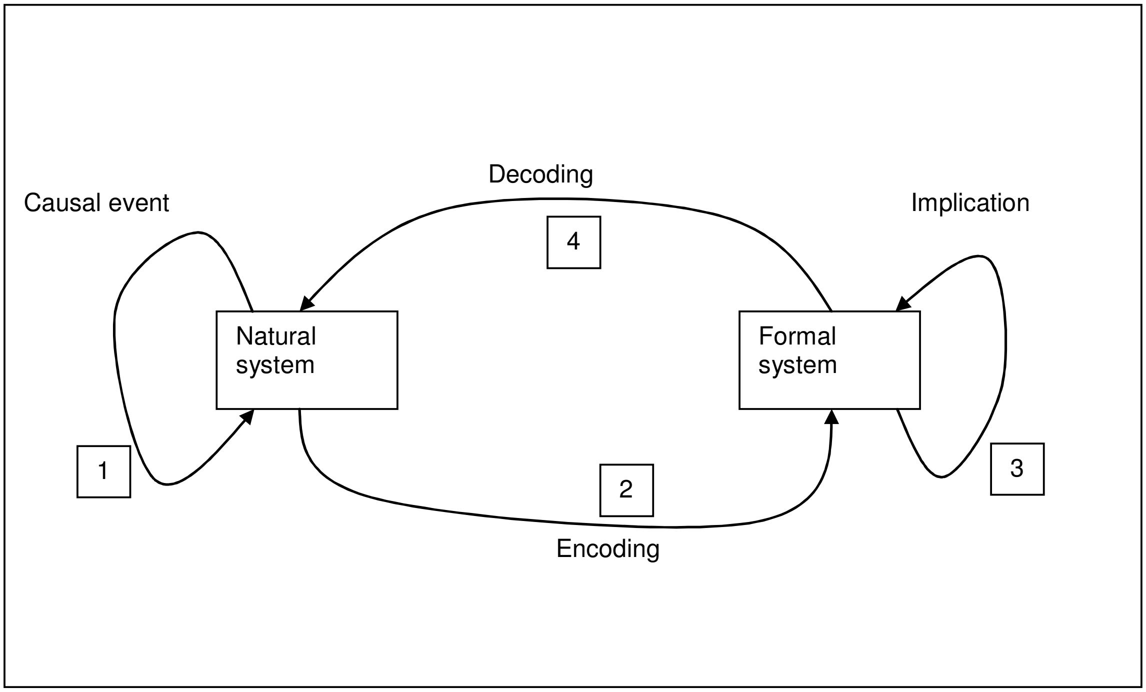


Figure 2.10 Modeling relation according to Rosen

If all the parts of the diagram are in harmony, in other words if 1 = 2 + 3 + 4, we say that the diagram commutes and we have a model. A model of the world is the outcome of a successful application of the scientific method, but it can also arise in other, less formal ways. Whenever someone tries to make sense out of the world, they are trying to construct a successful modeling relation, or a model.

We use this concept for the definition of complexity. The world, from which we single out some smaller part, the natural system, is converted into a formal system that our mind can manipulate and we have a model. The world is complex. The formal system we choose to try to capture it can only be partially successful. For years we were satisfied with the Newtonian Paradigm as the formal system, forgot about there even being and encoding and decoding, and gradually began to change the ontology so that the Newtonian Paradigm actually replaced or became the real world (at least as seen through the eyes of science). As we began to look more deeply into the world we came up with aspects that the Newtonian Paradigm failed to capture. Then we needed an explanation. *Complexity* was born. Definition: complexity is the property of a real world system that is manifest in the inability of any one formalism being adequate to capture all its properties. We can state simply that the complexity of a real world system is the not explainable part of the system.

2.4.2 Complexity of the model of a system according to Edmonds

Edmonds (1999) states that it is impossible to measure real world complexity. His definition is based on a property of a model of a system.

Definition: complexity is that property of a model which makes it difficult to formulate its overall behaviour in a given language, even when given reasonably complete information about its atomic components and their inter-relations.

This is a general definition, which is intended to have different interpretations in different contexts. It relates the difficulty in formalisation of the whole to that of the formalisation of its parts (typically a 'top-down' model compared to a 'bottom-up' one) in the language. It is only applicable in cases where there is at least a possibility of gaining significant information about the components, thus clearly separating ignorance from complexity. Different conceptions of complexity depending on the base language chosen, the type of difficulty focused on and the type of formulation desired within that language.
The important aspects of this approach are that:

1) it applies to models rather than natural systems;
2) complexity is distinguished from ignorance;
3) it is relative to the modelling language it is expressed in;
4) it is relative to the identification of components and overall behaviour;
5) complexity is a global characteristic of a model;
6) you will get different kinds of complexities from different types of difficulty;
7) complexity represents the gap between component knowledge and knowledge of global (or emergent) behaviour;
8) since difficulty is sometimes comparative, complexity will be also.

The approach of Edmonds to complexity can be considered as a continuation of the ideas of Herbert Simon. Simon (1962) developed a theory of "hierarchical systems" that forms the basis for the above mentioned aspects (4), (5) and (7). The principle of "bounded rationality" (Simon 1955) can be considered as a fundament of aspect (2), as "rational ignorance" is ultimately a choice. Simon (1977) states: "Complexity may lie in the structure of a system, but it may also lie in the eye of the beholder of that system"; this viewpoint forms the base of aspects (1), (3), (6) and (8). The specific contribution by Edwards is in my opinion aspect (7): in Figure 2.11 we can see that the gap between the component models and the overall model of the system is a measure for complexity according to Edmonds. This gap is what Simon called the "nearly decomposability" of the components of a hierarchical structured system. Thus Edwards translates this "nearly decomposability" of the components to a measure of complexity of the overall system. Edwards is formalizing the more informal approach of Simon.

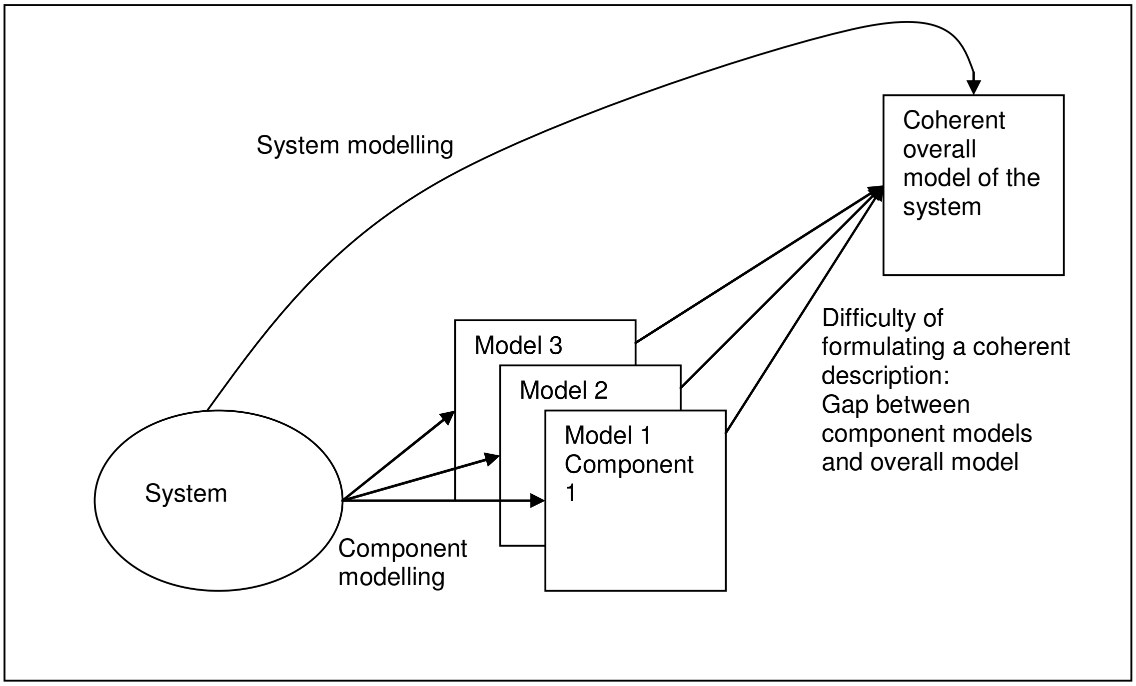


Figure 2.11 Complexity according to Edmonds

2.4.3 Complexity, ignorance and the validity of the model of a system

The *validity* of the model of a system can be defined as (the probability of) a correct explanation or prediction of the behaviour of the system by the model (see Figure 2.4). The difference between complexity and ignorance can be explained with this concept of the validity of a model of a system (see Figure 2.12):

Ignorance is a property of the relation between the system and the representation of the system:

In reality there is a system.

We have a view on that system by our 'Weltanshauung' (German for "view of the world" (Wood-Harper 1985)) and we form a representation of that system (according to Leeuw (1980) while Edmonds calls this also a model). The Weltanschauung can essentially be equated to the notion of a viewpoint (Proper et al 2005).

We can make a model of the representation with a certain correspondence between elements and relations in the model and elements and relations in the representation.

Ignorance can be considered as the lack of completeness of the representation compared to the system in reality.

Ignorance concerning not relevant aspects of the system is a choice.

We might state that the source of ignorance is the not explainable part of the system, which is the definition of complexity according to Rosen (section 2.4.1).

Complexity is a property of the *model* as such (as defined by Edmonds). We might define this as the *explainable* complexity, unlike the *not explainable* complexity of the *system* according to the definition of Rosen, see Figure 2.12. In the remaining of this thesis the Rosen complexity concept will not be used.

Validity of the model of a system is a property of the *relation* between the model and the system in reality (measurable by the correctness of explanations or predictions of the behaviour of the system made by the model).

The relation between validity and ignorance can be elucidated using the concepts "content validity" and "construct validity" (Straub 1989). The content validity refers to the question whether the constructs and their relations are a good representation of the system (the intention of the representation). The construct validity pertains to the definition of the variables that make up the constructs, which can be considered as the model of the representation. In chapter 6 this will be further elaborated.

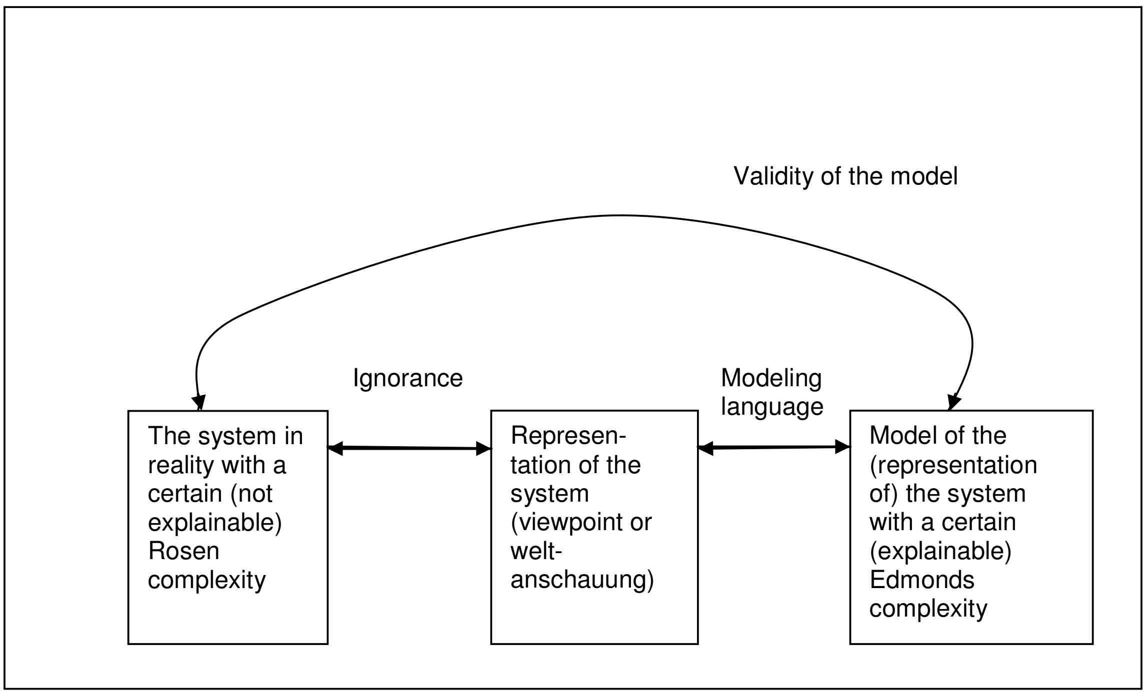


Figure 2.12 Ignorance versus complexity and validity of a model

2.4.4 Measures of complexity

Broadly, existing measures of complexity can be seen as (Edmonds 1999):
(1) A special case of the above mentioned definition of Edmonds (the difficulty to formulate the overall behaviour of a model of a system).
(2) A relativisation of the approach either to some physical attribute (e.g. scale) or some 'privileged' framework to 'objectivise' it ("ontological" approach).
(3) A weak characterisation of complexity better suited to some other descriptive label, such as 'information' ("descriptive" approach).

Ad (1) Oriented to the properties of the relation between model and system.
If a system can be modelled in many different and irreconcilable ways, then we will always have to settle for an incomplete model of that system. In such circumstances the

system may well exhibit behaviour that would only be predicted by another model. Thus such systems are, in a fundamental way, irreducible. This approach can be extended in restricted circumstances to measuring complexity by the *number of inequivalent descriptions* (Casti 1986). In terms of Figure 2.12 we could say that there are different viewpoints with different corresponding models, which makes it difficult to determine the overall behaviour of the system.

Ad (2) Oriented to the "ontological" properties of the system.
(a) The greater the extent of *inter-connections* between components of a system, the more difficult it is to decompose the system without changing its behaviour. Thus the connectance of a system (especially when analysed as a graph (Ramamoorthy 1966)) becomes a good indication of the potential for complex behaviour.
(b) If one is focusing on the topology of a model, then one improvement on the simple size of the network as an indication of its complexity is the *number of relations* indicated between the nodes. Rouse and Rouse (1979) in their study of the time taken to complete tasks found a strong correlation between the time taken to perform fault diagnosis tasks with complex relations and the number of internal relations in that circuit (represented by a wiring connection).
(c) There is clearly a sense in which people use "complexity" to indicate the number of parts but seems rarely used just to indicate this. *Size* seems not to be a sufficient condition for complexity. On the other hand a certain minimum size does seem to be a necessary condition for complexity. It is very hard to imagine anything complex made of only two parts. The rate of potential complexity seems to increase very fast with size. This does not, of course, mean that all large systems are complex. Anderson (1972) points out that size can make a qualitative difference to the behaviour of systems as Von Neumann (1966) also suggests.

Ad (3) Oriented to the properties of the "descriptive" model of the system.
(a) The *Algorithmic Information Complexity* (AIC) of a string of symbols is the length of the shortest program to produce it as an output. The program is usually taken as running on a Turing Machine (Solomonoff 1964; Kolmogorov 1965; Chaitin 1966).
(b) Bennett (1986) defines '*logical depth'* as the running-time to generate the object in question by a near-incompressible program.
(c) In physics, *entropy* measures the level of disorder in a thermodynamic system. The more disordered it is, the more information is needed to describe it precisely. Thus complexity and entropy can be associated, although this was not intended by its originators (Shannon and Weaver 1949). Entropy based measures are essentially probabilistic (Grassberger 1986).
(d) The *amount of information* a system encodes or the amount of information needed to describe a system has a loose connection with its complexity. There is a close connection between the amount of information and disorder. Information can be measured deterministically using algorithmic information complexity or probabilistically using entropy. Klir (1985) states that complexity should be proportional to the information required to resolve any uncertainty. Some approaches which seek to combine elements of both algorithmic and Shannon information include Gell-Mann and Lloyd (1996) and Rissanen (1987). Computational complexity has been extended to cover information flow by adding a cost function to the information used by a computation (Traub and Wozniakowski 1991). Applications include: systems problem solving (Klir 1984) and the estimation of the information of a pattern (Nielsen 1996).
(e) A complex system is likely to exhibit a greater *variety* in terms of its behaviour and

properties. Thus variety is an indication of complexity. Variety can be measured by the simple counting of types, the spread of numerical values or the simple presence of sudden changes (Ashby 1956; Heylighen 1990; Huberman and Hogg 1986; McShea 1991). In this way it overlaps with information and entropic measures.

In the next section we will give an example of the complexity of an artificial system.

2.4.5 Complexity of a model of an artificial system using the C-K theory

The relation between a model and a (to be designed) system is a central issue in the "C-K theory" (Hatchuel and Weil 2003, 2009; Ondrus and Pigneur 2009). In this theory, the starting point of a design project is the formulation of an idea, a specification, a "concept", which is an incomplete or ambiguous set of desired properties qualifying the system to be designed. An example is a concept of an information system. In Figure 2.13 the source of the concept of an information system can be found in the I/C part of the Information management Model (Figure 2.7).

The theory assumes a space of knowledge (K), which is the established knowledge available to a designer and contains propositions of partly known objects as well as relations between these objects. In the example of the information system there are two sources of knowledge:

- Business knowledge that can be found in the B part of Figure 2.13.
- Technological knowledge that can be found in the T part of Figure 2.13.

Propositions in K have a logical status (true or false in classic logic, non standard logic could be adopted as well). K is expandable since its content changes over time.
A "concept" is a proposition implying that "an object verifies a group of properties". A concept has no logical status in the space of knowledge (K). In fact, when a concept is proposed, it is not possible to prove that it is a proposition of K. Concepts are considered as sets that can only be partitioned or included (not searched). If a property is added, the set is partitioned in subsets. If a property is removed, the set is included in a set that contains it. The process of adding and removing properties to or from concepts is the central mechanism for the design reasoning activity. The space of concepts (C) has a tree structure based on these partitions and inclusions.

Four operators have been defined, represented in the so called "design square" (see Figure 2.13):
K → C operator: this operator adds or removes properties from K to concepts in C. It creates "disjunctions" when it transforms a proposition into a concept. This corresponds to the generation of alternatives. It expands the space C with elements from K.
C → K operator: this operator seeks for properties in K that could be added or removed to reach propositions with a logical status. It creates "conjunctions" which could be accepted as finished design. This corresponds to evaluation using an experimental plan, a prototype, or testing. It expands knowledge with the help of concepts.
C → C operator: this operator controls the expansion of the space or tree of concepts, by partition or inclusion.
K → K operator: this operator allows expanding the space of knowledge using logic and proving new theorems.

The expansion mechanisms help to define design as "the reasoning activity which starts with a concept about a partially unknown object and attempts to expand it into other concepts and/or to generate new knowledge". Design generates the co-expansion of the two spaces: design is the process by which K → C disjunctions are generated, then expanded by partition or inclusion, to reach C → K conjunctions.

In the example of the information system the ultimate design, based on expanded knowledge (Figure 2.13) is the basis for the Technological part of the system and thus for the Information/Communication that is available for the users of the system. C and K are both models of the Business and are also models of the Information system to be designed. Using the definition of complexity of Edmonds we can define the *complexity* of K as the amount of *knowledge* to assemble the components in K (considered as black boxes) to a whole that is eventually the designed information system. The ignorance between the *K model and the information system* is zero, and the validity of the K model is 100%, as the system has to be realised according to the model. Important to notice that the components of the system are considered as black boxes, just as the corresponding components of the K model: there is of course ignorance concerning the *content* of these black boxes, but we are not interested in this content. We are only interested in the *behaviour* of these black boxes, which is described in the K model, so from this point of view there is no ignorance between information system and the K model. Another aspect is the ignorance between the *C model and the Business*: as the Business is not completely modelled in the information system, there is always an amount of ignorance between Business and the C model. The process in the "design square" can be considered as a learning loop, which ultimately reduces the ignorance between Business and C model.

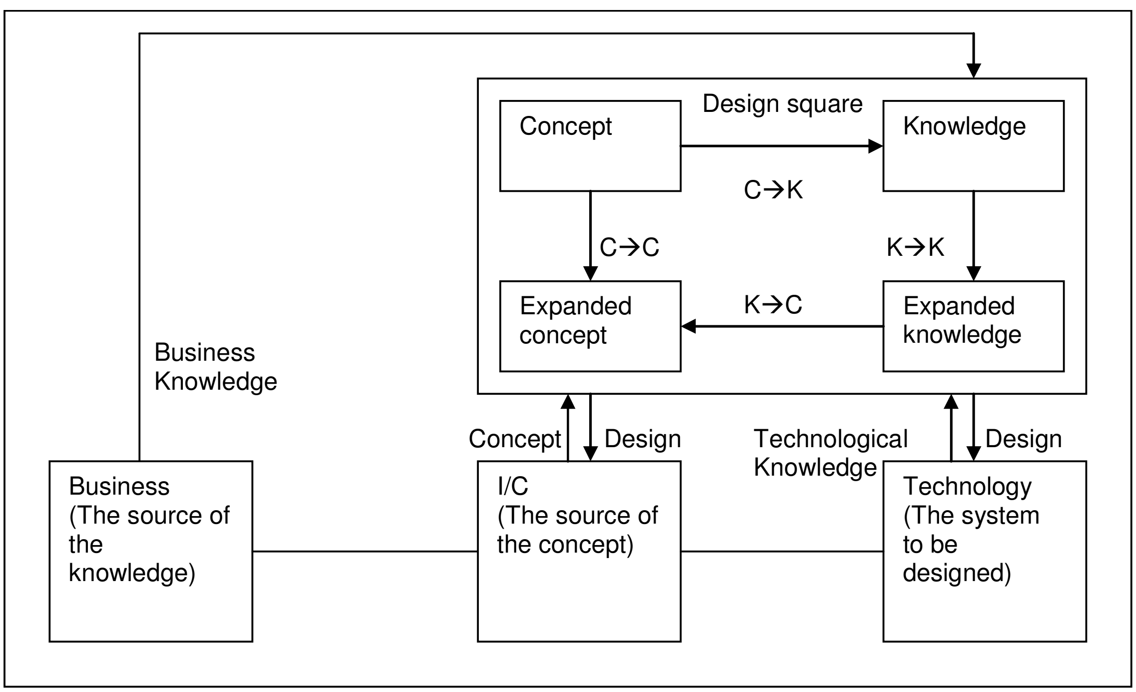


Figure 2.13 C-K theory design models

The complexity (or knowledge) of K is composed of two types: business complexity ("essential" complexity (Brooks 1986; 2003)) and technological complexity ("accidental" complexity (Brooks 1986; 2003)). As the essential complexity of the Business is not completely modelled in the K model, the remaining ignorance between Business and C model can be a dangerous source of wrong decisions, based on an illusion of valid information systems (Ciborra et al 2000). An example is the whole of financial systems of banks that are apparently based on too much ignorance, which was part of the cause of the financial crisis in October 2008. The danger of too much ignorance between Business and essential complexity in information systems can be caused by too much focus of ICT departments on limitation of accidental complexity by standardization. In practice we often see the emergence of "paper" processes and the excessive usage of spreadsheets by users whose "agility demand" is insufficiently supported by excessive standardized systems.

Both essential and accidental complexities of information systems have been growing exponentially in the last 50 years. However, the essential complexity is growing relatively faster than the accidental complexity, as the technological components (black boxes) have every year more functionality. So there is more and more "hidden" complexity, which makes technology easier to manage. On the other hand, the essential complexity consists of units of information that stay in essence the same, although with graphical displays this can be easier "transported" to the mind of the user. But there is no "technological" development in the brains of the users, so the whole of essential complexities of information systems is getting more and more difficult to perceive by human minds. The accidental complexity and the possibilities to control this type of complexity are the primary subject of this research, as this is related to the efficiency of the Technology. The possibilities to control essential complexity are however of secondary importance in this research, as this is related to efficacy of the Information/Communication for the Business. This is what Soh and Markus (1995) call the "ICT use process", see Figure 1.1. The efficiency of the ICT-use process is highly determined by the alignment between applications and business processes. In this research we do investigate the productivity of the business processes in relation to the ICT assets, but we do not analyse in depth the causes of economies of scale in business processes.

2.4.6 The measurement of complexity in this research

The definition of Edmonds (complexity represents the gap between component knowledge and knowledge of global (or emergent) behaviour) can be made operational using the complexity concept of Gershenson and Heylighen (2005). They define complexity in a recursive way: the complexity of a system increases with the number of distinct components, the number of connections between them, the complexities of the components, and the complexities of the connections. This is a recursive definition that is general enough to be applied in different contexts. For example, everything else being equal, a firm will be more complex than another one if it has more divisions, if its divisions have more employees, if the divisions have more channels of interaction, and/or if its channel of interactions involves more person-to-person interactions.

There is a clear relation between these two definitions: the overall behavior will be more/less difficult to derive if the number and complexity of individual components and relations increase/decrease. In both cases the complexity of the whole is defined relatively to the complexities of the components and relations. So if two systems A and B consist of a different number of the same basic components and relations, then the complexities of A and B can be expressed in some sum of complexities of basic components and relations. In that way the complexities of A and B can be made comparable, while the complexities of basic components and relations have arbitrary values. So it doesn't matter that complexity is the property of the *model* of a system, to make complexities of systems A and B comparable. This property will be used in the benchmarking of comparable organizations.

Ashby (1973) proposes that the degree of complexity should be measured "by the quantity of information required to describe the vital system". This is known as the Law of the requisite Knowledge (Ashby 1958; Conant and Ashby 1970). In this definition the description of the system can be considered as a model of the system. The quantity of information, required to describe the vital system is a specification of the "difficulty to formulate its overall behaviour in a given language" (according to definition of complexity of Edmonds). So this is a special case of the definition of Edmonds.

Backlund (2002) goes one step further and defines it thus: "Since complexity is something perceived by an observer, the complexity of the system being observed is, one could say, a measure of the effort, or rather the perceived effort, that is required to understand and cope with the system." This definition can also be considered as a special case of Edmonds' definition, as the effort to understand the system is a measure of the "difficulty to formulate the overall behavior". Thus the perceived complexity of a system is partly a property of the system and partly a property of the observer. So two observers will need a different amount of effort to understand the same system at the same validity level (in the sense of making correct explanations or predictions). The difference between the two observers can be found in the knowledge they have about this system or this kind of systems. This brings us to epistemological questions that will not be further treated here.

In this research we will use two different ways to measure the complexity of a system:

1) Based on the "ontological" definition of Gershenson and Heylighen (2005): the complexity of a system is determined by the number of different elements and relations.
2) Using the "descriptive" definition of Ashby (1973): complexity is measured by the quantity of information to describe the system.

In terms of figure 2.12 these two ways can be considered as two different representations of a system. In the process of modeling these representations, we will use in both cases the definition of Backlund (2002), so the complexity is *measured* as the effort to understand and cope with the system by the observer:
Ad 1) The system is *perceived* as a set of sets of elements and relations, that have to be understood by an observer.
Ad 2) The system is *perceived* as a quantity of information (represented in some way) that has to be understood by an observer.
We will show that these both views are interchangeable in the sense that view 2 can be expressed in terms of elements and relations and that view 1 can be expressed as a quantity of information. However, as a starting point we will use these views and in chapter 3 the interchangeability will be further elaborated.

2.5 Resource based view

In this section we will first introduce the Resource Based View (RBV) concept. This will subsequently be defined more precisely, using the framework of Peppard and Ward (2004). We will relate this framework to the Information Management Framework (Maes 1999).

2.5.1 Introduction RBV

ICT assets and ICT management can both be considered as ICT resources within the framework of the resource-based view (RBV). This section describes the theoretical background of the RBV and the role of ICT infrastructure as an important ICT asset. Barney (1991) proposes that firms can obtain competitive advantages on the basis of corporate resources that are firm-specific, valuable, rare, difficult to imitate, and not strategically substitutable by other resources. Grant (1991) and Makadok (2001) emphasize that although resources in themselves can serve as basic units of analysis, firms create competitive advantage by assembling these resources to create organizational capabilities. According to Santhanam and Hartono (2003), IS researchers have adopted this capability notion of resources by arguing that although it is not hard for competitors to duplicate organizations' investments in ICT resources by purchasing the same hardware and software, these resources *per se* do not provide sustained competitive advantages. It is, however, the way in which firms leverage their ICT investments to create unique capabilities that impact their overall effectiveness (Clemons and Row 1991; Mata et al. 1995). Karimi et al. (2007) state that infrastructure resources refer to a firm's shared ICT *assets* (e.g., hardware, software tools, networks, databases, and data centres). They are the foundations of a firm's ICT architecture, its blueprint or major design that supports its multiple applications and user groups (Bharadwaj 2000; Luftman 2000; Ross 2003). Following a RBV perspective on building strategic-level capabilities, the individual ICT asset is commodity-like, widely available, suitable for imitation, and relatively easy to obtain, and therefore incapable of generating long-term economic rents. For this reason, it is hardly considered to be a source of sustained competitive advantage alone (Mata et al 1995; Ray et al 2005). ICT infrastructure resources, however, will ensure the success of a firm's ICT architecture, by their highly firm-specific nature, and the way in which they evolve over longer periods of time, during which gradual enhancements can be made to meet the changing business needs (Allen and Boynton1991; Scott-Morton 1991). In this research, we will investigate the importance of ICT infrastructure resources as the foundation of the organization's application architecture, and validate the efficacy of ICT management policies on the basis of the amount of expenditures in ICT infrastructure.

According to Kumar (2004), IS researchers have also recognized that ICT infrastructure flexibility includes technical ICT infrastructure flexibility as well as human ICT infrastructure flexibility (Henderson and Venkatraman 1994; Duncan 1995; Broadbent et al 1999; Byrd and Turner 2000; Wade and Hulland 2004). Effective human infrastructures require technology management knowledge and skills, business-functional knowledge and skills, interpersonal and management knowledge and skills, as well as technical knowledge and skills (Lee et al 1995)**.** ICT infrastructure flexibility is therefore multidimensional and includes the ability to upgrade different parts of the infrastructure for network purposes, to integrate disparate data sources through the use of middleware, to counteract system failure due to redundant components or systems, and to add new applications to components or application frameworks (Byrd and Turner 2000; Fan et al 2000; Hwang et al 2002). We believe that a flexible ICT infrastructure drives organizations' business value (Broadbent et al 1999), and in particular leverages the economies of scale in ICT.

2.5.2 RBV in Information Management Framework

Peppard and Ward (2004) introduced a framework clearly defining the key concepts they use: resources, competencies and capability. *Resources* are stocks of available factors that are owned or controlled by the organization. The data, information, knowledge, systems and technology owned or available to the organization are an increasingly important set of resources. *Competencies* refer to an organization's capacity to deploy resources, usually in combination, using organizational processes, to effect a desired end. They refer to the organization's ability to deploy combinations of specific resources to accomplish a given task. *Capability* refers to the strategic application of competencies i.e. their use and deployment to accomplish given organizational goals. The concepts resources, competencies and capability can be positioned in the Information Management Framework, see Figure 2.14.:

- Resources can be placed at the operational level,
- competences at the structural level, and
- capabilities at the strategic level.

Besides the process theory of Soh and Markus (see Figure 1.1) can be related to the Information Management Model:

- ICT conversion process in the Technology column,
- ICT use process in the I/C column, and
- competitive process in the Business column.

The transformation from resources to competences and to capabilities takes place in every column, whereby interrelations between columns play an important role.

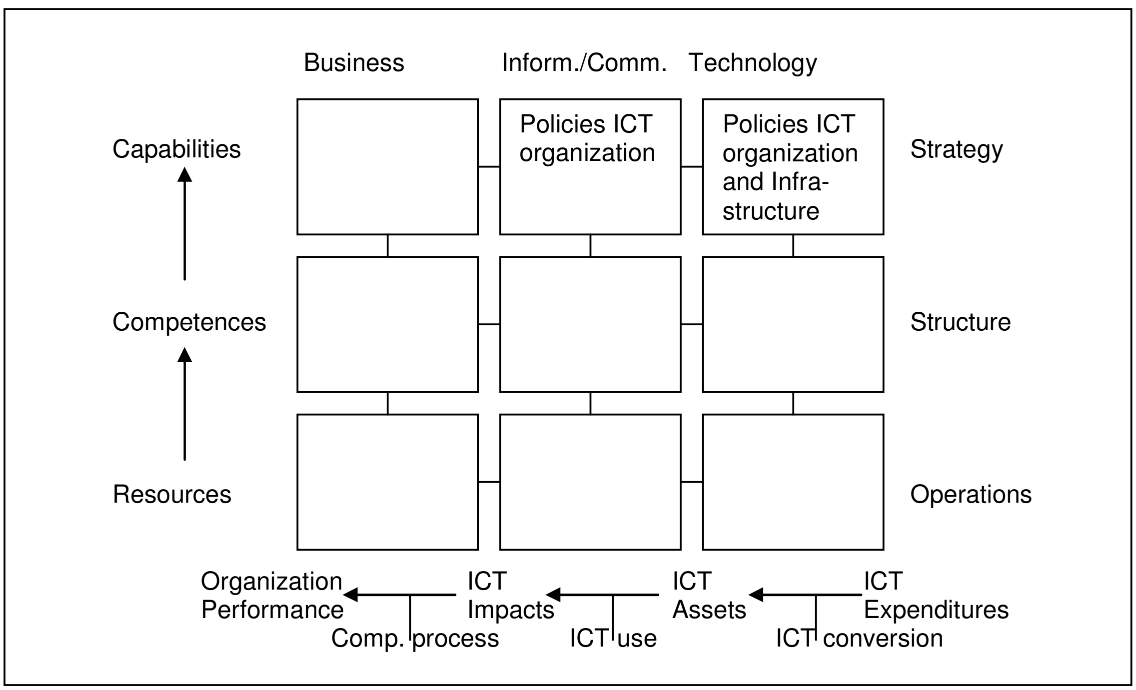


Figure 2.14 Resource based view in Information Management Framework

Policies at the strategic level guide this transformation process and in this research we will focus on the infrastructure policy (in Figure 2.14 strategic level in technology column). According to Peppard and Ward (2004) a flexible and re-usable ICT infrastructure provides the technical platform, services and specialist resources needed to respond quickly to required business changes as well as the capacity to develop innovative IS applications. Through the deployment of technical knowledge and skills, the organization ‘creates’ an ICT infrastructure that influences future options and speed of response but has a degree of permanence attached to it. The infrastructure can be viewed as the embodiment of knowledge and skill. The ICT infrastructure provides the shared foundation of the organization’s ability for building and using business applications. While many software applications are designed for one specific business purpose, other applications and most hardware, networks, operating systems and databases are designed to be shared and to serve many business purposes. A major problem with ICT infrastructure and associated services is that they are not always adequately planned for. It is generally accumulated rather than designed to serve the business in times of change and consequently it is often rather fragmented and technically incompatible, at least in parts. The ICT infrastructure only defines the technological capability required to support the business and its strategy, if it adequately addresses the need for flexibility to deal with changing business needs and priorities.

As stated above, not only technical policies, but also human policies will be investigated, regarding the development of ICT human resources (HIR) to HIR capabilities. In the Technology column of Figure 2.14 the HIR are responsible for the development of infrastructure capabilities and in the I/C column the HIR are responsible for the support of the ICT users, that develop the I/C capabilities of the organization. The maturity of the ICT organization, which is formed by HIR in collaboration with ICT users, is described by for example the Capability Maturity Model Integration (CMMI Product Team 2002) or COBIT 4.0 (2005). The policies that must lead to these capabilities can be placed in Figure 2.14 at the strategy level in the I/C column and in the Technology column.

Besides these factors there are complementary organizational practices that raise the returns from ICT investments. Hitt and Brynjolfsson (1997) found that increased investment in ICT is linked to a system of decentralized authority and related practices. These can be considered as competences and capabilities in the Business column. Bassellier et al. (2001) consider the ICT knowledge of business professionals (which leads to competences and capabilities in the Business column) and the business knowledge of ICT professionals (which leads to competences and capabilities in the I/C column) as important factors. Bhatt and Grover (2005) mention organizational learning, which is important in the development from resources to capabilities in all columns of Figure 2.14. Brynjolfsson and Hitt (2003) stressed that complementary investments take time; an implication of this argument is that the long-run benefits of computerization should exceed the short-run contribution. These additional benefits from computerization arise as firms implement complementary changes in the rest of the business. Therefore, the resulting effects of computerization on output may be greater than the factor share of computer capital. However, the benefits of these complementary organizational practices are only visible after years. Especially investments in infrastructure take long time before the results are visible. We will deal with this aspect in more detail in section 2.7.3.

Other authors who have studied the relation between ICT and management effectiveness, are Van Nievelt and Willcocks (1997) and Strassmann (1985). Their research identifies the effect of ICT on the productivity of management, referred to as OPI – Organizational Performance Index (Van Nievelt and Willcocks 1997) or ROM – Return on Management (Strassmann 1985). The McKinsey Global Institute (2001) further refines this type of research, arguing that there are genuine differences in the effective utilization of ICT among lines of businesses. The Institute, therefore, emphasizes the need for branch-specific research such as elaborated upon in our study. Further, ample research has been conducted in the area of ICT evaluation techniques (Ballantine and Stray 1998; Powell 1992). This research, however, hardly addresses the question to what extent the improvement of the evaluation leads to better ICT decision making and a more effective and efficient use of ICT.

In this research we will focus on the policies necessary for the ICT conversion process from ICT expenditure to ICT assets. The efficacy of ICT management policies is defined as the ability of ICT management to govern an efficient and effective conversion from operational ICT expenditure to ICT assets. This implies that effective policies create the conditions for an efficient and effective ICT conversion process. We will investigate policies that guide the transformation to technical and organizational capabilities from technical and human ICT resources.

2.6 Economies of scale

In a well-known passage from The Wealth of Nations, Adam Smith (1776) argues that the gains from specialization arise from the repetition of the same task, which improves dexterity. This saves time otherwise lost in switching from one activity to another, and may lead to increased mechanization (and automation). These universally accepted principles also apply to information processing by ICT labor. Individuals do get better at repeatedly processing the same type of information. Time is lost in switching from processing one kind of information to another, and time can be saved with the help of computers in completing simple and mechanical processing tasks. So specialization, made possible by a larger scale, leads to a higher productivity not only in general (Silberston 1972), but also to information processing (Bolton 1994) by ICT labour. Furthermore the information processing by ICT labour can be partly automated: for example tools for the automation of management and distribution of (new versions of) hardware and software (IDC 2007).

The drawback of specialization is a greater need for control and communication (Williamson 1967; Bolton 1994): the larger the organization, the more bureaucratic rigidity (Williamson 1996) and processing bottlenecks (Simon 1947). Another disadvantage of a larger scale is the complexity of the ICT assets: the number of relations between hardware/software components increases with the square of the number of components. This leads to non-linear documentation requirements and an exponential increase in problem solving difficulty (Simon 1977; IDC 2007). However, there are only few publications about economies of scale effects in *ICT management*, see for example (Barron 1992; Looijen 2000). This is in steep contrast with the many studies on economies of scale in *software development* (e.g. Banker and Kemerer 1989; Banker et al.1994; Boehm and Sullivan 1999; Kitchenham 2002).

The literature on ICT and *business* productivity makes a key distinction between labour productivity that results from simple substitution of ICT for labour and the gains ushered in from fundamental improvement in management practices, business processes and strategies (Davenport and Short 1990; Bresnahan et al 2002; Brynjolfsson and Hitt 2003). The former is labelled as capital deepening, while the latter is referred to as multi-factor productivity or total factor productivity. Input driven productivity can be the result of ICT substituting other types of capital or labour inputs. In other words, capital deepening may be subject to economies of scale type of effects if there are diminishing returns to scale in the organizational production function. At the same time, corporate strategies, superior business processes and organizational learning that underlie multi-factor productivity are not independent of ICT investments but lead to ICT spending as well. Such types of productivity impacts may be less subject to diminishing returns, and the economies of scale type of arguments may be less relevant here and fall outside the scope of this research.

Related to the issue of the differential impact of IT, Tallon et al. (2000) build upon Porter's arguments of operational effectiveness and strategic positioning to hypothesize two fundamental differences in the way ICT can transform firms. First, firms can enhance operational *business* effectiveness by using ICT to reduce operating costs, to improve productivity, and by using ICT to increase responsiveness to customer needs. Second, ICT can improve the strategic position of firms by extending market reach or by using ICT to change industry or market practices. In this research we will benchmark Housing Corporations, Municipalities and Hospitals, which operate in stable market conditions. Therefore we assume that these organizations focus on improving productivity.

Besides economies of *scale* there is a concept called "economies of *scope*" (Teece 1980) that refers to the common and recurrent use of propriety know-how for different products in a multi-product enterprise. This can be translated in the ICT environment to the use of common know-how for the management of different ICT assets. We will in this research not consider the economies of scope as a separate dimension besides economies of scale.

2.7 Definitions of efficacy ICT management policies

Earl (1989) defines ICT management policies as the total of "information technology strategy" and "information management strategy", where the information technology strategy can be considered as the combination of "systemic competences" and "architecture" (Henderson and Venkatraman 1994). Information management strategy can be defined as "specifying the decision rights and accountability framework to encourage desirable behavior of the ICT conversion process" (Weill and Ross 2004). At the execution level the ICT management activities are carried out by "processes" and "skills" (Henderson and Venkatraman 1994). In fact, ICT management policies form the consistent and calculated approach to dealing with information technology in order to maximize the efficiency and effectiveness of the information function, given a particular timeframe. The efficacy of ICT management policies is defined in this research as the ability of ICT management to govern an efficient and effective conversion from operational ICT expenditure to ICT assets. This implies that effective policies create the conditions for an efficient and effective ICT conversion process (see Figure 2.14). Efficacy therefore refers to both optimal utilization of technological resources and labour (or skills), which has become increasingly important with respect to the leverage of commodities. In the following sections we will deal with the technology policy and the maturity of the ICT organization.

2.7.1 Technology or infrastructure policy

The importance of technological resources, especially the ICT infrastructure as part of the ICT architecture, has been described extensively by many researchers (Weill 1993; Van Nievelt and Willcocks 1997; Ross et al 2006). According to Weill and Broadbent (1998) “infrastructure” is defined as the basic framework of shared ICT services, including transactional applications (see Figure 2.15). “Applications” are subdivided into informational, and strategic software components (see Figure 2.15). If an organization has a “utility view” on ICT, it should concentrate its ICT investments on infrastructure and transactional applications to attain cost savings by economies of scale (Weill and Broadbent 1998). If an organization has an “enabling view” on ICT, its focus is on investing in informational and strategic applications on top of the up-to-date infrastructure services and transactional applications, to attain flexibility (Weill and Broadbent 1998).
In this research we use the following definitions of infrastructure and applications, which are slightly different from the definitions of Weill and Broadbent (see Figure 2.15):

The Infrastructure “system”, consisting of hardware and software components delivering infrastructure services (in more detail defined in Appendix 1):

- Workstations
- Peripherals
- Infrastructure data communications
- Servers and storage
- Communications speech and video
- Facilities
- Infrastructure software (server operating systems and middleware)

Applications and data:

- Software and software services, including the interfaces between applications, and the corresponding databases.

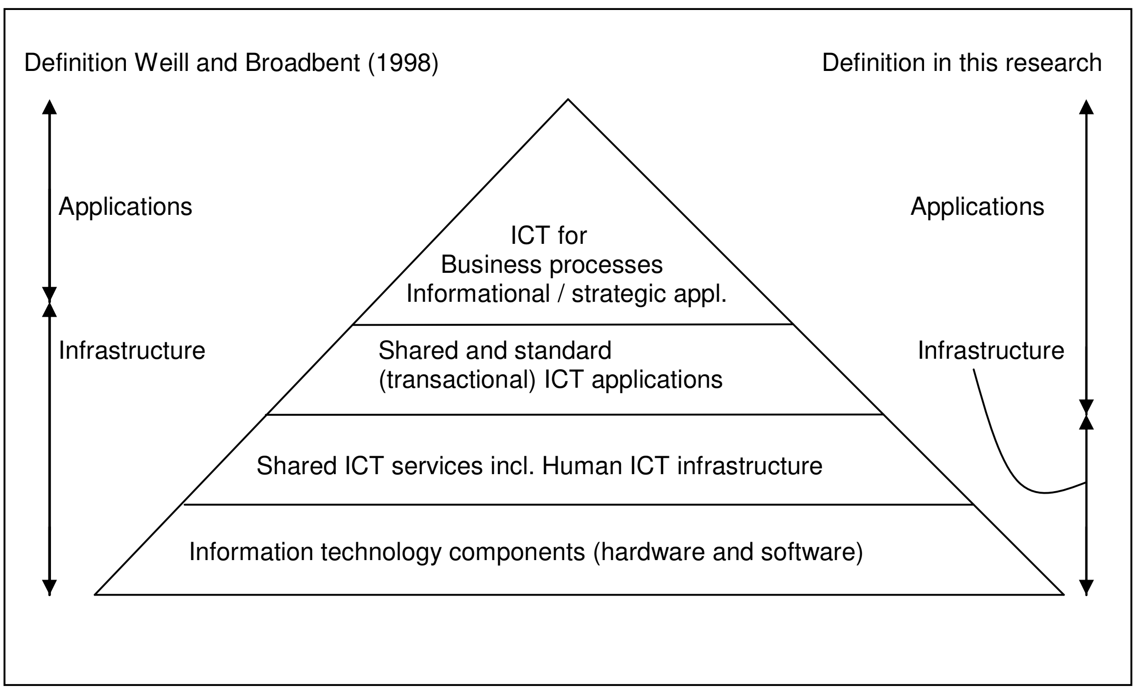


Figure 2.15 Definitions of infrastructure and applications

Why are enough budgets for infrastructure investments important? The relation between functionality and cost of infrastructure is influenced by the general technological development. We can state that every subsequent year the cost of a piece of infrastructure with certain functionality is lower than in the former year. This is based on the 'law of Moore (1965)' who postulated that the number of transistors that could be fabricated on a semiconductor chip would increase at 40% per year. It was a remarkable prediction that still holds today. This trend holds not only for computing, but also for storage and communications (Roberts 2000; Hutcheson 2005; Ekman et al 2005). That means that the costs per unit of performance for infrastructure facilities could decrease every year with about 40%. An interesting counterpoint to Moore's Law is Wirth's Law: "software is slowing faster than hardware is accelerating" (Larus 2008). So the growing functionality of software consumes the growing performance of infrastructure facilities at a constant cost level. The additional functionality of hardware and software (Technical Information Resources or TIR) is eventually divided between additional functionality for users and for Human Information Resources (HIR) that perform the management of HW/SW. This is demonstrated Figure 2.6. With the additional management software the HIR are able to manage (or control) the TIR with more functionality without an increase in requisite knowledge. Thus not only the cost of TIR remains the same, but also the cost of HIR remains the same in spite of yearly TIR functionality growth of 40%. For example in the period 2002-2007 for Housing Corporations the cost of TIR remained on average around 70% of total ICT cost. The most important part of the HIR in the ICT conversion process is what is called in Figure 2.15 the "Human ICT infrastructure". These people are responsible for the management of the hardware, systems software and the technical aspects of the applications software. So it is obvious to hypothesize that if an organization neglects the replacement of outdated infrastructure, then an excess of Human ICT infrastructure is necessary to manage hardware and software effectively. Also the investment in modern tools for hardware/software management is timesaving for the Human ICT infrastructure. All this implies that an organization should strive to spend sufficient budget on infrastructure hardware and software to attain as much as possible economies of scale with the Human ICT infrastructure.

In terms of the productivity of the ICT conversion process (Figure 1.2) the following can be stated:

- Modern infrastructure delivers more value (in terms of functionality) for money than outdated infrastructure. So modern infrastructure is more productive (in terms of the relation between ICT assets and ICT expenditure), because it delivers <u>more ICT assets functionality per €</u> ICT expenditure.
- Modern infrastructure needs per € the same amount of HIR as outdated infrastructure. So modern infrastructure is more productive (in terms of the relation between ICT assets and ICT expenditure), because it needs <u>less HIR cost</u> (as part of ICT expenditure) <u>per €</u> infrastructure hardware and software (as part of ICT assets).

If an organization has a "utility view" (Weill and Broadbent 1998) on ICT, and has a low ICT budget, then it runs the risk of not spending enough on infrastructure, to realize up-to-date shared infrastructure services. Without shared infrastructure services every application needs to include its own middleware components, which is a source of complexity. The consequence is that the productivity of the ICT conversion process is low.

As is explained in Figure 1.2, the business productivity is also influenced by ICT management policies. If the technological policy is primarily focused at the ICT infrastructure

("infrastructure driven"), then the productivity of the ICT conversion process will be optimized. However, if the policy is focused on the ICT applications *("application driven")*, then the productivity of the business processes will be optimized (Bharadwaj 2000; Kim 2004; Karimi et al 2007). Therefore we will define a lower boundary on the infrastructure expenditures from the point of view of the ICT conversion process, and a lower boundary on the expenditures for applications from the point of view of the business processes (this will be explained in more detail in section 2.7.3). As stated, this research is directed primarily at the productivity of the ICT conversion process and secondarily at the productivity of the business processes. Therefore the Information Systems Strategy (Earl 1989) remains outside the scope of this research.

2.7.2 Maturity ICT organization

The management resources are approached from the point of view of the maturity of the ICT organization, as measured by quality systems. An overview of the quality systems in ICT which are nowadays commonly accepted is given by Cater-Steel et al (2006); they present IT Infrastructure Library (ITIL 2008), Control Objectives for Information and related Technology (COBIT 4.0 2005), Capability Maturity Model Integration (CMMI Product Team 2002), and the ISO 9000 Quality Management System (ISO 2008). The focus of ITIL is to provide a comprehensive and cohesive set of templates and best practices for core ICT operational processes (ITIL 2008). COBIT's control objectives are categorized into four domains: planning and organization, acquisition and implementation, delivery and support, and monitoring (COBIT 4.0 2005). The planning and organization domain covers the use of ICT and how it can help the organization achieve its goals and objectives. The acquisition and implementation domain addresses the organization's strategy in identifying its ICT requirements, acquiring the technology, and implementing this technology within the organization's current business processes. The delivery and support domain focuses on the delivery aspects of the ICT applications, also covering the support processes that ensure the effective and efficient functioning of these applications. The monitoring domain deals with the organization's strategy in assessing its ICT needs, regardless of whether the current ICT applications are still meeting the objectives for which they were designed, or whether or not the controls necessary to comply with the regulatory requirements are still effective (COBIT 4.0 2005). CMMI describes the principles and practices that underlie the maturity of the software development process. The framework was originally intended to help software development organizations improve their software processes by following an evolutionary path from ad hoc and chaotic to mature and disciplined software processes (CMMI Product Team 2002). ISO 9000 refers to a set of quality management standards that enable an organization to fulfil 'the customer's quality requirements and applicable regulatory requirements, while aiming to enhance customer satisfaction, and achieve continual improvement of its performance in pursuit of these objectives' (ISO 2008).

In this research we will use COBIT 4.0 (world wide standard for EDP auditing) and ITIL V.2 (de facto standard in Dutch organizations) as frameworks for description of organizational processes and structures. COBIT is published by ITGI and positioned as a high-level governance and control framework. ITIL was developed since 1989 in the UK by the Central Computer and Telecommunication Agency (CCTA) which was incorporated into the Office of Government Commerce (OGC) in 2001. The scope of COBIT 4.0 is wider than ITIL v.2 and it is possible to position the ITIL processes within the COBIT framework. In ISACA

(2005) an overview is given of best practices COBIT 4.0 and ITIL v.2. However not yet widely accepted, there is a newer version of COBIT (4.1) and a newer version of ITIL (v.3). In ISACA (2008) an overview is given of best practices COBIT 4.1 and ITIL v.3.

ITIL v.2 comprises ten service management processes and additional functions which are split into service support disciplines focused on operative services and service delivery disciplines focused on long-term assurance of ICT services. The service support domain comprises Incident, Problem, Configurations, Change, and Release Management where the first is designed to enable the usage of ICT services. The other processes are designed for adaptation, documentation, and problem resolving. The service delivery domain comprises Service Level, Financial, Capacity, Continuity, and Availability Management where the first is designed to interact with the business by negotiating Service Level Agreements, for example. The other processes are to assure a high service quality.

The COBIT 4.0 Framework consists of:

Processes that have to be executed by an ICT organization, divided in the categories Plan and Organise, Acquire and Implement, Deliver and Support, Monitor.

Resources of the ICT organization: Data, Application systems, Technology, Facilities and People. In this research Application systems including Data, plus Technology and Facilities are part of TIR. People are part of HIR.

Quality criteria for control (or governance) of the ICT organization: Efficacy, Efficiency, Confidentiality, Integrity, Availability, Compliance and Reliability. In this research we will focus upon Efficacy and Efficiency, while Integrity, Availability, Compliance and Reliability will be considered as boundary conditions, which will not be investigated.

Maturity levels of the ICT organization, which will be used in the questionnaire:

0) There is a lack of all recognizable process. In fact, the organization has not even recognized that there is an issue to be addressed.
1) *Ad Hoc*: shows evidence that the organization has recognized issues exist and need to be addressed. There are no standardized processes. Ad hoc approaches are applied on an individual or case-by-case basis.
2) *Repeatable*: there is an awareness of issues. Performance indicators are being developed. Basic measurements have been identified, as have assessment methods and techniques.
3) *Defined*: the need to act is understood and accepted. Procedures have been standardized, documented and implemented. Balanced scorecard ideas are being adopted by the organization.
4) *Managed*: full understanding exists of issues on all levels. Process excellence is built on a formal training curriculum. ICT is fully aligned with the business strategy. Continuous improvement has started to be addressed.
5) *Optimized*: There is a forward-looking understanding of issues and solutions. Processes have been refined to a level of external best practice based on the results of continuous improvement and maturity modelling with other organizations.

There is a discussion in Quality literature about the cost of Quality in general. The "*classical view"* of quality cost behavior in the P-A-F (Prevention-Appraisal-Failure) model holds that an optimum CoQ (Cost of Quality) exists at the level at which the cost of securing higher quality would exceed the benefits of the improved quality. This concept is, however, often challenged, and it is argued that there is no economic level of quality, that spending on prevention can always be justified and that the optimum quality level in fact equals zero defects ("*modern view*": Plunkett and Dale 1988). The two conflicting views of the economic level of quality costs are shown in Figure 2.16. The results of the quality cost simulation study of Burgess (1996) suggest that both views can be reconciled within one model. Burgess supports the classical view in certain time constrained conditions, whereas under an infinite time horizon the modern view prevails. Similarly, Marcellus and Dada (1991) suggest that the traditional trade-off model may be an accurate, static representation of quality cost economics, but that in dynamic, multi-period settings, failure costs can continue to decline over time with no corresponding increase in prevention and appraisal costs. Ittner (1996) provides empirical evidence to support this behavior. Despite the continuing discussion on economic quality levels, the basic principles of the P-A-F categorization are still generally recognized and accepted (Schiffauerova and Thomson 2006).

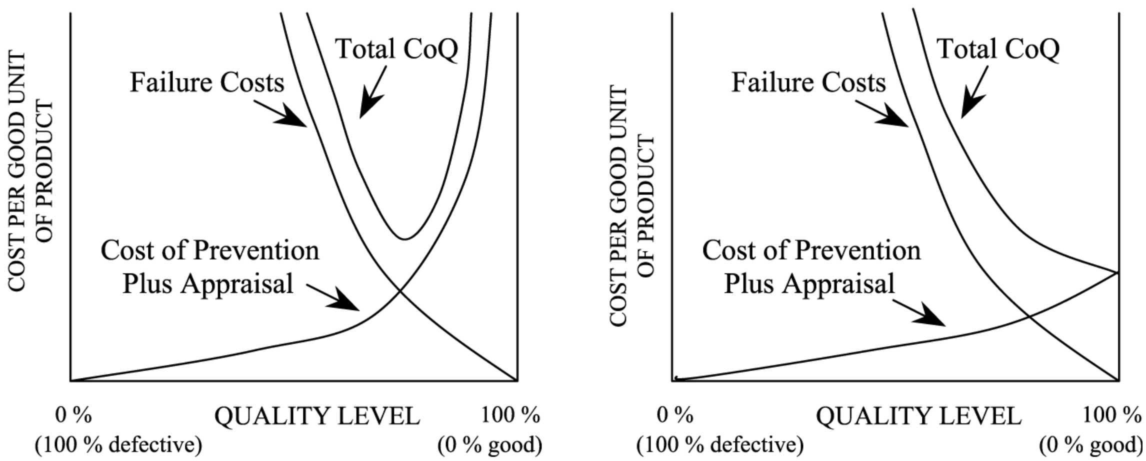


Figure 2.16 "Classical view" on the left and the "modern view" on the right

We will apply this general theory about the cost of Quality in the ICT environment. In this research the quality level is defined by the COBIT maturity level. The costs of quality can be defined at two levels: firstly the cost of ICT management and secondly the total cost of ICT. For now we will define the costs of quality as the cost of ICT management. The Failure costs can thus be defined in ITIL terms as the costs of incident and problem management. The costs of prevention and appraisal are composed of the other ICT management processes. We think that total cost of ICT management (total CoQ in Figure 2.16) behaves according to the classical view (left side in Figure 2.16), because it is possible to continue endlessly with improvement of organization and procedures. The service to the customers will improve more and more, but the cost of ICT management will rise at a certain moment. The organizations that will be investigated in this research have relatively low ICT budgets and have relatively low quality levels, so we think that improving the COBIT maturity level will lower the total cost of ICT management.

As stated, this research is directed primarily at the productivity of the ICT conversion process and secondarily at the productivity of the business processes. Therefore we did not consider the possible improvement of Business-ICT alignment at a higher level of COBIT maturity, as indicated in Figure 1.2.

2.7.3 Cybernetic view on ICT management policies

The Operational ICT management activities in the ICT conversion process as defined in Figure 1.2 are controlled (or governed) by the ICT management policies at a higher level. In Figure 2.8 the Information Management Framework is represented from a control point of view, where ICT management policies can be posted at the structural and strategic level. The Operational ICT management activities are represented in Figure 2.9 and consist of Human Information Resources (HIR) controlling Technical Information Resources (TIR: infrastructure and applications) as also depicted in Figures 2.6 and 2.7. So the operational HIR can be considered as a Controlling Organ for the TIR as a Target System (Leeuw and Volberda 1996). We will use a system-theoretic model to deepen the understanding in the impact of ICT management policies on the ICT conversion process and the Business processes (as represented in Figure 1.2). In Figure 2.17, right hand side, the control of a Target System TS by a Controlling Organ CO is represented. The *control capability* of CO (Leeuw and Volberda 1996) is determined by 5 aspects: CO has a (1) goal (or norm), a (2) model of the TS (in its environment) and a (3) limited information processing capacity; based upon the (4) information about the TS, (5) control of the TS is exercised by CO. For this moment we limit ourselves to the internal control and do not describe the external control of the environment of the system by CO.

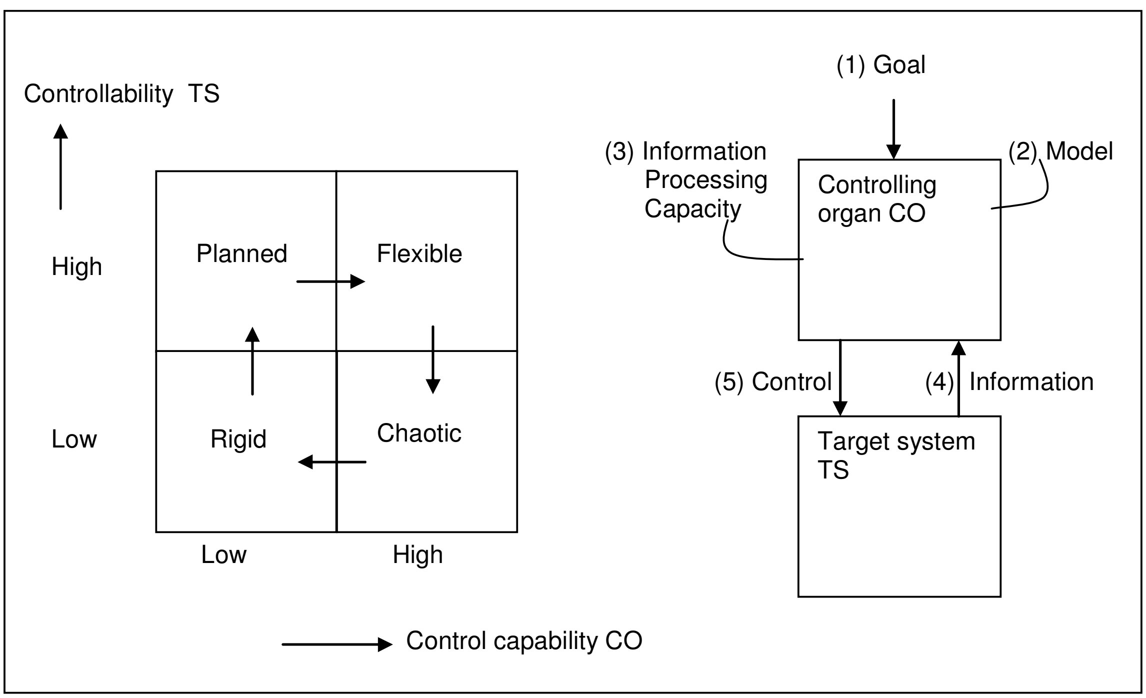


Figure 2.17 Control Target System TS by Controlling Organ CO

The *controllability* of TS is determined by the amount of information that has to be processed by CO to generate control actions: if a little (c.q. large) amount of information has to be processed, then TS has high (c.q. low) controllability. A large amount of information is coupled with a complex model, a large information processing capacity and more complicated control actions. If two TS's have the same basic components, then the amount of information is determined by the amount of relations between these components: in a situation of disorder there are more relations than in structured situation. Therefore a high entropy (or disorder) of the TS results in a more complex model, large amount of information, a high information processing capacity of CO and more complicated control actions. This is the situation of a high requisite variety (Ashby 1958).

If TS has a high controllability, then effective control of that system can be executed with less effort by the CO, compared with TS with a low controllability. If a CO has a high control capability, then effective control of a certain TS can be executed with less effort by the CO, compared with a CO that has a low control capability. If CO has a limited control capability in relation to the necessary control effort for TS, then it is only able to execute operational control, to keep the TS going. If CO has sufficient control capability to execute the necessary control effort, then it is also able to change the structure of TS, to fulfil the requirements of the environment (Heylighen and Joslyn 2001).

In Figure 2.17, left hand side, the four possible control situations are represented (Volberda 1996):
Rigid: *low* controllability of TS (large amount of information necessary / large requisite variety) combined with a *low* control capability of CO (limited information processing capacity): CO is only able to execute operational control, to keep the TS going. There is no effort left to change the structure of TS; therefore the requirements of the environment cannot be fulfilled, which is the meaning of the word "rigid".
Planned: *high* controllability of TS (little amount of information necessary) combined with a *low* control capability of CO (limited information processing capacity): a limited amount of effort is available to change the structure of TS. The priority of these changes is to keep a simple structure of TS. There is not enough capability to fulfil immediately the requirements of the environment, but it is possible to plan the changes (which is the meaning of the word "planned").
Flexible: *high* controllability of TS (little amount of information necessary) combined with a *high* control capability of CO (large information processing capacity): a large amount of effort is available to change the structure of TS. There is enough capability to fulfil immediately the requirements of the environment, which is the meaning of the word "flexible".
Chaotic: *low* controllability of TS (large amount of information necessary) combined with a *high* control capability of CO (large information processing capacity): a limited amount of effort is available to change the structure of TS. The priority of these changes is to fulfil immediately the requirements of the environment (keep the customer happy on the short term), at the cost of a complex structure of TS. The high resulting level of disorder in the TS is characterized by the word "chaotic".

Translation of system-theoretic principles to the ICT conversion process

Let us translate these system-theoretic principles to the ICT conversion process. TS consists of ICT assets (applications, infrastructure and users (Soh and Markus 1995)) and CO is the

ICT management (human resources responsible for *operational* control of ICT assets). The *control capability* of CO is determined by the 5 mentioned aspects. The goal (1) is to keep business (ICT users in business processes) and ICT (applications and infrastructure) aligned. The model (2) that CO has of TS is the knowledge (formally captured and "in" the ICT people) of TS. The limited information processing capacity (3) is determined by automated control systems, human procedures and by the experience of the ICT people to solve problems and to prepare and execute changes. Information (4) of TS is produced automatically (hardware / software) or via helpdesk (users). Control (5) is exercised by ICT people solving problems and executing changes. The effort to exercise control depends upon the degree of standardization of processes:

Low control capability: if there are no standardized processes, then ad hoc approaches are applied on an individual or case-by-case basis. Every problem and change is unique and the necessary effort is maximal. This is the case in a situation with a low ICT organization maturity.

High control capability: if processes are standardized and optimized, then economies of scale are possible to execute repeatable activities and the necessary effort can be minimized. This is the case in a situation with a high ICT organization maturity.

The *controllability* of TS is determined by the degree of standardization of ICT assets and the amount of information that has to be processed by CO to generate control actions:

High controllability: the degree of standardization is maximal if TS is built according to a service oriented layered architecture (Gartner Research 2003; Chappell 2004; Papazoglou and van den Heuvel 2007) which requires that infrastructural components are standardized and not outdated. In this ordered situation the amount of information to solve problems and implement changes is minimal. This is the situation when ICT management is focussed on infrastructure as a solid basis for applications, to be characterized as "*infrastructure driven*".

Low controllability: If TS is build from applications with their own unique hardware, operating system and middleware layers, then the infrastructure ages out of date with the applications (that have in general a longer life than infrastructure components). In this situation of disorder much more information is necessary to solve problems and implements changes. This is the situation when ICT management has primarily an external focus, to be characterized as "*application driven*".

Let's now consider in more detail the four situations in Figure 2.17 from the (operational) ICT conversion point of view:

Rigidity: there is a low level of organizational maturity, the focus is application driven and there is insufficient attention for the ICT infrastructure.

A lot of individual energy is spent to do the maintenance of the islands of individual applications.

For the users this is a situation of rigidity, because all the energy is spent on problem and symptom solving.

We expect that this situation requires relatively the most HIR effort, because all energy is in maintenance and problem solving.

Planned: there is still a low level of organizational maturity, the focus is infrastructure driven and there is now management attention to upgrade the ICT infrastructure.

There is a vision to change the ICT infrastructure conform an overall architecture. However there is little attention for the users' demand for applications, as there is no structured communication between users and ICT department. In this situation the right things (in the sense of a vision) are done in the wrong (in the sense of immature) way.

We expect that in this situation total ICT expenditure is lower than in the situation of rigidity, because there is less outdated hardware/software and less energy spent on problem solving.

Flexibility: the ICT maturity is sufficient and there is a balanced spending on infrastructure renewal (caused by the infrastructural focus) and new applications.

There is enough vision and enough budgets to implement the right infrastructure and applications portfolio.

The ICT department is able to react in a flexible way on changes in business processes

We expect that this situation requires relatively the least HIR effort, because the right things are done in the right way.

Chaos: the ICT maturity is sufficient, but too much spending on new applications whereas the ICT infrastructure gets insufficient attention (caused by the focus on applications). This is a situation of strategic chaos.

There are enough procedures, but not enough vision (or power to implement a vision) to invest sufficiently in the infrastructure.

The consequence is a chaos in the development of different applications without an overall architecture. In this situation the wrong things are done in the right way, because there is no balanced ICT strategy. This situation often happens when the ICT management is insufficiently high positioned in the organization: the ICT organization is a "puppet on a string" in the hands of influential people in the organization. This often happens in "professional bureaucratic" organizations (Mintzberg 1979), like for example hospitals, where the real power is part of the "operating core".

We expect that in this situation total ICT expenditure is higher than in the situation of flexibility.

These four situations can be positioned in the ICT management framework (Figure 2.7) in terms of where is the place (power) of the ICT decision making.

Planned: strategy level, technology column, as there is an infrastructure focus and the ICT manager has the power to build an infrastructural base. The business accepts this situation (of an application development stop) with the promise that in the future there is more room for application implementation.

Flexible: strategy level, I/C column, as there is a CIO with vision, power and enough budgets to implement the right infrastructure and applications portfolio. The business wants more applications, but accepts the necessary investments in infrastructure.

Chaos: strategy level, business column, as the ICT organization is a "puppet on a string" in the hands of influential people in the organization, that want their applications implemented. For example in hospitals it often happens that certain medical specialists convince general management of the necessity of an application, that has to be implemented immediately, in spite of the fact that there is a big overlap in functionality with other applications.

Rigidity: strategy level, business column, this is comparable with the chaos situation, as far as the relative low power of the ICT department is concerned. However, as the organizational maturity is low and the infrastructure is also outdated, the ICT organization is not able to implement the necessary applications quickly. This causes a situation of rigidity for the users in the business.

Relation of the control concept with the view on ICT

The four different control concepts can be related with the view on ICT of the organization:

Planned: if an organization has a "utility view" (Weill and Broadbent 1998) on ICT and a relatively low level of ICT maturity, it should concentrate its ICT investments on infrastructure and transactional applications. With insufficient attention for the ICT infrastructure, the organization runs the risk to come into a situation of rigidity.
In this situation of scarce financial resources for ICT there is however also a danger of insufficient spending on applications, with negative consequences for the support of business processes by applications. Thus there is a delicate balance between investments in infrastructure and in applications (Enns et al 2001; Enns et al 2003).
Flexibility: if an organization has an "enabling view" (Weill and Broadbent 1998) on ICT and a relatively high level of ICT maturity, it makes sense to invest in informational and strategic applications (on top of a mature infrastructure and transactional applications). However with insufficient attention for the ICT infrastructure, the organization runs the risk to get into a situation of chaos.

Growth of the ICT conversion process to a higher level of control and stability

If an organization is in a situation of chaos, then it is not easy to go back to a situation of flexibility. It is not enough to spend more on infrastructure, because the dismantling of the spaghetti of applications requires first a situation of rigidity, in which the specifications are frozen and the organization has to accept that it has an ICT-problem. After that a solid infrastructural base has to be built in a planned situation with only the necessary application development. If the infrastructure is in place there is room for a new system of applications within the framework of application architecture, to reach a situation of flexibility. Very often organizations slowly and imperceptibly grow after some years to a situation of chaos again, after which a new transition is necessary (according to the arrows in Figure 2.17). The growth of systems by a continuous transition to higher level (nearly decomposable) units is already extensively described (Simon 1962; Turchin 1990). The transitions from flexibility to chaos and from chaos to order are central themes in complexity theory (Prigogine and Stengers 1984; Holland 1996). These ideas have been applied to the functioning of organizations (Leeuw and Volberda 1996; Volberda 1996), but we could not find references in the ICT domain.

2.8 Conclusion

The theoretic foundations in this research consist of three pillars. Firstly the science of cybernetics and complexity, which is treated extendedly, because this will be used in various parts in this research. The control concept will be used in the definition of the basic hypothesis H1 and the complexity concept will be used to explain (dis)economies of scale in the conversion of ICT expenditure to ICT assets. Secondly the Resource Based View (RBV) as a fundament for the definition of ICT assets and ICT management. Thirdly the economic theories about economies of scale.

Upon these pillars we have built the theories that are construct specific. In this chapter we treated the theoretical foundations of ICT management policies, concerning ICT infrastructure and ICT organization. In the next chapter we will further elaborate the ICT conversion process from ICT expenditure to ICT assets and the Business processes from ICT assets to Organization performance.

3 CONSTRUCTS, HYPOTHESES AND PROXIES

3.1 Introduction

In this chapter we will define the basic hypothesis H1 of this research concerning the relations between (1) efficacy of ICT management policies, the (2) ICT expenditure and the (3) scale of ICT assets. Subsequently these three constructs will be further elaborated: for every construct an additional proxy is defined as a further specification and refinement of hypothesis H1. ICT expenditure will be defined using the theory of Total Cost of Ownership, according to Maanen and Berghout (2001). The definition and measurement of the scale of ICT assets will be elaborated based upon theories of complexity. The efficacy of ICT management policies, concerning ICT infrastructure and ICT organization will be based upon the theories treated in chapter 2. Furthermore hypothesis H2 between the (1) efficacy of ICT management, the (3) scale of ICT assets and the (4) Organization performance is defined. Finally the relations between constructs, hypotheses and proxies are made explicit in a research model.

3.2 Basic hypothesis (H1)

In this section we will first elaborate some principles of economies of scale, as presented in the theory section in chapter 2. Afterwards the basic hypothesis H1 will be derived. In Figure 3.1 the relation between scale and expenditure is represented, based on McConnell (1945) and Stigler (1958). In Figure 3.1 the positive and negative effects of Figure 1.2 are illustrated: if scale < S1 then economies of scale are stronger than diseconomies of scale; if scale > S2 then diseconomies of scale are stronger; if S1 <= scale <= S2 then there is a balance between the two effects. It is however obvious that these two effects, considered separately, are present at every scale level and are affected by ICT management policies.

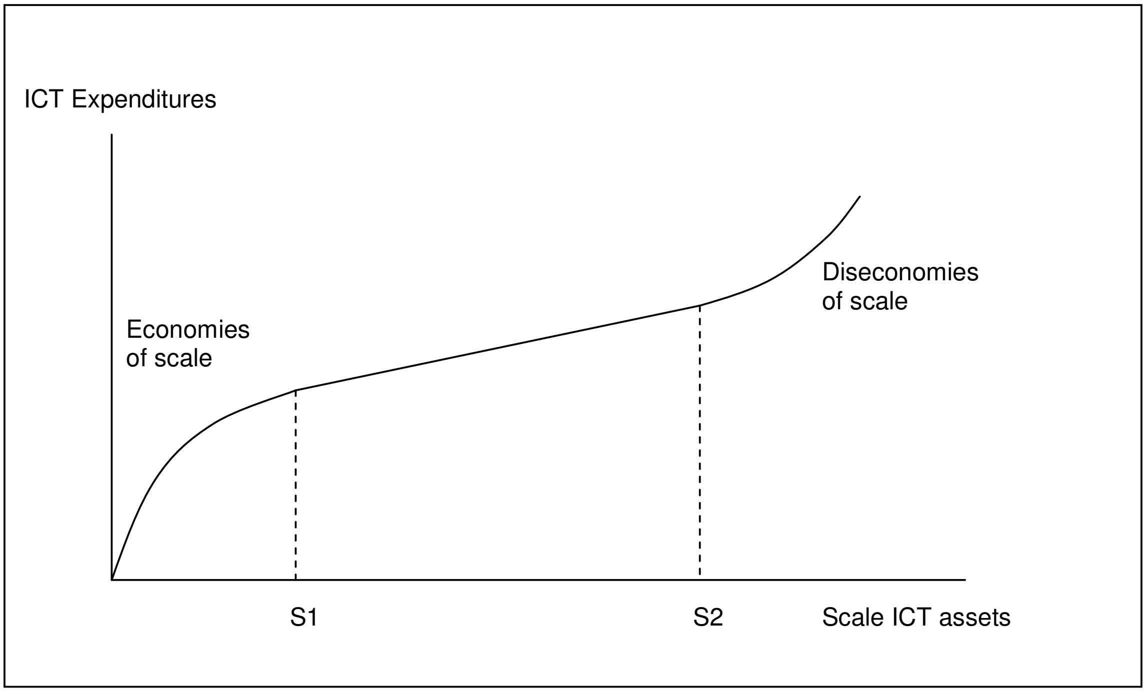


Figure 3.1 Relation between scale ICT assets and ICT expenditure

The basic hypothesis in this research study is that the efficacy of ICT management policies determines the productivity of the operational ICT conversion process, thus:

(H1) When the (1) efficacy of ICT management policies is low, the (2) ICT expenditure is higher than average, given the (3) scale of ICT assets.

And vice versa,

(H1') When the (1) efficacy of ICT management policies is high, the (2) ICT expenditure is lower than average, given the (3) scale of ICT assets.

Next, we will discuss the hypothesis in more detail. To explain the transformation trajectory from inputs to outputs (Figure 1.2), we use a process perspective (Melville et al. 2004) and a production function. In prior work on the ICT productivity impact, production functions have been used to relate output to several inputs, including ICT (Mukhopadhyay et al.1997; Brynjolfsson and Hitt 2003; Haynes and Thompson 2000; Wagner and Weitzel 2007).
The hypotheses can be defined in terms of a Cobb-Douglas production function (Cobb and Douglas 1928) where:
Scale of ICT assets = x
ICT expenditure = y
Consequently, $y = a.x^b$, and:
Low efficacy of ICT management policies: diseconomies of scale and b(low) >1 (H1)
High efficacy of ICT management policies: economies of scale and b(high) < 1 (H1')

In Figure 3.2 these relations are depicted graphically by the unceasing lines. The dotted line in Figure 3.2 for all organizations has the same shape as the line in Figure 3.1.

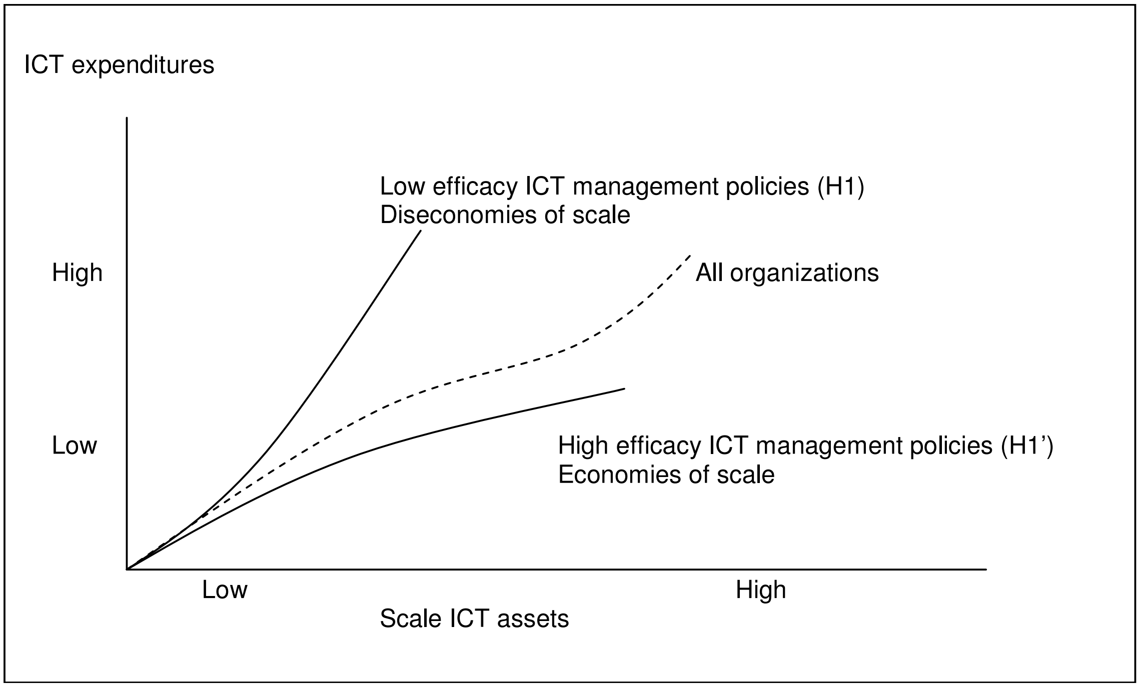


Figure 3.2 ICT expenditure = f (ICT assets, ICT management policies)

So Figure 3.1 can be translated into the low efficacy policies line in Figure 3.2 when S1=S2=0, and into the high efficacy policies line when S1$\rightarrow \infty$. Thus the assumptions with respect to hypothesis H1 are:
Organizations where the efficacy of ICT management policies is high never reach point S1.
To organizations where the efficacy of ICT management policies is low applies: S1=S2=0.

Note that we will not investigate the exact form of the dotted line for all organizations in Figure 3.2 (the line in Figure 3.1). There is a debate in software engineering about the question why this isn't a straight line (Kitchenham 2002). In that case the effects of economies and diseconomies of scale are equally strong at all scales. Also in that situation we can maintain our hypothesis H1, so the exact form of the line in Figure 3.1 is not important for this research.

In the next chapters the three constructs will be further elaborated.

3.3 ICT expenditure (P1)

In this section proxy P1 concerning the definition and measurement of ICT expenditure will be formulated. Different models of Total Cost of Ownership (TCO) assessment and benchmarking are described by Maanen and Berghout (2001), David et al (2002), and Gartner Consulting (2007). The TCO of an organization can be defined as all the costs associated with the ownership and use of ICT by the organization over a certain period of time. These models distinguish themselves from the general cost models in that they consider *all* costs of a certain ICT *object* (facility, system or component) over the *entire life cycle* of this object. TCO models force one to consider ICT expenditure beyond the initial investment, i.e. throughout the entire life cycle of the information systems. Furthermore, they predefine the cost categories and, consequently, help one not to overlook particular types of costs. The actual value that is measured depends on both the timeframe and the point of reference. For example, an ICT organization that provides a certain information system will experience different costs and a different TCO value than the individual business units using this system. In this research the following types of costs are considered:

a) Total ICT expenditure (= sum of hardware/software and personnel, including innovation): an important goal of ICT management is to minimize the Total ICT expenditure at a given scale of ICT assets. This results in the “total productivity” (Tangen 2005).
b) Costs of ICT personnel engaged in operations and maintenance: the relation between ICT management practices and operational ICT staffing levels is an important research topic (IDC 2007). This results in the “operational labour productivity” (Tangen 2005).

It is assumed that the FTE (Full Time Equivalent) costs per year concerning ICT operations and maintenance is a better estimator of ICT expenditure than the total ICT costs per year, because the scale of ICT assets is the only determinant of the FTE costs of ICT operations and maintenance. During one particular year, a major project may have a great impact on the total ICT costs. The ICT assets created by this project, however, could well remain in operation for many more years to come. Therefore, the following proxy assumption concerning ICT expenditure can be defined:

(P1) The cost of ICT human resources concerning operations and maintenance is a better measure of the (2) ICT expenditure construct than the total ICT cost.

P1 implies that hypothesis H1 can be better validated when ICT expenditure is defined by the human resources required for ICT operations and maintenance than by the total ICT costs.

3.4 Scale ICT assets (P2)

In this section we will formulate proxy P2 concerning the definition and measurement of the scale of ICT assets. ICT assets are defined by Soh and Markus (1995) as (1) useful, well-designed applications, (2) flexible ICT infrastructures with good “reach” and “range” (Keen 1991, Weill and Broadbent 1998), and (3) high levels of user ICT knowledge and skills. As the complexity growth of ICT assets is a source of diseconomies of scale, we will define complexity in relation to the scale of ICT assets. In this section we will explain how the curves in Figure 3.2 arise, based on more or less proportional growth of complexity in relation to the scale of ICT assets.

As stated in theoretical section about complexity in chapter 2, complexity can be defined as the number of different elements and relations (the “ontological” view). As ICT assets can be considered as a system of interacting elements, we can state the following:
Complexity ICT assets = f(scale and relations concerning ICT assets).

With respect to benchmarking organizations of the same type (for example Housing Corporations), we believe that the levels of user ICT knowledge and skills are comparable in organizations of the same kind, because their business processes are similar. (This assumption will be discussed in section 6.3.1). So the differences in the complexity of organizations of the same scale are determined by the relations concerning ICT infrastructure elements, applications and users.

The second view on complexity is based on the quantity of information ("descriptive" view) to describe the vital system (Ashby 1973). The quantity of information to describe the ICT assets is assumed to depend on the cost of the ICT assets. So in this view the scale of ICT assets is measured by the cost of ICT assets.

These views on complexity will be further detailed in the next sections.

3.4.1 "Ontological" complexity view based on relations

In this section the "ontological" complexity of ICT assets is assumed to be dependant on the relations concerning ICT infrastructure elements, applications and users. First we will analyze the relation between scale and complexity in general. Afterwards this will be applied to the ICT environment.

Relation between scale and complexity in general

In Figure 3.3 an object model is presented of a system, consisting of N elements, maximum N*(N-1) relations between elements, Nt element types and maximum Nt*(Nt-1) relations between element types.

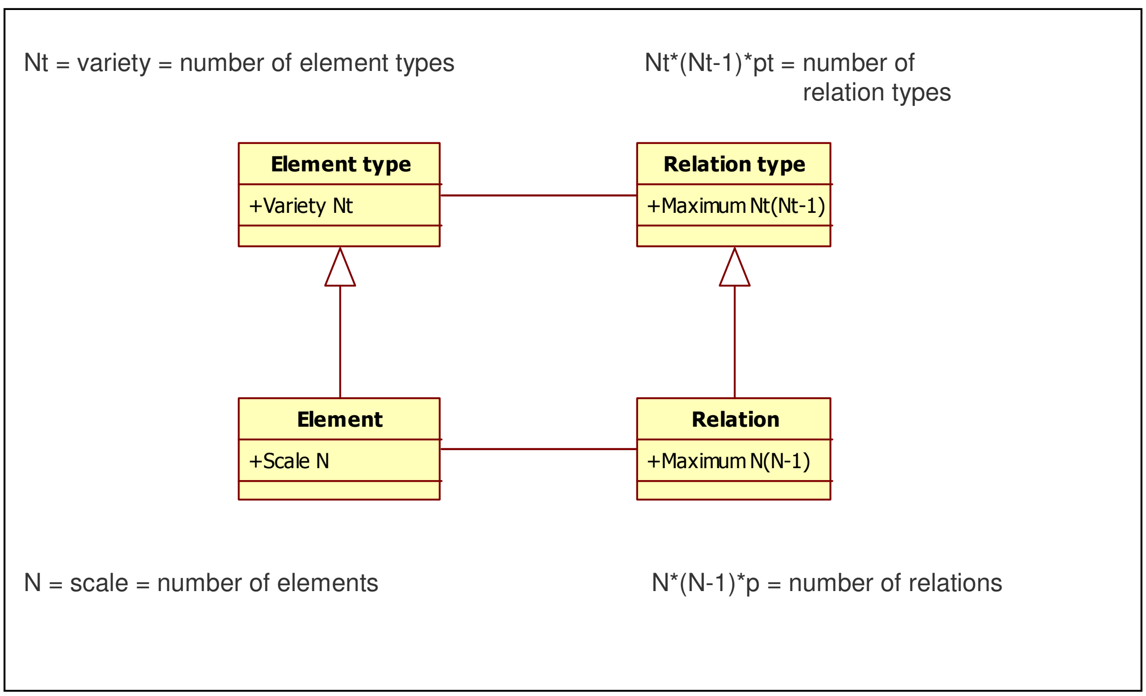


Figure 3.3 Object model of a system with elements and relations

Definitions of scale, relations and variety:
Scale = number of elements = N
Element relations = N*(N-1)*p, where p is the percentile [dimensionless] of relations between elements (if p=0 then there are no relations, if p=1 then every element is related to every other element, if 0<p<1 then some elements are related to some other elements, dependant of the value of p).
Variety = number of element types = Nt.
Element type relations = Nt*(Nt-1)*pt, where pt is the percentile of relations between element types (if pt=0 then there are no relation types, if pt=1 then every element type is related to every other element type, if 0<pt<1 then some element types are related to some other element types, dependant of the value of pt).
We assume that in general there is a variety growth when there is a scale growth. This can be expressed as: Nt = q*N (the lowest possible value of q=1/N when Nt=1 and the highest possible value of q=1, when Nt=N). The factor q is dimensionless.

Backlund (2002) defines complexity thus: "Since complexity is something perceived by an observer, the complexity of the system being observed is, one could say, a measure of the effort, or rather the perceived effort, that is required to understand and cope with the system." Using this concept, we define the effort to understand and cope with the system as the effort to understand and cope with elements, relations, element types and relation types.
This can be formalized as follows:

Complexity = N*a + N*(N-1)*p*b + Nt*at + Nt*(Nt-1)*pt*bt.

Where a, b, at and bt are the average effort to understand one element, one relation, one element type respectively one relation type.
However, the theory of economies of scale assumes that specialization leads to lower effort at higher scale: $N_2>N_1 \rightarrow (a_2<a_1$ and $b_2<b_1)$. This does not hold for element types, as they are all unique.
So the values of a and b are dependant of the values of N: a_N and b_N
A more precise definition of complexity is thus:

Complexity = $N*a_N + N*(N-1)*p*b_N + Nt*at + Nt*(Nt-1)*pt*bt$

This can be written (using Nt=q*N) as:

Complexity = $N*a_N + N*(N-1)*p*b_N + q*N*at + q*N*(q*N-1)*pt*bt$
$= N*(a_N - p*b_N + q*at - q*pt*bt) + N^2*(p*b_N + q^2*pt*bt)$

This can be further simplified to:

Complexity = N * (Factor 1) + N^2 * (Factor 2),
with:
Factor 1 = $a_N - p*b_N + q*at - q*pt*bt$
Factor 2 = $p*b_N + q^2*pt*bt$

The relation between scale (N) and complexity is depicted in Figure 3.4.

If the effect of economies of scale (caused by diminishing values of a_N and b_N at greater values of N) is stronger than the effect of diseconomies of scale (caused by N^2) then the resulting curve has the "less than proportional" form, else the resulting curve has the "more than proportional" form.

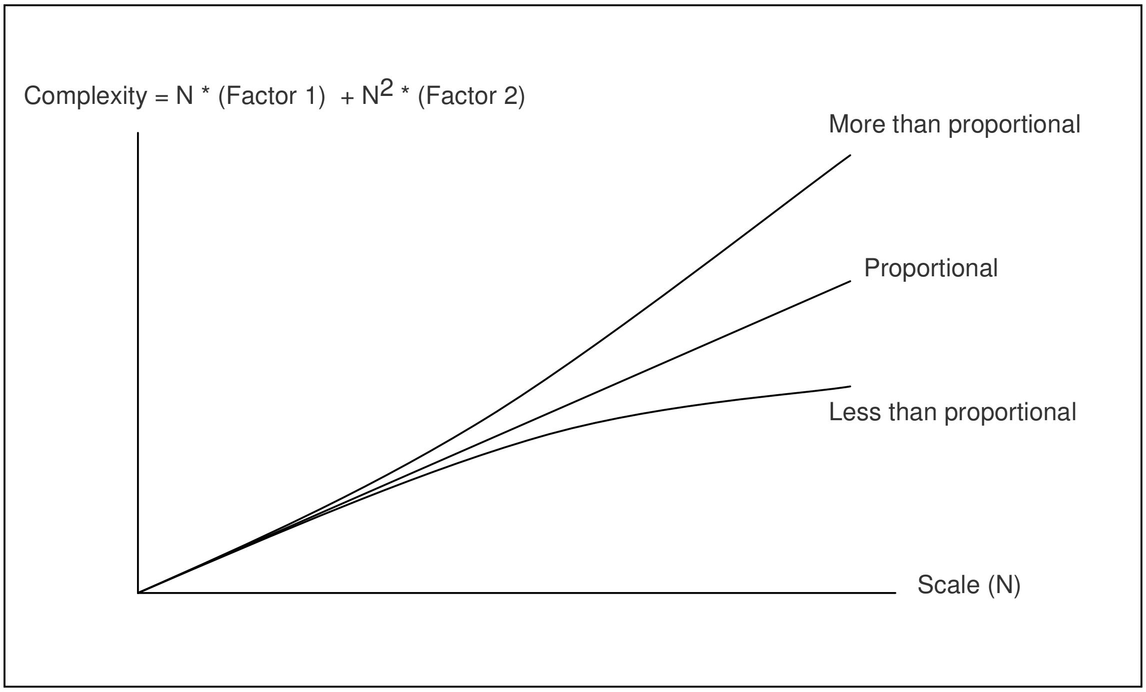


Figure 3.4 Relation between scale and complexity

Next we will find out whether the curves of Figure 3.4 also hold in the case of a system of ICT assets.

Relation between scale and complexity in the ICT environment

ICT assets are considered as a system of interrelated ICT infrastructure elements, applications and users. The relation between applications and infrastructure elements can be defined using the concept of services, which is described by various authors (Weill and Broadbent 1998; Dedene et al 2004). The elements in Figure 3.3 will be translated according to the IM framework at the operational level (Figure 2.9) in resources, services and users, see Figure 3.5. In this figure a difference is made between elements (users, services and resources) and element types (user types, service types and resource types) as in Figure 3.3:

At the operational level in Figure 2.9 and in Figure 3.5 we have the following entities:

Individual *users* are part of the Business. For example a person using the financial application SAP.

The application on the user-interface, and defined as user *service*, delivers Information to individual users. For example SAP on the desktop.

The user service is made up by different mainly infrastructural Technological *resources*. For example the server with the SAP database.

At a higher level in Figure 2.9 and in Figure 3.5 we find the entity types that are the generalizations of the entities at the operational level; this is the level of the development/test/acceptation environment:

User types can be considered as the key users that perform the test and acceptation of the applications. For example the key user for a SAP module.

User *service types* are the applications in the development/test/acceptation environment. For example the SAP module in the development/test/acceptation environment.

Resource types are the mainly infrastructure resources in the development/test/acceptation environment, that together provide for the user service type. For example the test server with the SAP test database.

The scale of the elements (*number of elements*) of the system in Figure 3.5 is defined as the cardinality of the sets of elements at the operational level: the number of users (o), the number of user services (n) and the number of resources (m).
The *number of relations* of the system in Figure 3.5 is defined as the cardinality of the sets of relations at the operational level: between users and user services (pus*o*n, where pus is the percentile of user-service combinations) and between user services and resources (psr*n*m, where psr is the percentile of service-resource combinations).
The variety of the elements (*number of element types*) of the system in Figure 3.5 is defined as the cardinality of the sets of element types: the number of user types (ot), the number of user service types (nt) and the number of resource types (mt).
The *number of relation types* of the system in Figure 3.5 is defined as the cardinality of the sets of relations at the type level: between user types and user service types (pust*ot*nt, where pust is the percentile of user type - server type combinations) and between user service types and resource types (psrt*nt*mt, where psrt is the percentile of service type – resource type combinations).
There are 1-n relations between the type level and the instantiations at the operational level.

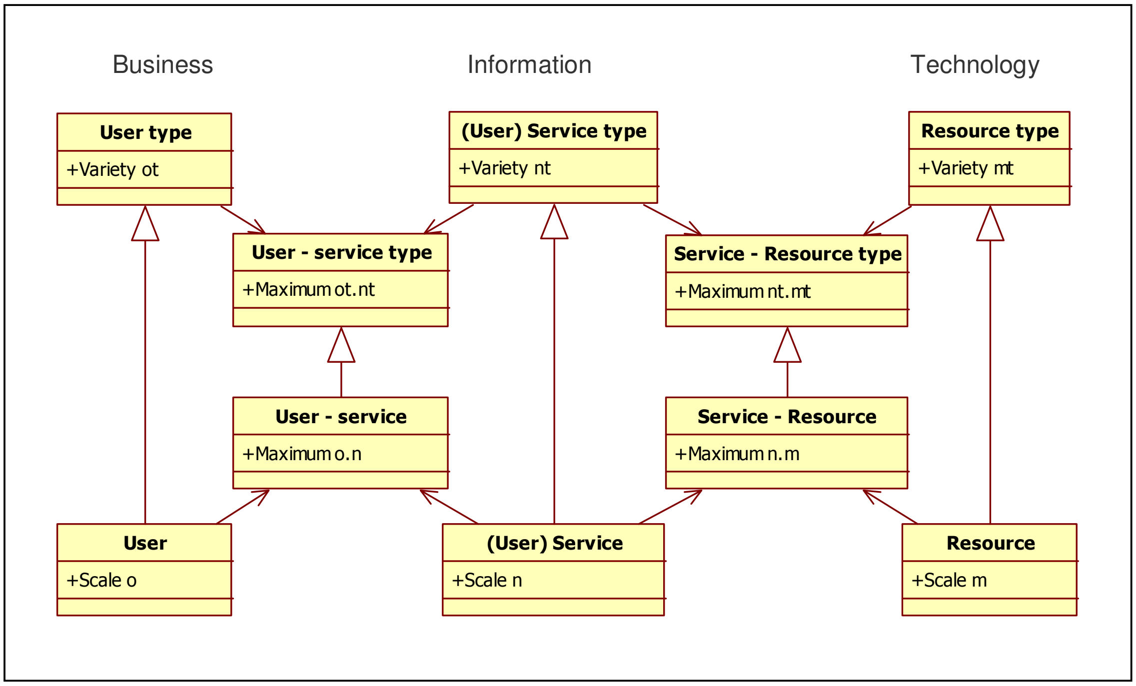


Figure 3.5 Object model of ICT assets

The complexity of the ICT system in Figure 3.5 at the *operational level* is determined by the effort (ICT labour) to handle the various elements and relations:

Number of different users (o). Every user needs to be administrated and needs more or less support, independent of the usage of the services, that generates a fixed amount of work per user (au). This type of effort (o*au) is called *user maintenance*.

Number of different user services (n). For every service there is a fixed amount of effort to *maintain the service* (as), independent of the number of users. This amount of effort (n*as) is defined as *service maintenance*.

Number of different resources (m). Every resource needs to be installed and maintained (effort ar), independent of the usage of the resource by services. We call this (total effort m*ar) *resource maintenance*.

Service-variety of users (the different user services per user (total pus*o*n)). Every service to a user needs more or less support; this is the variable amount of effort (bus) per user, dependant on the amount of service usage by the user. We call this (total effort pus*o*n*bus) *functional user service support*.

Resource-variety of user services (the different resources per user service (total psr*n*m)). Every resource for a user service needs more or less effort; this is the variable amount of effort (bsr) to assemble the user service, dependant on the amount of resource usage for the user service. We call this (total effort psr*n*m*bsr) *technical service delivery*.

The complexity of the ICT system in Figure 3.5 is at the *type level* determined by the effort (ICT labour) to handle the various element types and relation types:

User maintenance per user type (aut): the time to communicate with the user-representatives about the development, test and acceptance of the ICT system, independent of the services as such.

Total effort ot*aut.
Service maintenance per service type (ast): the time to develop and test a service type, independent of the resources and independent of the users.
Total effort: nt*ast.
Resource maintenance per resource type (art): time for installation, configuration, test and acceptance of the resource type independent of the service types.
Total effort mt*art.
User support per user type per service type (bust): the time to communicate with the user-representatives about development, test and acceptance of the service type.
Total effort pust*ot*nt*bust.
Service delivery per service type per resource type (bsrt): the time to develop and test the configuration of the resource type with respect to the service type.
Total effort psrt*nt*mt*bsrt.

Total complexity =
o*au + n*as + m*ar
+ pus*o*n*bus + psr*n*m*bsr
+ ot*aut + nt*ast + mt*art
+ pust*ot*nt*bust + psrt*nt*mt*bsrt

We will show now that the structure of this formula is the same as:

Complexity (Figure 3.4) = N * (Factor 1) + N^2 * (Factor 2)

First we will define an overall scale variable N with o = c_u*N and n = c_s*N and m = c_r*N, where c_u and c_s and c_r are factors [dimensionless] to determine the specific values of o and n and m in relation to N.
The same <u>assumption</u> holds for an overall scale variable Nt with ot = ct_u*Nt and nt = ct_s*Nt and mt = c_r*Nt.
Now we can translate the complexity as f(o,n,m,ot,nt,mt) in g(N,Nt):
Total complexity =
c_u*N *au + c_s*N *as + c_r*N *ar
+ pus* c_u*N * c_s*N *bus + psr* c_s*N * c_r*N *bsr
+ ct_u*Nt *aut + ct_s*Nt *ast + ct_r*Nt *art
+ pust* ct_u*Nt * ct_s*Nt *bust + psrt* ct_s*Nt * ct_r*Nt *bsrt

This can be written more simply as:

Total complexity =
N*(c_u*au + c_s*as + c_r*ar)
+ N^2* (pus* c_u* c_s*bus + psr* c_s*c_r*bsr)
+ Nt*(ct_u*aut + ct_s*ast + ct_r*art)
+ Nt^2 * (pust* ct_u* ct_s*bust + psrt* ct_s* ct_r*bsrt)

Now we can see clearly that Total complexity depends on N, Nt, N^2 and Nt^2. We can define this still more simply by <u>assuming</u> that Nt = q*N, so the number of types Nt grows proportionally with the scale N. The factor q is dimensionless. Then the formula gets the following form:

Total complexity =
$N*(c_u*au + c_s*as + c_r*ar)$
$+ N^2* (pus* c_u* c_s*bus + psr* c_s*c_r*bsr)$
$+ N*q*(ct_u*aut + ct_s*ast + ct_r*art)$
$+ N^2 *q^2* (pust* ct_u* ct_s*bust + psrt* ct_s* ct_r*bsrt)$

This can be written as:

Total complexity =
$N*(c_u*au + c_s*as + c_r*ar + q*(ct_u*aut + ct_s*ast + ct_r*art))$
$+ N^2* (pus* c_u* c_s*bus + psr* c_s*c_r*bsr + q^2* (pust* ct_u* ct_s*bust + psrt* ct_s* ct_r*bsrt))$

Now the structure of the formula is:

Total complexity = $N*$ (Factor 1) + N^2 * (Factor 2),
with:
Factor 1 = $c_u*au + c_s*as + c_r*ar + q*(ct_u*aut + ct_s*ast + ct_r*art)$
Factor 2 = $pus* c_u* c_s*bus + psr* c_s*c_r*bsr + q^2* (pust* ct_u* ct_s*bust + psrt* ct_s* ct_r*bsrt)$

We discussed already the assumption that the diminishing values of au, as, ar, bus and bsr at greater values of N are responsible for the economies of scale. So a more precise definition is:

Factor 1 = $c_u*au_N + c_s*as_N + c_r*ar_N + q*(ct_u*aut + ct_s*ast + ct_r*art)$
Factor 2 =
$pus* c_u* c_s*bus_N + psr* c_s*c_r*bsr_N$
$+ q^2* (pust* ct_u* ct_s*bust + psrt* ct_s* ct_r*bsrt)$

If the effect of economies of scale (caused by diminishing values of au_N, as_N, ar_N, bus_N and bsr_N at greater values of N) is stronger than the effect of diseconomies of scale (caused by N^2) then the resulting curve in Figure 3.4 has the "less than proportional" form, else the resulting curve has the "more than proportional" form.

The dimension of Factor 1 is the same as the dimension of a ([hour/piece] or [€/piece] in different variants au, as, ar, aut, ast and art), because c, p and q factors (in different variants) are dimensionless. This also holds for the dimension of Factor 2, which is the same as the dimension of b ([hour/piece^2] or [€/piece^2] in the variants bus, bsr, bust and bsrt). So the dimension of Total complexity can be time [hour] or cost [€].
In the next section we will define a view on complexity that is based on the amount of information to manage ICT assets.

3.4.2 "Descriptive" complexity view based on the quantity of information

In this view complexity is determined by the amount of information to describe a system (Asby 1973) of a certain scale, measured by the cost of the system. For the measurement of the amount of information we will use again the definition of Backlund (2002): "Since complexity is something perceived by an observer, the complexity of the system being observed is, one could say, a measure of the effort, or rather the perceived effort, that is required to understand and cope with the system". So we assume there is a relation between the cost of the ICT assets and the effort of ICT management to understand and cope with the ICT assets.

In this section we will first translate the scale of ICT assets, defined in cost [€] to the effort of ICT labour (= complexity ICT assets), defined in cost [€].
Based on Figure 3.5, the following ICT labour activities are defined on the *operational level*:

- *Resource maintenance per resource* (average value ar): effort for resource i: ar_i
- *Service delivery per service per resource* (average value bsr): effort to let use resource i by service j: $bsr_{i,j}$
- *Service maintenance per service* (average value as): effort for service j: as_j
- *User support per user per service* (average value bus): effort to support the use of service j by user k: $bus_{j,k}$
- *User maintenance per user* (average value au): effort to support user k: au_k

The effort of ICT-labour (= complexity ICT assets) will be determined based on the assumption that ar_i, as_j, au_k, $bsr_{i,j}$ and $bus_{j,k}$ depend on the cost of the concerning ICT assets.

In Figure 3.6 an overview is presented of the ICT assets and ICT asset types. Now the relation between resource (types) and service (types) is represented by an arrow, to indicate that the cost of resource (types) are "translated" to service (types). The same holds for the relation between service (types) and user (types). The cost of the ICT assets are as follows:

- The cost (cr_i) of the resource (r_i) is the starting point.
- The amount of resource usage per service ($f_{i,j}$) is the base of the distribution of the cost of resource (r_i) to the cost of service (s_j), see Figure 3.6, according to Dedene et al (2004).
- The cost (cs_j) of a service (s_j) is the sum of the distributed resource costs to that service.
- The amount of service usage per user ($g_{j,k}$) is the base of the distribution of the cost of service (s_j) to the cost of user (u_k) according to Dedene et al (2004).
- The cost (cu_k) of a user (u_k) is the sum of the distributed service costs to that user.

The relation between the cost of user services (cs_1 , cs_2 , ……. cs_n) and cost of resources (cr_1 , cr_2 , …….. cr_m) can be represented as follows (see Figure 3.6):

$$(cs_1 , cs_2 , \ldots\ldots cs_n) = F * (cr_1 , cr_2 , \ldots\ldots cr_m)$$

where F is a (n x m) matrix filled with factors $f_{i,j}$. The resource cost (cr_i) is distributed to the cost of the service (cs_j) according to a factor $f_{i,j}$ with $0 <= f_{i,j} <= 1$

The relation between the cost of users (cu_1 , cu_2 , ……. cu_o) and the cost of services (cs_1 , cs_2 , ……. cs_n) can be represented as follows:

(cu_1 , cu_2 , ……. cu_o) = G * (cs_1 , cs_2 , ……. cs_n)

where G is a (o x n) matrix filled with factors $g_{j,k}$. The service cost (cs_j) is distributed to the cost of the user (cu_k) according to a factor $g_{j,k}$ with $0 <= g_{j,k} <= 1$

The total cost of resources equals the total cost of services and the total cost of users:

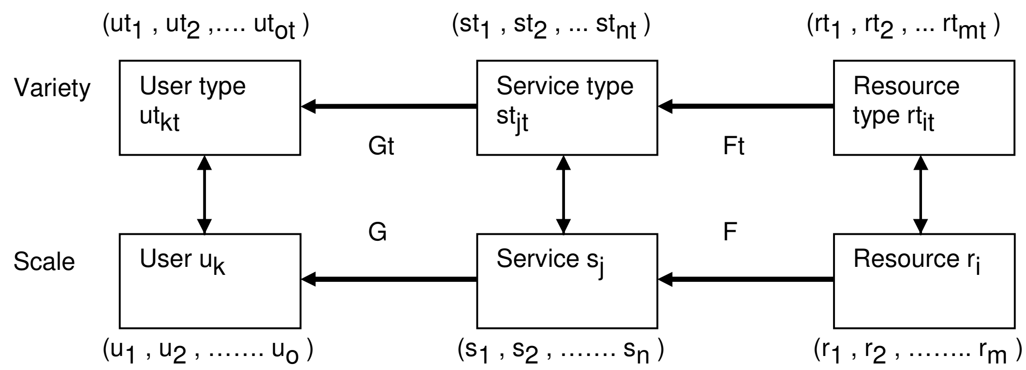
CA = $cr_1 + cr_2 + \ldots\ldots\ldots cr_m = cs_1 + cs_2 + \ldots\ldots\ldots cs_n = cu_1 + cu_2 + \ldots\ldots\ldots cu_o$

The total cost of ICT labour to handle technological resources is CLR, to maintain services is CLS, to deliver user support is CLU, to assemble resources to services is CLSR and to deliver services to users is CLUS. So total cost of ICT labour (= total complexity ICT assets at the scale (instantiation) level):

CL = CLR+CSL+CLU+CLSR+CLUS.

For every Euro [€] of resource cost an amount of CLR/CA [€] is spent on labour cost (resource complexity / scale ratio which is dimensionless).
The same holds for service labour:
(CLS/CA is the service complexity / scale ratio),
and for user labour:
(CLU/CA is the user complexity / scale ratio).
This rule can also be applied for resource-service labour:
(CLSR/CA is the resource-service complexity / scale ratio),
and for service-user labour:
(CLUS/CA is the service-user complexity / scale ratio).

Thus the ICT labour cost [€] for resource i: $ar_i = cr_i$ * CLR/CA.
For service j: $as_j = cs_j$ * CLS/CA
And for user k: $au_k = cu_k$ * CLU/CA
For resource i – service j: $bsr_{i,j} = f_{i,j} * cr_i$ * CLSR/CA
For service j – user k: $bus_{j,k} = g_{j,k} * cs_j$ * CLUS/CA



F = relation between resources and services = (n x m) matrix filled with factors $f_{i,j}$
G = relation between services and users = (o x n) matrix filled with factors $g_{j,k}$
Ft = relation between R-types and S-types = (nt x mt) matrix filled with factors $ft_{it,jt}$
Gt = relation between S-types and U-types = (ot x nt) matrix filled with factors $gt_{jt,kt}$

Figure 3.6 Process model of users, user services and resources

Based on Figure 3.5 and Figure 3.6, the following ICT labour activities are defined on the *variety-level*:

Resource maintenance per resource type (average value art): effort for resource it: art_{it}

Service delivery per service type per resource type (average value bsrt): effort to let use resource type it by service type jt: $bsrt_{it,jt}$

Service maintenance per service type (average value ast): effort for service type jt: ast_{jt}

User support per user type per service type (average value bust): effort to support the use of service type jt by user type kt: $bust_{jt,kt}$

User maintenance per user type (average value aut): effort to support user type kt: aut_{kt}

The effort of ICT-labour (= total complexity ICT assets at the type level) will be determined based on the assumption that art_{it}, ast_{jt}, aut_{kt}, $bsrt_{it,jt}$ and $bust_{jt,kt}$ depend on the cost of the concerning ICT asset types.

The cost of the ICT asset types are as follows:

The cost (crt_{it}) of the resource type (rt_{it}) is the starting point.

The amount of resource type usage per service type ($ft_{it,jt}$) is the base of the distribution of the cost of resource type (rt_{it}) to the cost of service type (st_{jt})

The cost (cst_{jt}) of a service type (st_{jt}) is the sum of the distributed resource type costs to that service type.

The amount of service type usage per user type ($gt_{jt,kt}$) is the base of the distribution of the cost of service type (st_{jt}) to the cost of user type (ut_{kt})

The cost (cut_{kt}) of a user type (ut_{kt}) is the sum of the distributed service type costs to that user type.

The relation between the cost of user service types (cst_1 , cst_2 , ……. cst_{nt}) and cost of resource types (crt_1 , crt_2 , …….. crt_{mt}) can be represented as follows (see Figure 3.6):

$$(cst_1 , cst_2 , \ldots\ldots\ cst_{nt}) = Ft * (crt_1 , crt_2 , \ldots\ldots crt_{mt})$$

where Ft is a (nt x mt) matrix filled with factors $ft_{it,jt.}$ The resource type cost (crt_{it}) is distributed to the cost of the service type (cst_{jt}) according to a factor $ft_{it,jt}$
with $0 <= ft_{it,jt} <= 1$
The relation between the cost of user types (cut_1 , cut_2 , ……. cut_{ot}) and the cost of service types (cst_1 , cst_2 , ……. cst_{nt}) can be represented as follows:

$$(cut_1 , cut_2 , \ldots\ldots\ cut_{ot}) = Gt * (cst_1 , cst_2 , \ldots\ldots\ cst_{nt})$$

where Gt is a (ot x nt) matrix filled with factors $gt_{jt,kt.}$ The service type cost (cst_{jt}) is distributed to the cost of the user type (cut_{kt}) according to a factor $gt_{jt,kt}$
with $0 <= gt_{jt,kt} <= 1$

The total cost of resource types equals the total cost of service types and the total cost of user types:

$$CAt = crt_1 + crt_2 + \ldots\ldots\ crt_{nt} = cst_1 + cst_2 + \ldots\ldots\ cst_{mt} = cut_1 + cut_2 + \ldots\ldots\ cut_{ot}$$

The total cost of ICT labour to handle technological resource types is CLRt, to maintain service types is CLSt, to deliver user type support is CLUt, to assemble resource types to service types is CLSRt and to deliver service types to user types is CLUSt. So total cost of ICT labour (= total complexity ICT assets at the type level):

CLt = CLRt+CSLt+CLUt+CLSRt+CLUSt.

For every Euro [€] of resource type cost an amount of CLRt/CAt [€] is spent on labour cost (resource type complexity / scale ratio which is dimensionless).
The same holds for service type labour:
CLSt/CAt is the service type complexity / scale ratio.
And for user type labour:
CLUt/CAt is the user type complexity / scale ratio.
This rule can also be applied for: resource type - service type labour:
CLSRt/CAt is the resource type - service type complexity / scale ratio.
And for service type - user type labour:
CLUSt is the service type - user type complexity / scale ratio.

Thus the ICT labour cost [€] for resource type it: $art_{it} = crt_{it} * CLRt/CAt$.
For service type jt: $ast_{jt} = cst_{jt} * CLSt/CAt$
And for user type kt: $aut_{kt} = cut_{kt} * CLUt/CAt$

For resource type it – service type jt: $bsrt_{it,jt} = ft_{it,jt} * crt_{it} * CLSRt/CAt$
For service type jt – user type kt: $bust_{jt,kt} = gt_{jt,kt} * cst_{jt} * CLUSt/Cat$

Until now we have determined the ICT labour cost as a measure of the complexity of every resource(type), service(type), user(type), resource-service relation(type) and service-user relation(type). This is based upon the assumption that there is a fixed cost-complexity ratio for every resource(type), service(type), user(type), resource-service relation(type) and service-user relation(type).

In the next section we will analyze the relation between the cost view and the number view on complexity.

3.4.3 Relation between the "ontological" and "descriptive" view on complexity

We now have two ways to determine the effort of ICT labour (= complexity ICT assets) to manage ICT assets, based on the definition of Backlund (2002). In the first way the *number* of ICT asset/relation(types) based on an "ontological" view on ICT assets is the starting-point; in the second way the *cost* of ICT asset/relation(types) based on an "descriptive" view on ICT assets is the point of departure to determine the effort of ICT labour. In the first way we use the average cost of ICT labour *per asset/relation(type)* and in the second case we use the average cost of ICT labour *per € of asset/relation(types)*. Next the average cost values of the number view will be expressed in the specific cost values of the cost view. Every cost component is followed by an indication ES (economies of scale possibility) or DES (diseconomies of scale possibility). These indications are the same as already discussed in the number view (Figure 3.4).

The following ICT labour activities on the *scale-level* in Figure 3.5 (the number view) can be expressed in terms of Figure 3.6 (the cost view):

Resource maintenance (m resources) = m*(average value ar) = $\sum_{i=1}^{m} ar_i$
→ ES (higher m → lower ar)

Service delivery (n services, m resources, percentile psr) = psr*n*m*(average value bsr)
= psr * $\sum_{i=1}^{m} \sum_{j=1}^{n} bsr_{i,j}$ → DES (quadratic effect n*m more important than ES bsr)

Service maintenance (n services) = n*(average value as) = $\sum_{j=1}^{n} as_j$
→ ES (higher n → lower as)

User support (o users, n services, percentile pus) = pus*o*n*(average value bus)
= pus * $\sum_{j=1}^{n} \sum_{k=1}^{o} bus_{j,k}$ → DES (quadratic effect o*n more important than ES bus)

User maintenance (o users) = o*(average value au) = $\sum_{k=1}^{o} au_k$
→ ES (higher o → lower au)

The same holds for ICT labour activities on the *variety-level*:

Resource maintenance (mt resource types) = mt*(average value art) = $\sum_{it=1}^{mt} art_i$
→ DES (by higher mt)

Service delivery (nt service types, mt resource types, percentile psrt)
= psrt*nt*mt*(average value bsrt)
= $psrt * \sum_{it=1}^{mt} \sum_{jt=1}^{nt} bsrt_{it,jt}$ → DES (by higher nt*mt)

Service maintenance (nt service types) = nt*(average value ast)
= $\sum_{jt=1}^{nt} ast_{jt}$ → DES (by higher nt)

User support (ot user types, nt service types, percentile pust)
= pust*ot*nt*(average value bust)
= $pust * \sum_{jt=1}^{nt} \sum_{kt=1}^{ot} bust_{jt,kt}$ → DES (by higher ot*nt)

User maintenance (ot user types) = ot*average value aut
= $\sum_{kt=1}^{ot} aut_{kt}$ → DES (by higher ot)

Total ICT labour in the cost view will be divided in two components: ICT labour 1 (which contains cost components with ES indications) and ICT labour 2 (which contains cost components with DES indications):

$$\text{ICT labour 1} = \sum_{i=1}^{m} ar_i + \sum_{j=1}^{n} as_j + \sum_{k=1}^{o} au_k$$

$$\text{ICT labour 2} = psr * \sum_{i=1}^{m} \sum_{j=1}^{n} bsr_{i,j} + pus * \sum_{j=1}^{n} \sum_{k=1}^{o} bus_{j,k} + \sum_{it=1}^{mt} art_{it} + \sum_{jt=1}^{nt} ast_{jt} + \sum_{kt=1}^{ot} aut_{kt}$$
$$+ psrt * \sum_{it=1}^{mt} \sum_{jt=1}^{nt} bsrt_{it,jt} + pust * \sum_{jt=1}^{nt} \sum_{kt=1}^{ot} bust_{jt,kt}$$

Total ICT labour = ICT labour 1 + ICT labour 2

If the effect of economies of scale in ICT labour 1 is stronger than the effect of diseconomies of scale in ICT labour 2 then the resulting curve in Figure 3.4 has the “less than proportional” form, else the resulting curve has the "more than proportional" form. The dimension of Total ICT labour is until now expressed in cost [€], but this can be translated in time [hour] if the appropriate tariffs per hour are used.

Before we continue with the definition of a proxy concerning the scale of ICT assets, we want to make three remarks, which can be derived from the complexity analysis above.
Firstly, *standardization* (keep mt, nt and ot as low as possible) is the key to attain economies of scale and to avoid diseconomies of scale:

The numbers of the same resources, services and users are greater when the types are as low as possible, so cost components ar, as and au will be minimized. This keeps ICT labour 1 as low as possible.

All the ICT labour activities on the variety-level will be minimized when the numbers of types are as low as possible. This keeps ICT labour 2 as low as possible.

Secondly, according to the definition of Backlund (2002) complexity of a system is a measure of the *perceived effort* to understand and cope with a system; this implies that the knowledge of the observer (or controller) of the system plays a pivotal role in the perception of complexity.
Thirdly, the relation between scale and complexity, as represented in Figure 3.4 is a support for *proxy assumption P1*; indeed, this is a theoretical underpinning of the relation between scale and ICT expenditure by HIR operations, as stated in proxy assumption P1.

Now we have made acceptable the possibilities for (dis)economies of scale of ICT labour in relation to the scale of ICT assets for two views on complexity: firstly if the effort (complexity) of ICT labour depends on the *number* of ICT asset/relation(types) and secondly if the effort of ICT labour depends on the *cost* of ICT asset/relation(types). We assume that the number view gives a better approximation of the effort (complexity) of ICT labour than the cost view. The number view is based upon *average* values of cost per ICT asset/relation(type), while the cost view is based upon the cost of every individual ICT asset/relation(type). We think that the "*Law of Large Numbers"* (Simon 1977) will cause a higher correlation between scale and complexity (on a higher level of aggregation) in case of the number view compared with the cost view. This is in accordance with the findings of Alpar and Kim (1990): they concluded that the usage of cost ratios for ICT performance may be misleading. Therefore the following proxy assumption concerning the scale of ICT assets can now be defined:

(P2) The number of ICT assets is a better measure of the (3) scale of ICT assets than the cost of hardware/software.

P2 implies that hypothesis H1 can be better validated by the number of ICT assets than by the cost of hardware/software. Besides there is a restriction: it is not allowed to measure the (3) scale of ICT assets by the cost of hardware/software and at the same time measure the (2) ICT expenditure by the total ICT costs, because this total also contains the cost of hardware/software. In the research model (Figure 3.10) the 3 *allowable* relations between the two measures of the (3) scale of ICT assets and the two measures of the (2) ICT expenditure are delineated by arrows numbered 1, 2 and 3.

3.5 Efficacy of ICT management policies (P3)

In this section proxy P3 will be formulated, concerning the definition and measurement of the efficacy of ICT management policies. The efficacy of ICT management policies is defined in this research as the ability of ICT management to govern an efficient and effective conversion from operational ICT expenditure to ICT assets. This implies that effective policies create the conditions for an efficient and effective ICT conversion process. Efficacy therefore refers to both optimal utilization of technological resources and labour (or skills), which has become increasingly important with respect to the leverage of commodities. In the following sections we will deal with the infrastructure policy and the maturity of the ICT organization, as stated in the theory section about ICT management policies.

The organizations investigated in this research (Housing Corporations, Municipalities and Hospitals) have relatively low expenditures on ICT, and can therefore be categorized as an organization with a "utility view" (Weill and Broadbent 1998). This is in contrast with the enabling view on ICT shared by, for instance, financial services, which spend more than 15% of their total expenditures on ICT. According to Weill and Broadbent (1998) Housing Corporations, Municipalities and Hospitals should concentrate on infrastructure and transactional applications. Lower ICT spending organizations often run the risk (by technological aging) that their investments in infrastructure are insufficient to replace their outdated hardware/software and to procure modern tools for hardware/software management. As a result these organizations do not attain economies of scale and are unable to counterbalance the complexity growth. We therefore believe that investments in infrastructure have a positive effect on economies of scale and a negative effect on diseconomies of scale. In Figure 2.17 and the next text, we made plausible that organizations with an infrastructure focus (planned and flexible), have more standardized ICT assets than organizations with an application focus (chaotic and rigid). And in Figure 3.5 and the next text we showed that standardized ICT assets lead to less complexity and lower ICT expenditure.

The importance of the quality system increases with the scale of the ICT organization, simply because a more complex organization is more complex to manage. Other effects of additional quality systems are the specialization of labour and an increase in the bureaucratic nature of the organizational structure. We expect that quality systems have a positive effect on economies of scale and a negative effect on diseconomies of scale. However, complex quality systems are also susceptible to bureaucratic rigidity, which is often associated with the not-for-profit Housing Corporations, Municipalities and Hospitals studied in this research. And bureaucracy leads to diseconomies of scale (Williamson 1996).
We stated already that total cost of ICT management (total CoQ in Figure 2.16) behaves according to the left side curve in Figure 2.16. The organizations that will be investigated in this research have relatively low ICT budgets and have relatively low quality levels, so we think that improving the COBIT maturity level will lower the total cost of ICT management. But we can also see in Figure 2.16 that this curve is almost horizontal in the neighborhood of the minimum. So the higher the maturity level, the less is the saving in ICT management costs, until the costs rise again at the right side of the minimum.

It can be stated that neglecting the infrastructure has more influence on the level of ICT expenditure than a low organizational maturity, because investments in infrastructure (in low ICT spending organizations) have both a positive effect on economies of scale and a negative effect on diseconomies of scale. A quality system (in a bureaucratic culture) has a positive effect on economies of scale and only a moderately negative effect on diseconomies of scale caused by bureaucratic rigidity. Furthermore the subjective determination of the maturity level, as described in section 1.4, gives rise to less confidence in the reliability of the maturity factor. Therefore, the following proxy assumption about the ICT management policies construct can be defined:

(P3) Investment in ICT infrastructure is a better measure of the (1) efficacy of ICT management policies construct than the maturity level of the ICT organization.

P3 implies that hypothesis H1 can be better validated when ICT management policies are defined by investments in infrastructure rather than by the maturity level of the ICT organization.

We can consider proxy P3 from a cybernetic point of view, as explained in Figure 2.17. The organizations investigated in this research have a relatively low level of ICT spending and ICT maturity. So these organizations can be positioned in the “Planned (P)” or “Rigidity (R)” quadrant of Figure 2.17. Thus the only important variable is the level of Infrastructure, to differentiate between P and R. This is in line with proxy P3.

3.6 Business productivity (H2)

We used the Information management framework (Maes 1999) to define the scope of the research model (see Figure 2.7). At the operational level services are delivered to the users in the business by TIR (Technical Information Resources). The HIR (Human Information Resources) in the nine blocks can be divided in two groups:

- Business HIR: this includes the “competitive process”, see Figure 2.14.
- Information/Communication and Technology HIR: this includes the “ICT conversion process” and the support of the “ICT use process”, see Figure 2.14.

ICT assets are defined as infrastructure, applications and users with appropriate knowledge (Soh and Markus 1995). ICT assets are delivered to users in the form of services (Figure 2.7): infrastructure services, application services and knowledge to use the services. The TIR is delivering infrastructure and application services; the HIR at operational I/C level is delivering the appropriate knowledge. The users at operational business level consume the services and translate them ultimately to some output of the organization, to be measured in the form of organization performance. The measurement of the services is a difficult point, especially as far as applications and knowledge is concerned. What is the value of applications for users? How can “ICT impacts” (see Figure 1.1 and Figure 2.14) be measured? See for example DeLone and McLean (1992, 2002) on this point. We assume that more and better services lead ultimately to more and better organization performance and we will not investigate ICT impacts.

Concerning the composition of the services there is always a tension between Business and Technology: users want their application services as specific as possible, to be able to optimize their business process; the ICT management prefers to deliver the application services as generic as possible, to be able to optimize the ICT processes. In Figure 2.15 the relation between infrastructure and applications is represented using the classification of Weill and Broadbent (1998). In this classification the shared and standard (transactional) applications are defined as part of the (extended) infrastructure. However in our research, due to availability of empirical data, we define the shared and standard applications as part of the whole of applications.

Thus the Business management wants to spend as much as possible on applications in order to optimize the business processes, and the ICT management wants to spend enough on infrastructure, in order to optimize ICT processes (as explained in section 2.7.3). From the point of view of the whole organization this can be defined as an optimization problem: what is the optimal spending on applications and infrastructure? In this research the investments in ICT infrastructure (as a measure of efficacy ICT management policies) were measured by the infrastructure part of the total ICT costs during the last years. This measure is called the Infrastructure Factor (IF), which will be further explained in chapter 4. In Figure 3.7 the relation between the Infrastructure Factor (IF) and Costs of ICT processes is represented: we assume that these costs decrease with increasing IF. On the other hand the Costs of Business Processes increase with increasing IF (and decreasing application functionality). Therefore there must be a minimum for the total costs (the sum of business costs and ICT costs) at a certain value of IF. We suppose there is a minimum value (Min) for IF below which the ICT expenditures rise more steeply and a maximum (Max) above which the business expenditures rise more steeply. Then there must be an area between Min and Max where total costs are more or less the same.

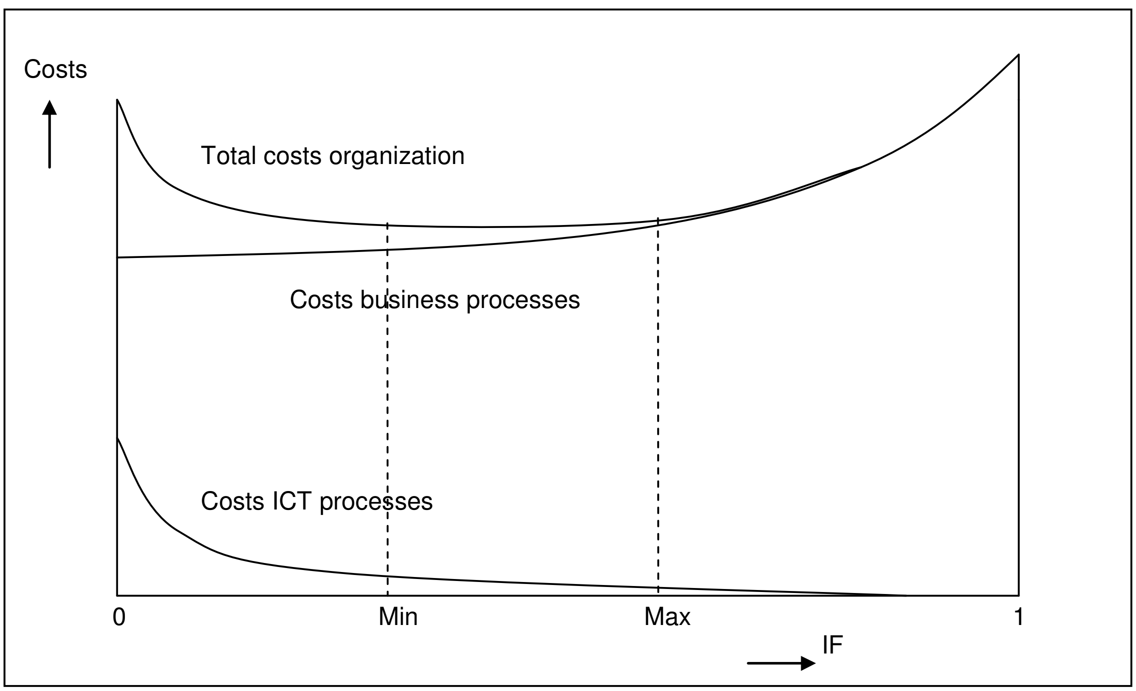


Figure 3.7 Relation between Infrastructure Factor and costs

For the determination of Min and Max we will use a process perspective and explain first the relations between input and output of the ICT conversion process and of the business processes (see Figure 1.2).

In chapter 3, basic hypothesis (H1), we explained the following:
The relation between the *output* (x) and the *input* (y) of the *ICT conversion process* is assumed to be a function of the form $y=ax^b$, see Figure 3.2. We think that in case of a low value of the infrastructure factor (IF) there is an effect of diseconomies of scale, therefore:
b(low efficacy ICT management policies) = b(IF low) >1.
In case of a high value of the infrastructure factor (IF) we assumed there is an effect of economies of scale, therefore:
b(high efficacy ICT management policies) = b(IF high) <1.
Hypotheses H1 is based on this idea,
with x = ICT assets,
and y = ICT expenditure
and productivity ICT conversion process = x/y.

The relation between the *input* (x) and the *output* (y) of the *Business processes* is also assumed to be a function of the form $y=ax^b$, see Figure 3.8.
Now x = ICT assets,
and y = Organization performance.

Therefore productivity business processes = y/x.
We think that in case of a low value of the infrastructure factor (IF) there is an effect of economies of scale (because of high spending on Applications), therefore b(IF low)>1; in case of a high value of the infrastructure factor (IF) there is an effect of diseconomies of scale (because of low spending on Applications), therefore b(IF low)<1. Note that the shape of the curves (in terms of IF low and IF high) in Figure 3.8 is opposite to the shape of the curves in Figure 3.2.

Also in the Business processes we assume the "ontological" complexity (see Figure 3.3) is growing with the square of the scale, which is the cause of diseconomies of scale, with lower than average Organization performance at higher scale as a result. If however these processes are structured and supported by applications, then economies of scale can be attained. Therefore the following hypothesis can be formulated:

(H2) When the (1) efficacy of ICT management policies measured by the Infrastructure Factor (IF) is low, the (4) organization performance is higher than average, given the (3) scale of ICT assets.

And vice versa,

(H2') When the (1) efficacy of ICT management policies measured by the Infrastructure Factor (IF) is high, the (4) organization performance is lower than average, given the (3) scale of ICT assets.

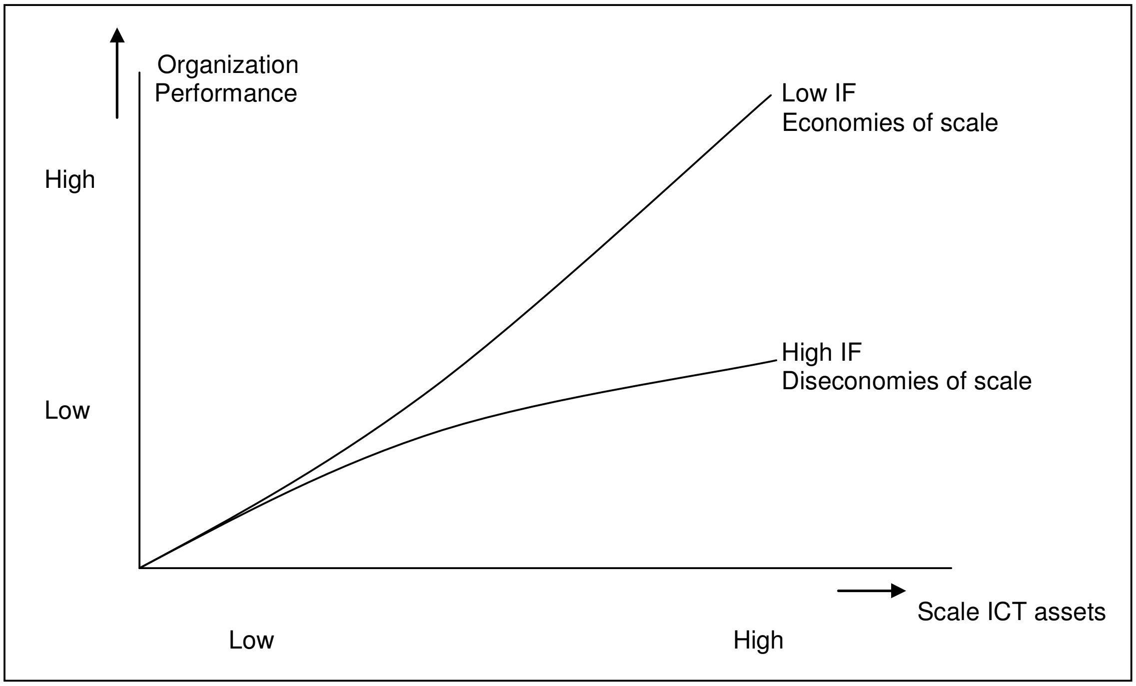


Figure 3.8 Relation between ICT assets and Organization performance

We will use "Turnover" as a measure of organization performance, to be able to compare this with the "Cost" of an organization. We assume that in the case of low IF (high spending on applications), the Margin (= Turnover - Cost) has a higher value than in the case of high IF (low spending on applications) at a certain value of ICT assets. According to Karimi et al (2007) "Greater IS resources …. are positively associated with higher business process outcomes". And Bharadway (2000) states: "Superior ICT capability will be associated with significantly higher profit ratios, and …. with significantly lower cost ratios". Also Santhanam and Hartono (2003) and Kim (2004) are drawing the same conclusion. This is visualized in Figure 3.9. The reason is that the organization (in the business processes) is working more efficiently in the case of high spending on applications, with more application functionality. Therefore we assume that more efficiency will result in less cost <u>and</u> in higher turnover.

Let us now determine the values of Min and Max in Figure 3.7.
We state that the value of Min is determined by the "Low efficacy ICT management policies" curve in Figure 3.2 for the ICT conversion process, because this is the diseconomies of scale curve. This curve can be considered as the "IF=Min" curve: organizations with an IF value less or equal to Min have diseconomies of scale in their ICT expenditure. Therefore, the points in Figure 3.7 with IF < Min have higher values of ICT costs. The determination of this Min ("low IF") value is part of the verification process of hypothesis H1.
In the same way the value of Max is determined by the "high IF" *cost* curve for the Business processes in Figure 3.9, because this is the diseconomies of scale curve. The points in Figure 3.7 with IF > Max have higher values of costs Business processes. The "high IF" value of the *cost* curve in Figure 3.9 is the same "high IF" value of the *turnover* curve in Figure 3.9. And the determination of this Max ("high IF") value is part of the verification process of hypothesis H2.

NB In the M&I dataset we do have Turnover and we do not have Costs to our disposition. So we are not able to formulate and analyze a hypothesis concerning Costs of the Business processes. Therefore we assume that in Figure 3.9 a lower IF (which means higher spending on Applications) leads to higher Turnover *and* lower Costs and thus higher Margin (as explained above and supported by references).

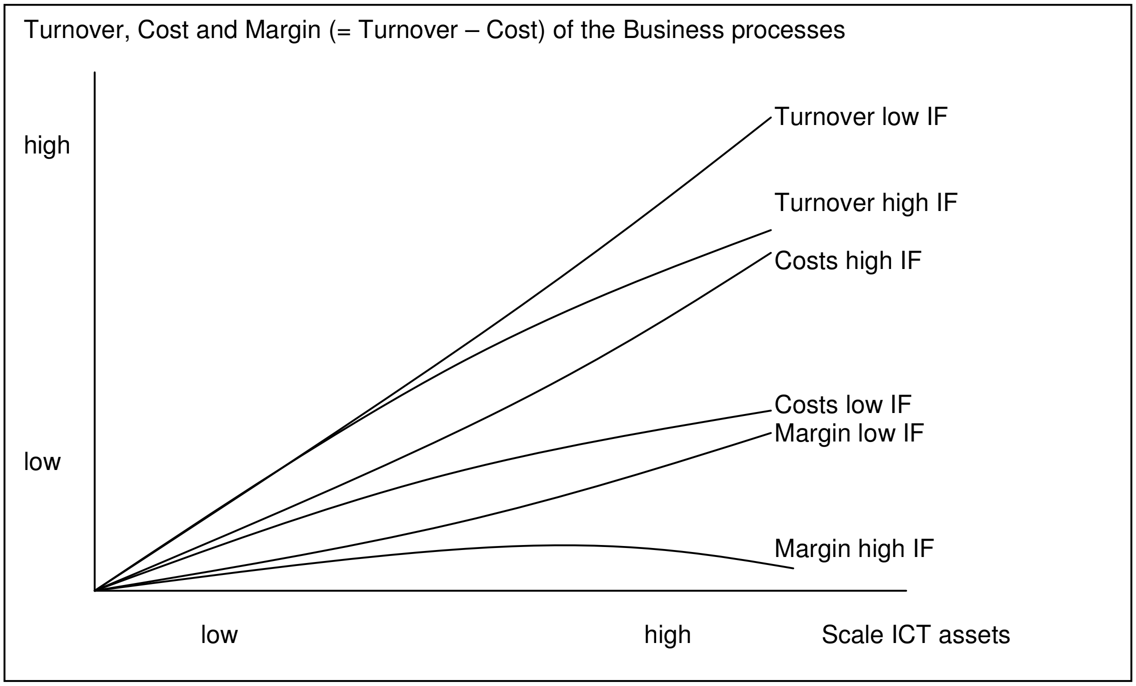


Figure 3.9 Relation between ICT assets versus turnover, cost and margin

The practical importance of the values of Min and Max for the Infrastructure Factor as a measure of efficacy of ICT management policies is that an advice can be given to ICT managers concerning the optimal composition of investments in infrastructure and applications. This is particularly important in organizations with a low level of ICT spending, with a "utility view" on ICT. In this situation the values on Min and Max will possibly coincide, and then there is a delicate balance between investments in infrastructure and applications.

Now that we have defined our hypotheses and proxy assumptions in detail, we are able to demonstrate the research model.

3.7 Research model

In this paragraph we first give an overview of definitions and hypotheses. Afterwards follows a research model with the relations between hypotheses, constructs and proxies.

3.7.1 Definitions

Below follows an overview of definitions of important terms (*constructs are numbered and printed italic*).

ICT conversion process = conversion ICT expenditure to ICT assets (Soh and Markus 1995)

Business processes = (conversion ICT assets to ICT impacts) + (conversion ICT impacts to organization performance) = conversion ICT assets to organization performance

ICT assets = infrastructure + applications + users (ICT assets are defined by Soh and Markus (1995) as (a) useful, well-designed applications, (b) flexible ICT infrastructures with good "reach" and "range" (Keen 1991, Weill and Broadbent 1998), and (c) high levels of user ICT knowledge and skills.)

Infrastructure = infrastructure system delivering infrastructure services = Information technology components (hardware and software) + human ICT infrastructure = workstations + peripherals + infrastructure data communications + servers and storage + communications speech and video + facilities + operating systems and middleware + human resources (see Figure 2.15)

Applications = application system delivering application services = software and software services + interfaces + databases + human resources (see Figure 2.15)

(1) Efficacy of ICT management policies = ability of ICT management to govern an efficient and effective conversion from operational ICT expenditure to ICT assets.
This implies that effective policies create the conditions for an efficient and effective ICT conversion process.
This is measured in the following ways:

- Investments in ICT infrastructure (as a result of the technology policy).
- Maturity of the ICT organization (as a result of the human infrastructure policy).

(2) ICT expenditure is defined in two possible ways:

- Total ICT costs (= sum of hardware/software and personnel, including innovation)
- Costs of ICT personnel engaged in operations and maintenance

(3) Scale of ICT assets is defined in two possible ways:

- Number of ICT assets.
- Cost of hardware / software (excluding cost of ICT human resources).

Complexity of ICT assets = effort of ICT labour to handle ICT assets (Backlund 2002)
= f (scale of ICT assets)

(4) Organization performance = output of the "competitive process" (Soh and Markus 1995), in this research measured by the turnover of the organization.

Productivity = output / input (Chew 1988)

Productivity ICT conversion process = (3) scale ICT assets / (2) ICT expenditure

Productivity Business processes = (4) organization performance / (3) scale ICT assets

3.7.2 Hypotheses and proxies

In the preceding sections we have derived the following hypotheses and proxy assumptions:

(H1) When the (1) efficacy of ICT management policies is low, the (2) ICT expenditure is higher than average, given the (3) scale of ICT assets.
(H1') When the (1) efficacy of ICT management policies is high, the (2) ICT expenditure is lower than average, given the (3) scale of ICT assets.
(P1) The cost of ICT human resources concerning operations and maintenance is a better measure of the (2) ICT expenditure construct than the total ICT cost.
(P2) The number of ICT assets is a better measure of the (3) scale of ICT assets than the cost of hardware/software.
(P3) Investment in ICT infrastructure is a better measure of the (1) efficacy of ICT management policies construct than the maturity level of the ICT organization.
(H2) When the (1) efficacy of ICT management policies measured by the Infrastructure Factor (IF) is low, the (4) organization performance is higher than average, given the (3) scale of ICT assets.
(H2') When the (1) efficacy of ICT management policies measured by the Infrastructure Factor (IF) is high, the (4) organization performance is lower than average, given the (3) scale of ICT assets.

3.7.3 Relations between hypotheses, constructs and proxies

In this section the relations between hypotheses, constructs and proxies will be represented as part of a research model. The second proxy assumption (P2) is that the number of ICT assets is a better measure of the (3) Scale of ICT assets than the cost of hardware/software. There is however a restriction: it is not allowed to measure the (3) scale of ICT assets by the cost of hardware/software and at the same time measure the (2) ICT expenditure by the total ICT costs, because this total also contains the cost of hardware/software. In the research model (Figure 3.10) the 3 allowable relations between the two measures of the (3) scale of ICT assets and the two measures of the (2) ICT expenditure are delineated by arrows numbered 1, 2 and 3. So the fourth possible relation between the cost of hardware/software and the total ICT cost is not drawn. This implies that the scope of proxy P2 is restricted to the arrows 2 and 3 and that the scope of proxy P1 is restricted to the arrows 1 and 2. This also means that hypothesis H1 will be tested firstly by the combination of arrows 1 and 2 and secondly by the combination of arrows 2 and 3.

H1 and H2 are relations *between* constructs; P1, P2 and P3 are related to the *definition of variables* that measure a construct, serving as refinements of H1 in this respect.
In the following chapter an additional proxy P2a will be defined, based on the *way of measurement* of the variable "number of ICT assets".

The constructs, hypotheses and proxies elaborated are represented in a research model (Figure 3.10). The position of hypotheses H1-H2 (thick arrows) and proxies P1-P3 (thin arrows) in relation to the respective constructs is indicated in Figure 3.10. The scope of P2a as a further refinement of the measurement of the number of ICT assets (which will be elaborated in the next chapter) is also indicated in Figure 3.10.

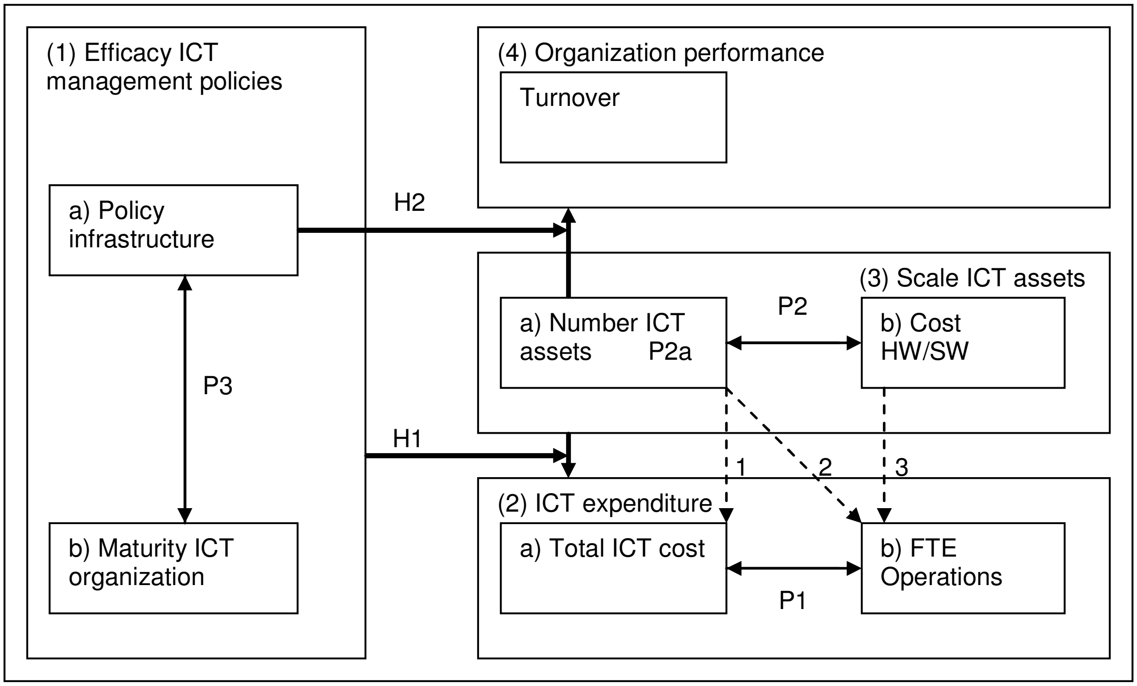


Figure 3.10 Research model

Next, we will relate our line of reasoning, hypotheses and approximations to the exploratory analysis of the data.

4 METHOD AND DATA

4.1 Introduction

In this chapter we present our empirical data sets. After that, we will deal with the measurement of the constructs. An additional proxy P2a will be defined, based on the way of measurement of the number of ICT assets. Then the research methodology is explained. The productivity is determined in two ways: the *absolute* productivity (= scale ICT assets / ICT expenditure) and the *relative* productivity using Data Envelopment Analysis (Charnes et al 1978).

4.2 Empirical data sets

Since 2002, consultancy firm M&I/Partners has carried out a yearly investigation to review the costs and maturity of ICT in Housing Corporations (Eekeren et al 2006), as explained in section 1.4.1. and Table 1.1. The results of the 2005 investigation are represented as costs per workstation in Figure 4.1. For ***secrecy*** reasons the 35 organizations were sorted by size in four groups: small (1-6), medium (7-17), large (18-27), and very large (28-35). The total ICT costs per workstation are made up of two categories: Infrastructure and Applications. Each cost category includes the relevant hardware, software, and personnel costs. The source data were collected using a cost model containing clear definitions of the above-mentioned ICT objects. The source data were validated in communication with the employees responsible for their management. In appendix 1 the cost model of M&I/Partners is defined in more detail.

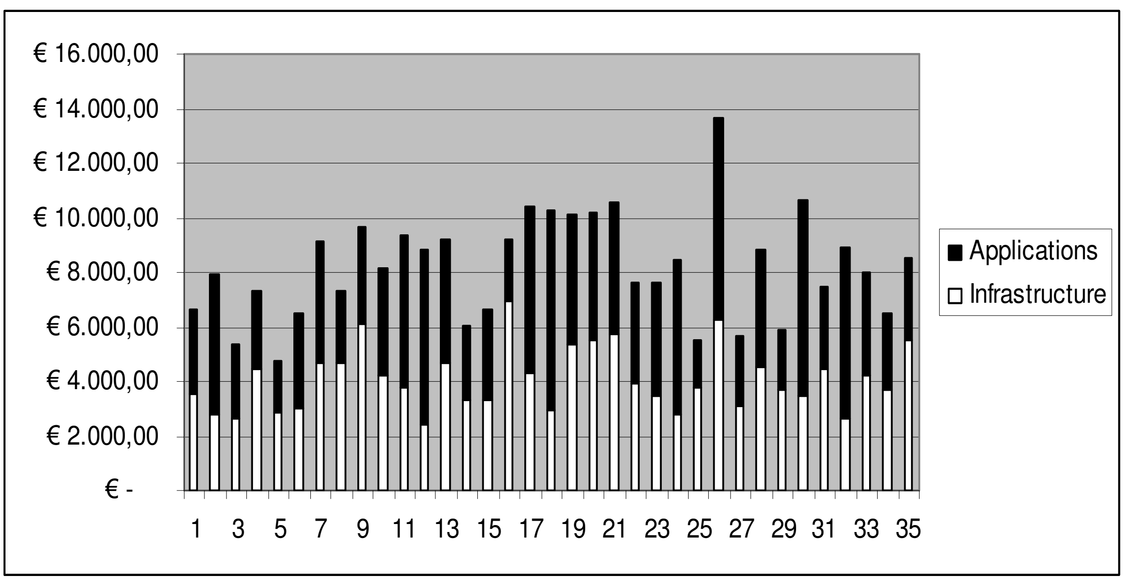


Figure 4.1 Housing Corporations' yearly ICT costs per workstation

A similar investigation has been held to review the costs and maturity of ICT in Municipalities and in Hospitals, see section 1.4.1. and Table 1.1. The collection of the ICT data gathered from the Municipalities and the Hospitals took place in a similar way as described above. Appendix 1 contains a more detailed description of the investigation.
We will now proceed with the measurement of the constructs defined.

4.3 Measurement of constructs

In this section the variables of the empirical dataset will be used to determine the measurement variables of the defined constructs.

4.3.1 Measurement of ICT expenditure

The TCO model used by M&I/Partners, based on Maanen and Berghout (2001), gives insight into the yearly ICT expenditure of an organization.
The ICT expenditure was measured by the total ICT costs of the organization. In Figure 4.2 this is represented as Total ICT cost = a+b+c+d+e+f.
Because of the availability of the data, we will use the *number of ICT Full Time Equivalents (FTE)* instead of the *costs* of ICT personnel for operations and maintenance in the remainder of this thesis. Infrastructure HW/SW costs are determined by costs for workstations, peripherals, servers and storage, communications and facilities, plus the infrastructure software costs. Applications SW cost concern software licences and services, including interfaces between applications. For more details see Appendix 1. Note that infrastructure software (server operating systems and middleware) is included in "Applications" instead of "Infrastructure" in the cost model of M&I/Partners. This is based on a different definition of "Infrastructure" as collection hardware components instead of a collection services including the integrative software. The advantage of the M&I definition is that the infrastructure is solely based on hardware, corresponding with the "law of Moore", as explained in section 2.7. The disadvantage of the M&I definition is that infrastructure software is not included, that is responsible for the increase of the productivity of the ICT management. However, it happens very often that an organization purchases productivity increasing infrastructure management software, which is not effectively implemented in the organization. The reason is that the processes in the ICT organization have to be changed, which is in general very time consuming: after years of effort the ICT organization benefits from these investments. Concluding, we consider the M&I definition better at this level of data granularity. Only if more detailed data is available about the costs of these organizational changes, then it is worthwhile to measure the infrastructural software.

Two divisions of Total ICT cost	TIR cost (HW/SW)	HIR (cost) operations	HIR cost innovation
Infrastructure cost	a	b	c
Applications cost	d	e	f
	Total IT cost = a+b+c+d+e+f		

Figure 4.2 Divisions of ICT cost

4.3.2 Measurement of the scale of the ICT assets

In the translation of the scale of ICT assets to ICT expenditure an intermediate variable is used, the complexity of ICT assets, as explained in section 3.4. As described there are two ways to determine the effort of ICT labour (= complexity ICT assets) to manage ICT assets, based on the definition of Backlund (2002). In the first way the *number* of ICT assets (including relations and types) is used to determine the scale of ICT assets; in the second way the *cost* of ICT assets are the point of departure to determine the scale of ICT assets. As indicated in the research model (Figure 3.10) these two views on measurement (number of ICT assets and costs of HW/SW) of the scale of ICT assets lead to the determination of the FTE Operations as measurement of ICT expenditure. First the "ontological" or number view will be elaborated and afterwards the "descriptive" or cost view.

"Ontological" or number view

As stated above, the scale of the ICT assets is in the "ontological" view defined by the scale of the applications, the scale of the infrastructure, and the scale of the users, see Figure 3.5. When comparing the scale of the ICT assets of two organizations of the same type (for example Housing Corporations), the following can be observed.
The scale of the *infrastructure* can be determined by establishing the number of different components. The number of workstations appears to be a good estimator of the number of other types of infrastructure components, such as servers and network components.
The scale of the *users* can be indicated by the number of different users, in general all employees of an organization. However, the number of *workstations* represents the scale of

the *active* users. In this research we therefore used both the number of FTE and the number of workstations.

The scale of *applications* will be determined in two ways, (a) and (b):

a) The portfolios of the *applications* are highly comparable because the Corporations' business processes and the information requirements are more or less similar. The variety of the applications is determined by the different business processes, which are highly comparable. For example, general ledger, word processing, and e-mail are used by every organization. Therefore the number of application types (*variety*) is more or less the same for all organizations of a particular benchmark group. This implies that the *scale* (a) of applications for two organizations with the same number of workstations is more or less the same.
b) One of the dataset's variables represents the number of application types, in accordance with the relevant business processes, that are supported by these applications. The weighted number of application types is determined by (1) the existence of operational applications and (2) the importance of theses applications for the business (see Appendix 1). This implies that the *scale* (b) of applications for two organizations with the same number of workstations is determined by this weighted number of application types.

In the above (see Figure 3.3) we defined an overall scale variable N representing the scale of the ICT assets. The scale of the ICT assets N was established by two variables:

a) The number of workstations as a representation of the scale of the infrastructure, the scale of the users and the scale (a) of the applications, based on the assumption that the application variety is equal for all organizations of the same type:
   Scale ICT assets = number of workstations
b) A combination of the number of workstations (scale infrastructure), the number of FTE of the organization (scale users) and the scale (b) of the applications, based on the weighted number of application types. Formally defined, according to the distance-based approach a compound measurement is conducted as follows (Poels and Dedene 2000):

   $$\textit{Scale ICT assets} = \sqrt{\textit{workstations}^2 + \textit{FTE}^2 + \textit{applications}^2}$$

   To make the 3 variables mutually comparable, each variable is divided by the average value of that variable.
   NB For the Municipalities and the Hospitals the number of applications is not known, so the scale is determined only by workstations and FTE.

In this research only organizations of the same type will be compared with each other and we think that the number of workstations is the best representation of the scale of ICT assets. We have only a simple count of applications without knowing whether these are simple or complex applications. We have only a simple count of users without knowing whether they are "light" or "heavy" users. Therefore we can define the following corollary on proxy assumption P2:

(P2a) The number of workstations is a better measurement of the (3) scale of ICT assets than the combined scale factor.

"Descriptive" or cost view

Earlier we pointed out that the translation of scale of the ICT assets to the effort of ICT management will in the "descriptive" view be based on the cost of HW/SW. In Figure 4.2 the cost of HW/SW (TIR) are represented as part of Total ICT cost. The TIR cost (a+d) can be related to the HIR cost operations (b+e). This is represented in the research model Figure 3.10 line 3, according to proxy P2.

4.3.3 Measurement of the efficacy of ICT management policies

The measurement of the efficacy of ICT management policies was approached from two different points of view:

a) The technological point of view, in which the investments in the ICT infrastructure are important.
b) The point of view of the maturity of the ICT organization.

Ad a) In this research the investments in ICT infrastructure were measured by the infrastructure part of the total ICT costs. This measure is called the Infrastructure Factor (IF). In terms of Figure 4.2 the following holds: Infrastructure factor = (infrastructure cost)/(total ICT cost) = (a+b+c)/(a+b+c+d+e+f). The infrastructure costs appear to vary from about 30% to 70% of the total ICT costs. We think that an investment in infrastructure will last for more years, so we determine the average IF for the years that precede a certain year, including that year; this measure is called the *average* IF. If for a certain organization data are available for the years 2002-2007, then the average IF for 2007 is the average of the IF values for the years 2002-2007. However, not all organizations participated in all benchmarks for all years. If for example for some organization data are only available for the years 2005 and 2007, then the average IF for 2007 is the average of the IF values for the years 2005 and 2007. In table 1.1 the number of organizations and the number of years are represented. The median number of years is 2 for Housing Corporations, 3 for Municipalities and 1 for Hospitals. In section 6.3.2 the limitations of the measurement of the average IF are discussed.

Ad b) The maturity of the ICT organization is defined by 17 different aspects, see Figure 4.3, based on COBIT and adjusted by means of the most relevant ITIL operational processes. M&I/Partners have translated these aspects into the specific situations of Housing Corporations, Municipalities and Hospitals. Each aspect can be scored on a scale from 0 (the process is not organized) to 5 (the process is completely optimized). Figure 4.3 represents the average maturity of the Housing Corporations in 2005. The 2004, 2006 and 2007 investigations show almost the same results (for the period 2002-2003 no maturity data were available). This measure is called the Maturity Factor (MF). For the Municipalities the maturity data are available for the period 2005-2007 (for 2004 no maturity data were available). For the Hospitals the maturity data are available for the period 2006-2008.

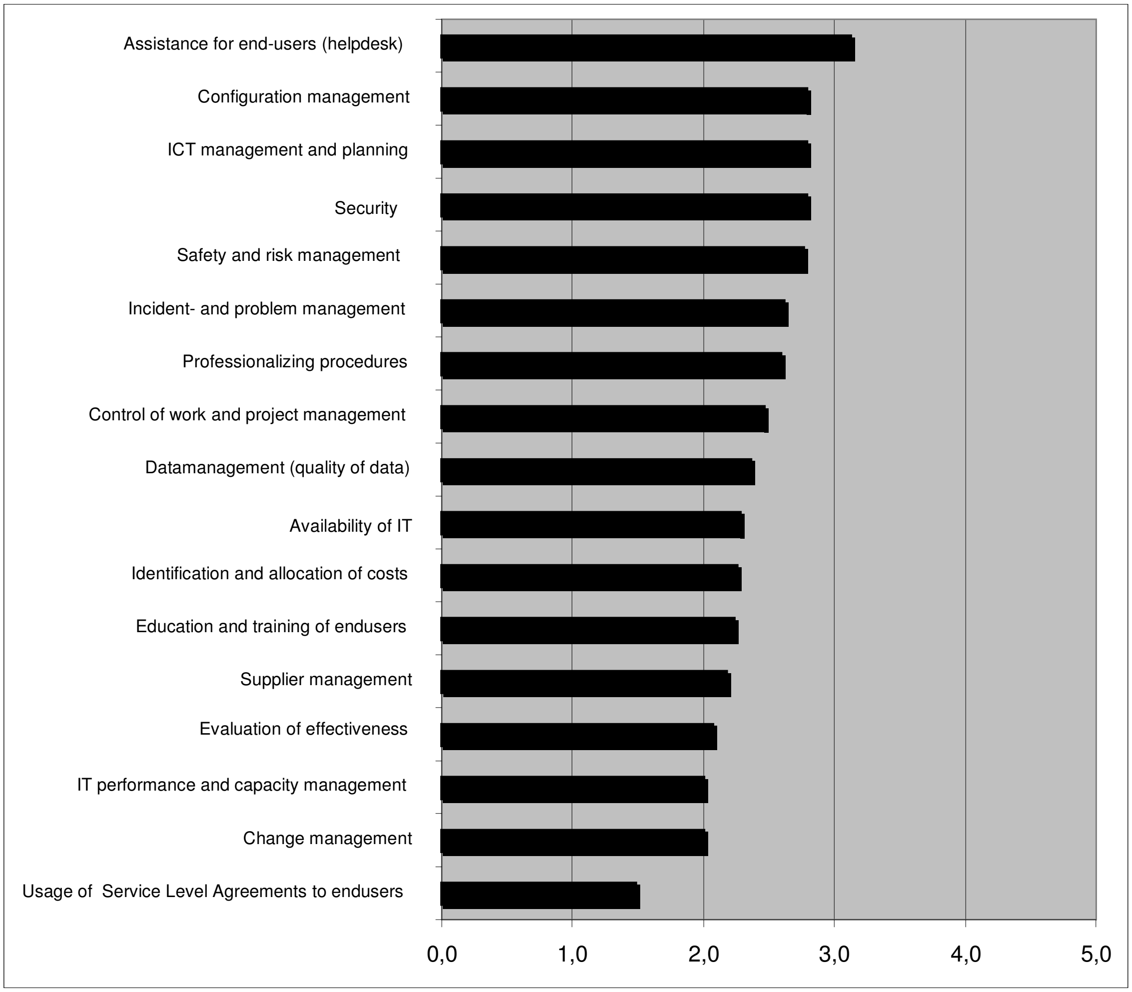


Figure 4.3 Average maturity of 17 aspects of the ICT organization

4.3.4 Measurement of organization performance

For the measurement of organization performance of Housing Corporations, Municipalities and Hospitals, the yearly turnover in € is available in the M&I dataset.

Based on the definitions of the constructs and the empirical data sets we are now able to develop a suitable methodology.

4.4 Methodology

In this research we will perform a global and a detailed analysis concerning the validity of the hypotheses H1-H2 and proxies P1-P3. The *global* analysis consists of Partial Least Square (PLS) regression and linear regression to obtain a global view regarding the validity of the hypotheses and proxy assumptions. In the *detailed* analysis we will determine in detail the validity of the hypotheses and proxies. All analyses are based on least squares:

- In the global view we assume linear relations between the inputs and outputs of the ICT respectively business processes.
- In the detailed view we assume functions of the form $y= a.x^b$ with y = output and x = input of the ICT respectively business processes.

Furthermore, in the global analysis we will analyse the whole dataset over all years, while in the detailed analysis we will perform a Mann Whitney analysis to separate the low and high productivity organizations in every year with statistical significance ($p<0,05$). In the global analysis no statistical significance analysis is performed. We expect that in the global view the degree of validity of hypotheses is higher than in the detailed view, as the requirements in the detailed view are more specific and the analysis is more rigorous. In Figure 4.4 the difference between the global view and detailed view is represented in terms of the degree of statistical significance, depicted on the x-axis.

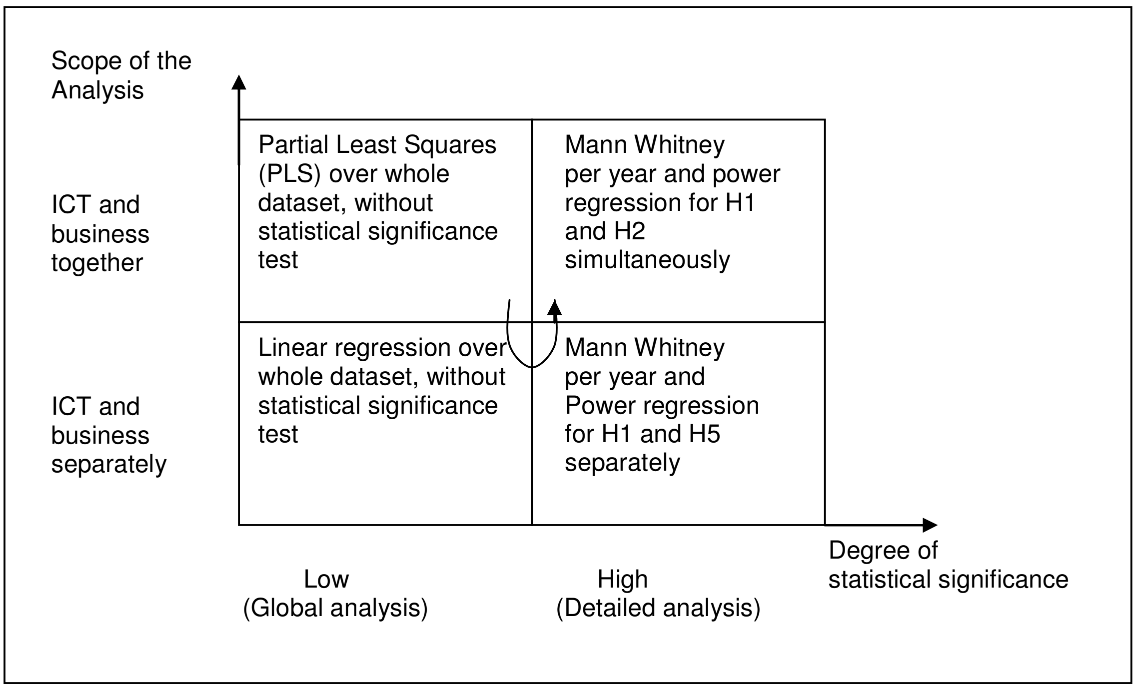


Figure 4.4 Scope and significance of global and detailed analysis

Another aspect is the scope of the analysis: the PLS method is a holistic analysis of the whole field of research, i.e. ICT and business together. Linear regression is concerning ICT and business separately. In Figure 4.4 the scope variable is depicted on the y-axis. The same distinction can be made in the detailed analysis: first we analyse H1 and H2 separately; afterwards H1 and H2 are simultaneously analyzed, as the scope is extended to ICT and business together. In Figure 4.4 an arrow is drawn to indicate the sequence of the four types of analyses, which become more and more rigorous in terms of statistical power (Baroudi and Orlikowski 1989). We try to reach an internal validity as high as possible, in testing our hypotheses by these four types of analysis. See further section 6.3 Limitations.

4.4.1 Global analysis

In the global analysis we will analyse the whole dataset over all years: we first perform PLS regression and afterwards linear regression.

PLS regression is a method to solve a Structural Equation Model (SEM), as explained by Gefen et al (2002). In Figure 4.5 a SEM model of this PhD research is represented, which is derived from the research model in Figure 3.10. Figure 4.5 consists of 4 ellipses, representing the 4 constructs of this Research; the ellipses are connected by arrows representing the dependencies between the constructs. The rectangles represent the variables measuring the constructs.
The ICT expenditure construct is measured by the reflective variables Total ICT cost and FTE Operations. Reflective variables "reflect" the construct and as a representation of the construct should be correlated (Cronbach's Alpha of Total ICT cost and FTE Operations has the value of 0,94). The arrows in Figure 4.5 go from the construct ICT expenditure to the 2 variables that reflect the construct.
The construct Organization performance is measured by the reflective variable Turnover.
The construct Scale of ICT assets is measured by the formative variables Number of ICT assets (Workstations, Applications and FTE Organization as is explained in relation to proxy P2a in section 4.3.2) and Cost TIR (Hardware/Software). Formative variables "cause" the construct i.e., represent different dimensions of it (arrows in Figure 4.5 go from the 4 variables to the construct Scale of ICT assets).
The construct Efficacy of ICT management policies is measured by the formative variables Infrastructure Factor (IF) and Maturity Factor (MF).

As we can see by the arrows in Figure 4.5, the construct ICT expenditure depends on the construct Scale ICT assets and on the construct Efficacy of ICT management policies. The same holds for the construct Organization Performance, that depends on the construct Scale ICT assets and on the construct Efficacy of ICT management policies. These dependencies are determined via an holistic analysis called PLS, minimizing the sum of squares of the differences between modelled values and real values (of the dataset). The difference between PLS and linear regression is that in linear regression the sum of squares of a more limited model is determined. We might say that in the case of Figure 4.5 the PLS model is the sum of two linear regression models: ICT expenditure = f (ICT assets, Efficacy of ICT management policies) and Organization performance = g (ICT assets, Efficacy of ICT management policies), as the sum of all squares is minimized.

NB Some relations in Figure 4.5 are excluded in the research model in Figure 3.10. The following combinations of dependant and independent variables will be excluded:

- The relation between TIR cost and Total ICT cost: in the research model Figure 3.10 we showed that we will not analyze this combination, as TIR cost are a part of Total ICT cost.
- The relation between TIR cost and Turnover: in the research model Figure 3.10 we showed that we will not analyze the influence of Hardware/Software cost on the Turnover.
- The relation between MF and Turnover: in the research model Figure 3.10 we showed that we will not analyze the influence of the maturity of the ICT organization on the Turnover.

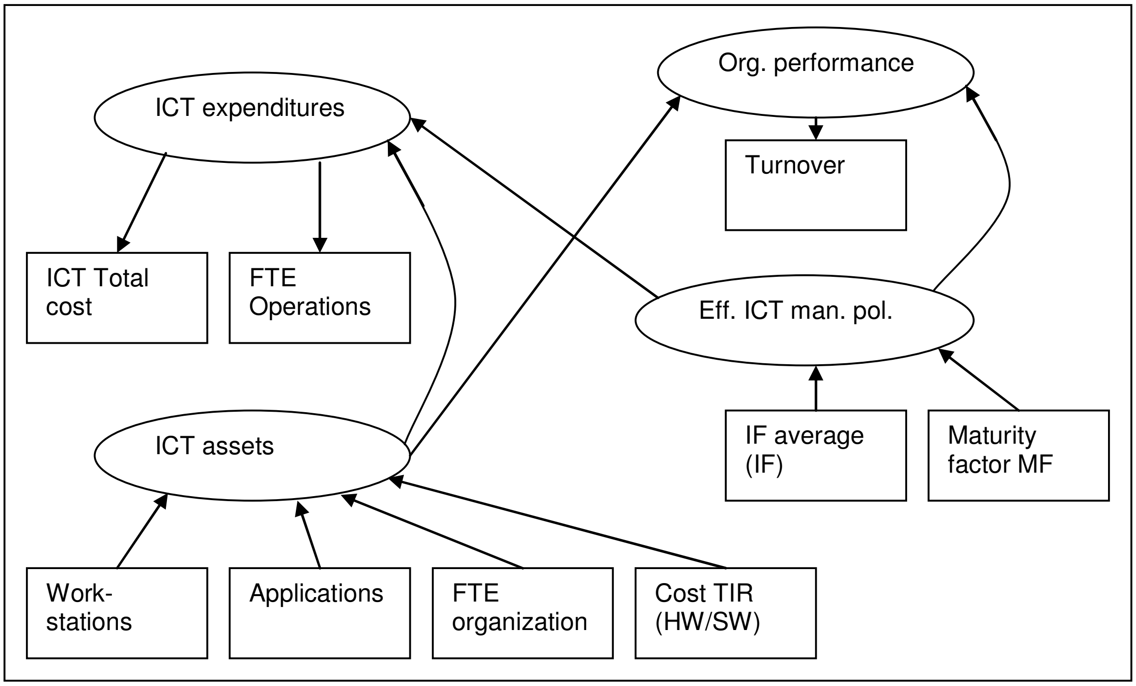


Figure 4.5 SEM model of this research

4.4.2 Detailed analysis

In the detailed analysis we will analyse the datasets for every year: we first perform a separate analysis of H1 and H2 and afterwards a simultaneous analysis of H1 and H2.

Separate analysis of H1 and H2

The detailed research methodology concerning the validity of the *hypothesis H1* is oriented to the determination of the parameters of the functions $y= a.x^b$ in Figure 3.2,
with y = ICT expenditure
and x = scale of ICT assets.

This process is executed in two ways: determining *absolute* productivity (= scale ICT assets / ICT expenditure) and determining *relative* productivity using Data Envelopment Analysis (which will be explained below).

We developed an analysis process consisting of three steps, see Figure 4.6:

1) For each of the 8 combinations (see Figure 3.10) of the:
    a. ICT management policies criterion, either a) Infrastructure Factor IF average or b) Maturity ICT organization MF,
    b. ICT Expenditure criterion, either a) total ICT costs or b) ICT personnel for operations and maintenance,
    c. ICT assets scale, either a) number ICT assets (measured by Workstations or the Combined scale factor) or b) cost HW/SW,

there were data available of a quantity of n_1 organizations in year 1, a quantity of n_2 in year 2, and a quantity of n_3 in year 3 (etcetera up to and including year 6).

2) For each year (1, 2 or 3) the (absolute or relative) productivity value of each organization was determined. Next, the group of organizations with the highest efficacy of ICT management policies was compared to a group (of the same size) with the lowest efficacy in terms of *productivity values* (the middle group was excluded). If Mann Whitney $p<0{,}05$, there is a statistically significant difference between the productivity values of the two groups in a particular year. In year 1, the high (and low) efficacy groups were assumed to consist of m_1 organizations. The same applied to year 2 (m_2) and year 3 (m_3).
3) For the total of $m_1+m_2+m_3$ organizations with high efficacy values in year 1-3, a regression analysis was performed resulting in a(high), b(high), and Rsq (high) in the equation $y = a.x^b$ with y = ICT expenditure and x = scale of ICT assets. Also for the total of $m_1+m_2+m_3$ organizations with low efficacy values in year 1-3 a regression analysis was performed, resulting in a(low), b(low) and Rsq (low).

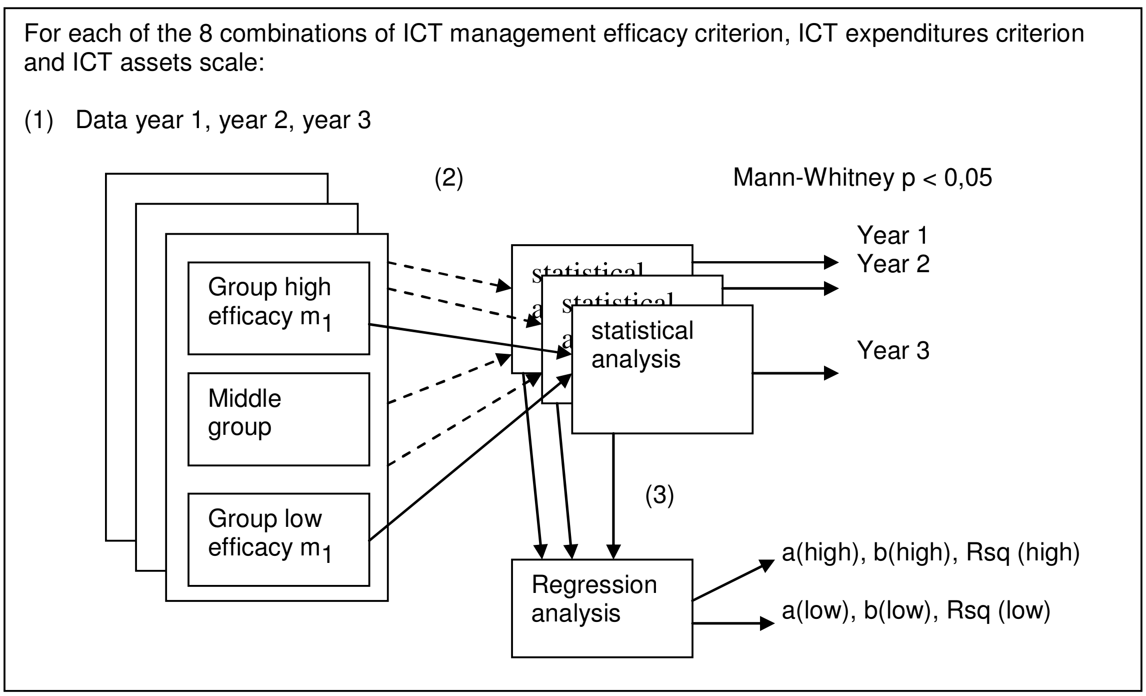


Figure 4.6 Overview of the analysis processes in steps (1), (2) and (3)

For measuring the *relative* productivity, Data Envelopment Analysis (DEA) is used (Charnes et al 1978; Banker et al 1984; Banker and Kemerer 1989; Stensrud and Myrtveit 2003; Leitner 2006). With this method the productivity of ICT is measured by calculating its relative productivity within a set of comparable organizations. This allows us to benchmark and rank these organizations with respect to their productivity. DEA is an approach to estimate the production function of organizations, enabling the assessment of their productivity. An advantage of this method is that it can cope with variables of different scales and that it incorporates multiple input and output ratios. But most of all, through its benchmarking approach, DEA provides a competitive analysis by matching actual practice with reference targets. As a result it reveals the strengths and weaknesses of an organization in relation to its peer organizations. Furthermore, it enables ranking, as the organizations under study are evaluated in a comparative manner.

The DEA model (maximisation of organizations' productivity by using linear programming) has the following form: Maximise ((sum of weighted outputs) / (sum of weighted inputs)). The higher this ratio, the more productive the organization. So this model evaluates different, independent organizations operating with the same technology. The productivity of each separate organization is measured relative to the other organizations, where the maximum productivity is 1. In general productivity is therefore delineated as follows:
$0 < productivity <= 1$.

Within the scope of this research productivity is defined as:

- Input: ICT expenditure
- Output: scale ICT assets
- Productivity = output / input (in DEA this quotient is called 'efficiency', but in this research the term 'productivity' is used).

The DEA frontier software used (Zhu 2003) was parameterised as follows: one input, more outputs, variable returns to scale. For a more detailed description of DEA see Appendix 2.

The research methodology concerning *hypothesis H2* is oriented to the determination of the parameters of the functions $y= a.x^b$ in Figure 3.8,
with x = scale of ICT assets
and y = Organization performance.

The absolute and relative productivity are determined as above described in Figure 4.6, for the following 2 combinations (see Figure 3.10):

a. ICT management policies criterion: measured by IF average.
b. Organization performance: measured by Turnover.
c. ICT assets scale: number ICT assets: measured by Workstations or the Combined scale factor.

Simultaneous analysis of H1 and H2

H1 and H2 will be *simultaneously* analyzed, as represented in Figure 4.7. In this Figure the ICT conversion process (1) and the Business processes (2) are represented by boxes. In the separate analyses these two processes are considered independently. However, for a reliable determination of the minimum ("Min") and maximum ("Max") value of the Infrastructure Factor IF (see Figure 3.7), we have to consider the ICT assets as output 1 equal to the ICT assets as input 2. Indeed, the same organizations that contribute to Graph (1), should contribute to Graph (2) in Figure 4.7. Therefore in the simultaneous analysis we have an additional constraint compared to the separate analysis: organizations that contribute to Graph (1) and that do not contribute to Graph (2), should be left out of the analysis of process (1) and vice versa.

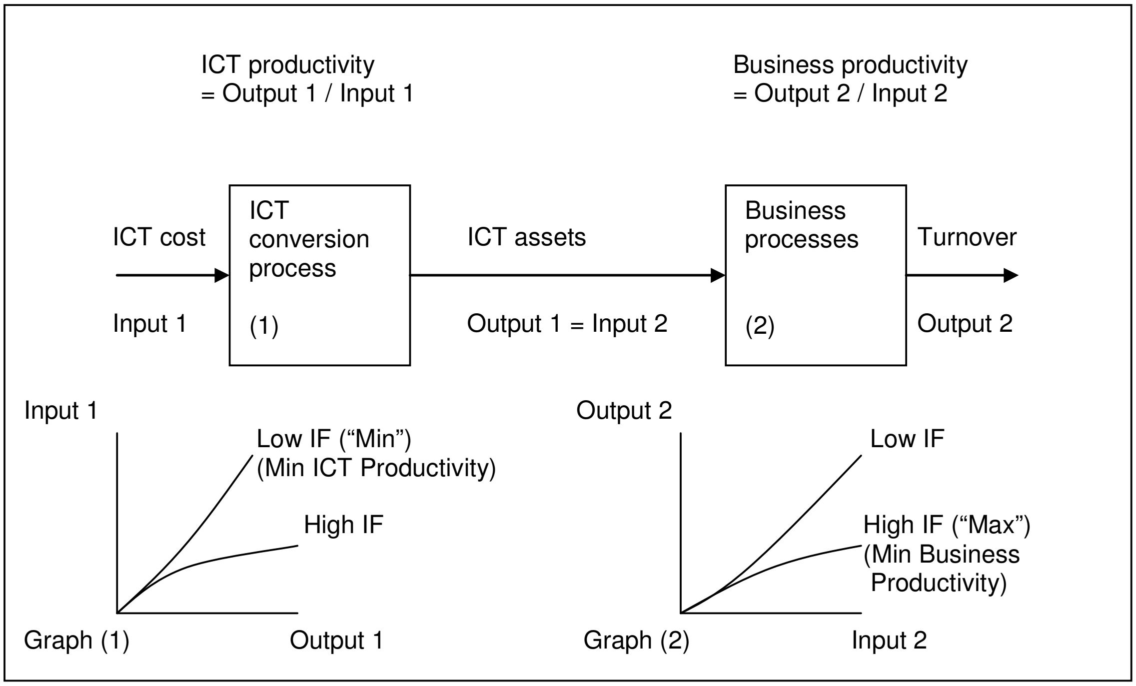


Figure 4.7 Simultaneous analysis ICT conversion and Business processes

4.5 Overview of the operationalization of constructs

In the preceding sections we have derived the following hypotheses and proxy assumptions:

(H1) When the (1) efficacy of ICT management policies is low, the (2) ICT expenditure is higher than average, given the (3) scale of ICT assets.

(H1’) When the (1) efficacy of ICT management policies is high, the (2) ICT expenditure is lower than average, given the (3) scale of ICT assets.

(P1) The cost of ICT human resources concerning operations and maintenance is a better measure of the (2) ICT expenditure construct than the total ICT cost.

(P2) The number of ICT assets is a better measure of the (3) scale of ICT assets than the cost of hardware/software.

(P2a) The number of workstations is a better measurement of the (3) scale of ICT assets than the combined scale factor.

(P3) Investment in ICT infrastructure is a better measure of the (1) efficacy of ICT management policies construct than the maturity level of the ICT organization.

(H2) When the (1) efficacy of ICT management policies measured by the Infrastructure Factor (IF) is low, the (4) Organization performance is higher than average, given the (3) scale of ICT assets.

(H2’) When the (1) efficacy of ICT management policies measured by the Infrastructure Factor (IF) is high, the (4) Organization performance is lower than average, given the (3) scale of ICT assets.

We used the following ways of measurement of the four constructs:
(1) Efficacy of ICT management policies: a) average Infrastructure Factor (IF) and b) Maturity Factor (MF).
(2) ICT expenditure: a) the number of ICT personnel for operations and maintenance, and b) total ICT costs.
(3) ICT assets scale: a) number of workstations, b) the combined scale factor and c) TIR cost (Hardware/software cost)
(4) Organization performance: Turnover.

In Table 4.1 the 10 possible combinations of measurements for hypothesis H1 and proxies P1-P3 are represented with “ICT”: excluded is the combination of Total ICT costs as ICT expenditure measure with TIR costs as measure of the scale of ICT assets, because the TIR costs are included in the Total ICT costs (“xxx”). For the analyses of hypothesis H2 there are 2 combinations, indicated in Table 4.1 with “OP” (Organization Performance).

Table 4.1 Measurement of combinations of constructs

management policy	expenditure construct	Scale of ICT assets		
		number WS	combined scale	TIR costs
IF	FTE oper	ICT	ICT	ICT
	total ICT costs	ICT OP	ICT OP	xxx
MF	FTE oper	ICT	ICT	ICT
	total ICT costs	ICT	ICT	xxx

In the following chapter the analyses and findings will be presented.

5 ANALYSIS AND FINDINGS

5.1 Introduction

According to Figure 4.4 we will first present the results of the global analysis (PLS and linear regression). Afterwards the results of the detailed analysis are treated: first Mann Whitney per year and power regression for H1 and H2 separately and then for H1 and H2 simultaneously.

5.2 Results global analysis

The data of the Housing Corporations (HC) are available for IF 6 years (the period 2002-7) and for Maturity Factor (MF) 4 years (the period 2004-7). In total 196 cases over 6 years were price-indexed with 1,5% per year and normalized ((value-μ)/σ). The data of the Municipalities (M) are available for the period 2004-7. In total 55 cases over 4 years were price-indexed with 1,5% per year and normalized. The data of the Hospitals (Hosp) are available for the period 2006-8. In total 37 cases over 3 years were price-indexed with 1,5% per year and normalized. There are no application data available for Municipalities and Hospitals. That implies that the combined scale factor (proxy P2a) is determined with Workstations and FTE organization only.

Comparison of total ICT costs of the different organizations

The average (in these datasets) ICT cost per workstation per year are respectively 8400 € (HC), 5400 € (M) and 6000 € (Hosp). The average ICT costs per FTE organization per year are respectively 10300 € (HC), 6500 € (M) and 5400 € (Hosp). The average spending of total costs on ICT is 2,0% (HC), 2,0% (M) and 6,2% (Hosp). We consider all these organizations to have a "utility view" (Weill and Broadbent 1998) on ICT, with cost savings via economies of scale as their primary strategy. However, in the last decade Hospitals have raised their ICT expenses from 4% to 6% of total costs and these organizations are now entering the "dependant view" (Weill and Broadbent 1998) phase, as diagnosis and treatment of patients is nowadays impossible without ICT. The average ICT infrastructure cost per year are respectively 3900 € (HC), 3600 € (M) and 3000 € (Hosp). The average infrastructure factor for the whole dataset is 0,47 (HC), 0,55 (M) and 0,55 (Hosp). And the average percentile of ICT Human Resource costs (related to total ICT costs) for the whole dataset is 0,30 (HC), 0,45 (M) and 0,23 (Hosp). The average number of workstations is 210 (HC), 1800 (M) and 1600 (Hosp). The big difference in size of the organizations can possibly explain the difference in total ICT cost per workstation between HC (8400 €) and M/Hosp (5400 respectively 6000 €), caused by economies of scale.

Correlation analysis

Table 5.1 shows an overview of the correlations between all variables for Housing Corporations, Municipalities and Hospitals. Firstly we see the high correlation values between the variables that are scale related (workstations, FTE organization, TIR (HW/SW), FTE Operations, ICT cost and Turnover). But more interesting are the correlations between Efficacy of ICT management policies (average Infrastructure Factor IF and Maturity Factor

MF) and the other variables (**bold** printed). In the case of Hospitals there is a relatively high (up to 0,65) positive correlation between IF and the scale related variables. This implies that the bigger the organization, the more is spent on infrastructure.
In the case of Municipalities this type of correlation has a maximum (positive) value of 0,26. In the case of Housing Corporations this type of correlation has a minimum (negative) value of -0,28, so the bigger the organization, the less is spent on infrastructure. One of the reasons why big Hospitals spend more on infrastructure than small Hospitals could be the multi-location character of these organizations. This often leads to more communications, storage and processing facilities than in the case of a single location. A second reason could be that big hospitals are the leaders in the transition from the "enabling view" to the "dependant view" (Weill and Broadbent 1998) which leads to additional expenses in ICT infrastructure.

The correlations between MF and the scale related variables are moderately positive for all organization types. This implies that the bigger the organization, the higher the maturity factor. It is interesting to see that for Housing Corporations there is a relatively high positive correlation (0,51) between MF and Applications. This correlation is much higher than between Applications and the scale related variables (maximum 0,30). As explained in section 1.4.3, Figure 1.3, the measurement of application availability and maturity ICT organization were both subjective. It could be possible that the additional positive correlation (0,51-0,30 as above explained) is in fact a measure of optimism of the persons in the organization that are responsible for the subjective answers on application and maturity questions.

Table 5.1 Correlations between all variables.

Housing Corporations (196 organizations)									
	WS	FTEorg	Comb	TIR	IF	MF	FTEOp	ICTCost	Turnover
WS	1,00								
FTEorg	0,96	1,00							
Comb	0,91	0,95	1,00						
TIR	0,87	0,85	0,87	1,00					
IF	**-0,18**	**-0,14**	**-0,11**	**-0,23**	1,00				
MF	**0,30**	**0,24**	**0,25**	**0,26**	-0,06	1,00			
FTE Oper	0,91	0,89	0,88	0,82	**-0,25**	**0,26**	1,00		
ICTCost	0,91	0,88	0,90	0,97	**-0,28**	**0,27**	0,89	1,00	
Turnover	0,91	0,88	0,85	0,81	**-0,23**	**0,25**	0,82	0,84	1,00
Applic	0,30	0,22	0,09	0,21	-0,21	**0,51**	0,26	0,23	0,22
Municipalities (55 organizations)									
	WS	FTEorg	Comb	TIR	IF	MF	FTEOp	ICTCost	Turnover
WS	1,00								
FTEorg	0,98	1,00							
Comb	0,98	0,98	1,00						
TIR	0,91	0,92	0,90	1,00					
IF	**0,25**	**0,23**	**0,24**	**0,19**	1,00				
MF	**0,08**	**0,05**	**0,07**	**0,17**	-0,15	1,00			
FTE Oper	0,85	0,87	0,87	0,84	**0,17**	**0,03**	1,00		
ICTCost	0,93	0,92	0,92	0,97	**0,18**	**0,18**	0,89	1,00	
Turnover	0,90	0,91	0,89	0,89	**0,23**	**0,30**	0,81	0,91	1,00
Hospitals (37 organizations)									
	WS	FTEorg	Comb	TIR	IF	MF	FTEOp	ICTCost	Turnover
WS	1,00								
FTEorg	0,94	1,00							
Comb	0,99	0,99	1,00						
TIR	0,91	0,89	0,91	1,00					
IF	**0,53**	**0,49**	**0,52**	**0,59**	1,00				
MF	**0,24**	**0,11**	**0,17**	**0,32**	0,11	1,00			
FTE Oper	0,81	0,77	0,80	0,72	**0,25**	**0,18**	1,00		
ICTCost	0,92	0,88	0,91	0,99	**0,57**	**0,34**	0,77	1,00	
Turnover	0,93	0,96	0,96	0,88	**0,55**	**0,22**	0,72	0,86	1,00

5.2.1 Partial Least Squares

The Structural Equation Model (SEM) in Figure 4.5 is calculated with Partial Least Squares (PLS) and the results are represented in Table 5.2. We see for every organization type 3 dependant variables (FTE Operations, Total ICT cost and Turnover), and 5 independent variables:

- 3 measures of the Scale of ICT assets: Workstations, Combination of workstations, FTE organization and Application availability (see section 4.3.2.) and TIR (Hardware/Software) cost.
- 2 measures of the Efficacy of ICT management policies: average IF and MF

The numbers in Table 5.2 represent the regression coefficients; the absolute value expresses the strength of a relation and the sign expresses the direction. For example the first 3 rows in the first column show that workstations have the strongest relation to FTE Operations for HC. Therefore the number **0,64** is bold represented. The following combinations of dependant and independent variables have to be excluded and are grey shaded:

- The relation between TIR and Total ICT cost: in the research model Figure 3.10 we showed that we will not analyze this combination, as TIR are a part of Total ICT cost.
- The relation between TIR and Turnover: in the research model Figure 3.10 we showed that we will not analyze the influence of Hardware/Software cost on the Turnover.
- The relation between MF and Turnover: in the research model Figure 3.10 we showed that we will not analyze the influence of the maturity of the ICT organization on the Turnover.

Table 5.2 Partial Least Squares

Housing corporations	FTE Operations	Total ICT Cost	Turnover
Workstations	**0,64**	**0,17**	0,76
Combination	0,29	0,16	0,11
TIR (HW/SW)	-0,02	0,68	0,05
Infrastructure factor IF	**-0,21**	**-0,08**	-0,06
Maturity factor MF	-0,01	0,00	-0,03
Municipalities	FTE Operations	Total ICT Cost	Turnover
Workstations	0,03	**0,25**	0,44
Combination	**0,52**	0,05	0,19
TIR (HW/SW)	0,35	0,70	0,28
Infrastructure factor IF	**-0,32**	**-0,02**	0,20
Maturity factor MF	-0,06	0,03	0,21
Hospitals	FTE Operations	Total ICT Cost	Turnover
Workstations	**1,05**	**0,27**	-0,75
Combination	0,16	-0,13	1,63
TIR (HW/SW)	-0,33	0,85	0,02
Infrastructure factor IF	**-1,00**	**-0,13**	0,37
Maturity factor MF	-0,03	0,02	0,12

From Table 5.2 we can conclude that workstations are in the case of Housing Corporations the most important measurement of Scale ICT assets, which validates proxies **P2** and **P2a**. The average IF is the most important ICT management criterion, which validates **P3**. We can see that 3 of the 4 values of ICT management policies have negative values in relation to ICT expenditure, which validates hypothesis **H1** for 75%. The value of ICT management policies (IF) is negative in relation to Turnover, which validates **H2** for 100%.
Furthermore the absolute values of Workstations and average IF are higher in the FTE Operations column than in the ICT cost column, which validates proxy **P1**.

From Table 5.2 we can conclude that workstations are in the case of Municipalities not the most important measurement of Scale ICT assets, which invalidates proxy **P2a**. However, the combined scale has a higher value than TIR, which validates **P2**. The average IF is the most important ICT management criterion, which validates **P3**. We can see that 3 of the 4 values of ICT management policies have negative values in relation to ICT expenditure, which validates hypothesis **H1** for 75%. The value of ICT management policies (IF) is positive in relation to Turnover, which validates **H2** for 0%.

Furthermore the absolute values of the scale of ICT assets and average IF are higher in the FTE Operations column than in the ICT cost column, which validates proxy **P1**.

From Table 5.2 we can conclude that workstations are in the case of Hospitals the most important measurement of Scale ICT assets, which validates proxies **P2** and **P2a**. The average IF is the most important ICT management criterion, which validates **P3**. We can see that 3 of the 4 values of ICT management policies have negative values in relation to ICT expenditure, which validates hypothesis **H1** for 75%. The value of ICT management policies (IF) is positive in relation to Turnover, which validates **H2** for 0%.
Furthermore the absolute values of Workstations and average IF are higher in the FTE Operations column than in the ICT cost column, which validates proxy **P1**.

All values above are summarized in Table 5.6. For now we can conclude from this superficial global analysis that our findings substantially support our hypotheses, especially for Housing Corporations.

5.2.2 Linear regression

We now analyze more in detail what is the degree of validity of the hypotheses and proxies, using linear regression. In Table 5.3 the results of Housing Corporations are represented, in the form of "combinations" of 9 numbers, representing the values of a, b and R2 for "low", "high" and "all" organizations. For example the first 3 rows and 3 columns represent the combination of Turnover and Workstations for Housing Corporations, sorted on IF (Average IF). There are in total 196 organizations, of which 33 "low IF" and 35 "high IF". Hereby "low" means lower than average minus standard deviation after normalizing the data. "High" means higher than average plus standard deviation. Some "combinations" are not filled in, in accordance with Table 4.1, and are grey shaded. In total we have 2 combinations with Turnover as dependant variable, 4 combinations with Total ICT cost as dependant variable and 6 combinations with FTE Operations as dependant variable. The independent variables are Workstations (WS), the Combined value (Comb) or TIR. For every combination the following results are represented in Table 5.3:

- The number (N) of low and high values after sort of 196 cases according to the corresponding management criterion (IF or MF). The high values are higher than the average plus the standard deviation (>1 in the normalized values). The low values are lower than the average minus the standard deviation (< -1 in the normalized values).
- The values a and b in the equation y = a + b.x with y = dependant variable and x = independent variable as a result of the linear regression.
- The value of squared multiple R (R2) as a result of the linear regression.
- If b(low)>b(all)>b(high) and R2(low)>0,7 and R2(all)>0,7 and R2(high)>0,7 then hypothesis H1 or H2 is validated (indicated in **bold**).

Table 5.3 Housing Corporations Linear Regression

ICT assets var		WS independant			Comb independant			TIR independant		
Sort on IF		low	high	all	low	high	all	low	high	all
	N	33	36	196	33	36	196	33	36	196
Turnover	a	0,03	-0,18	0,00	0,11	-0,27	0,00	xxx	xxx	xxx
	b	**1,06**	**0,63**	**0,91**	**0,96**	**0,54**	**0,85**	xxx	xxx	xxx
	R2	**0,87**	**0,84**	**0,82**	**0,72**	**0,74**	**0,71**	xxx	xxx	xxx
Cost ICT	a	0,16	-0,23	0,00	0,19	-0,33	0,00	xxx	xxx	xxx
	b	0,90	0,69	0,91	**0,92**	**0,60**	**0,90**	xxx	xxx	xxx
	R2	0,87	0,79	0,82	**0,90**	**0,72**	**0,81**	xxx	xxx	xxx
FTE Oper	a	0,14	-0,13	0,00	0,18	-0,24	0,00	0,18	-0,01	0,00
	b	**1,01**	**0,74**	**0,91**	**1,01**	**0,61**	**0,88**	1,08	0,71	0,82
	R2	**0,88**	**0,86**	**0,83**	**0,89**	**0,70**	**0,77**	0,78	0,51	0,67
ICT assets var		WS independant			Comb independant			TIR independant		
Sort on MF		low	high	all	low	high	all	low	high	all
	N	17	40	196	17	40	196	17	40	196
Turnover	a	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	b	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	R2	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Cost ICT	a	-0,09	-0,01	0,00	-0,02	0,02	0,00	xxx	xxx	xxx
	b	0,67	0,82	0,91	0,56	0,78	0,90	xxx	xxx	xxx
	R2	0,76	0,88	0,82	0,64	0,83	0,81	xxx	xxx	xxx
FTE Oper	a	0,00	-0,08	0,00	0,11	-0,03	0,00	0,05	-0,03	0,00
	b	0,96	0,93	0,91	0,79	0,86	0,88	0,96	0,96	0,82
	R2	0,85	0,86	0,83	0,70	0,78	0,77	0,56	0,65	0,67

We can conclude that Turnover has in both cases bold values, which validates hypothesis **H2** for 100% (see Table 5.6 column HC – LR). Cost ICT and FTE Operations have bold values in 3 of the 5 IF cases and in none of the 5 MF cases, which validates proxy **P3** and validates hypothesis **H1** in 30% of the cases. As none of the cases in the TIR column is bold, proxy **P2** is validated. However, as the WS column contains 2 bold cases and the Comb column contains 3 bold cases, **P2a** is **not** validated. **P1** is validated, as there are 2 bold cases in the FTE Operations rows and only 1 bold case in the Cost ICT rows.

In Table 5.4 the results of Municipalities are represented.

Table 5.4 Municipalities Linear Regression

ICT assets var		WS independant			Comb independant			TIR independant		
Sort on IF		low	high	all	low	high	all	low	high	all
	N	6	7	55	6	7	55	6	7	55
Turnover	a	0,171	-0,207	0,00	0,65	-0,215	0,00	xxx	xxx	xxx
	b	**1,23**	**0,802**	**0,903**	**1,919**	**0,874**	**0,886**	xxx	xxx	xxx
	R2	**0,968**	**0,962**	**0,816**	**0,994**	**0,983**	**0,784**	xxx	xxx	xxx
Cost ICT	a	0,416	-0,231	0,00	0,921	-0,24	0,00	xxx	xxx	xxx
	b	**1,391**	**0,842**	**0,93**	**2,123**	**0,917**	**0,915**	xxx	xxx	xxx
	R2	**0,973**	**0,943**	**0,865**	**0,956**	**0,964**	**0,837**	xxx	xxx	xxx
FTE Oper	a	0,574	-0,234	0,00	1,207	-0,24	0,00	0,001	-0,193	0,00
	b	**1,48**	**0,66**	**0,85**	**2,378**	**0,715**	**0,866**	0,969	0,647	0,835
	R2	**0,849**	**0,956**	**0,722**	**0,924**	**0,967**	**0,75**	0,669	0,976	0,698
ICT assets var		WS independant			Comb independant			TIR independant		
Sort on MF		low	high	all	low	high	all	low	high	all
	N	4	8	55	4	8	55	4	8	55
Turnover	a	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	b	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	R2	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Cost ICT	a	-0,259	0,159	0,00	-0,25	0,146	0,00	xxx	xxx	xxx
	b	**0,941**	**0,85**	**0,93**	**1,055**	**0,779**	**0,915**	xxx	xxx	xxx
	R2	**0,983**	**0,928**	**0,865**	**0,867**	**0,89**	**0,837**	xxx	xxx	xxx
FTE Oper	a	-0,08	0,177	0,00	-0,038	0,113	0,00	0,783	0,139	0,00
	b	1,034	0,564	0,85	**1,236**	**0,601**	**0,866**	1,716	0,551	0,835
	R2	0,959	0,6	0,722	**0,962**	**0,776**	**0,75**	0,989	0,534	0,698

We can now conclude that Turnover has in both 2 cases bold values, which validates hypothesis **H2** for 100% (see Table 5.6 column M – LR). Cost ICT and FTE Operations have bold values in 4 of the 5 IF cases and in 3 of the 5 MF cases, which validates proxy **P3** and validates hypothesis **H1** for 70%. As none of the cases in the TIR column is bold, proxy **P2** is validated. However, as the WS column contains 4 bold cases and the Comb column contains 5 bold cases, **P2a** is **not** validated. **P1** is **not** validated, as there are only 3 bold cases in the FTE Operations rows and 4 bold cases in the Cost ICT rows.

In Table 5.5 the results of Hospitals are represented.

Table 5.5 Hospitals Linear Regression

ICT assets var		WS independant			Comb independant			TIR independant		
Sort on IF		low	high	all	low	high	all	low	high	all
	N	5	5	37	5	5	37	5	5	37
Turnover	a	-0,245	-0,848	0,00	-0,187	-0,103	0,00	xxx	xxx	xxx
	b	0,711	1,79	0,934	0,775	1,142	0,96	xxx	xxx	xxx
	R2	0,814	0,917	0,873	0,855	0,918	0,921	xxx	xxx	xxx
Cost ICT	a	-0,464	0,109	0,00	-0,412	0,408	0,00	xxx	xxx	xxx
	b	0,688	0,748	0,921	0,741	0,487	0,914	xxx	xxx	xxx
	R2	0,904	0,626	0,849	0,928	0,654	0,836	xxx	xxx	xxx
FTE Oper	a	0,003	-0,287	0,00	0,071	-0,13	0,00	0,401	-0,624	0,00
	b	1,029	0,42	0,811	1,084	0,283	0,802	1,097	0,739	0,718
	R2	0,961	0,255	0,659	0,941	0,285	0,643	0,533	0,648	0,515
ICT assets var		WS independant			Comb independant			TIR independant		
Sort on MF		low	high	all	low	high	all	low	high	all
	N	6	5	37	6	5	37	6	5	37
Turnover	a	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	b	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
	R2	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx	xxx
Cost ICT	a	-0,181	0,397	0,00	-0,289	0,484	0,00	xxx	xxx	xxx
	b	0,785	0,748	0,921	0,815	0,794	0,914	xxx	xxx	xxx
	R2	0,872	0,92	0,849	0,932	0,91	0,836	xxx	xxx	xxx
FTE Oper	a	-0,015	0,199	0,00	-0,072	0,265	0,00	0,053	0,047	0,00
	b	0,491	0,617	0,811	0,458	0,695	0,802	0,284	0,682	0,718
	R2	0,539	0,586	0,659	0,466	0,653	0,643	0,139	0,522	0,515

In the case of the Hospitals there is not any combination with bold values, as a representation of the criterion (b(low)>b(all)>b(high) and R2(low)>0,7 and R2(all)>0,7 and R2(high)>0,7). As N is only 5 or 6 for "low" or "high" we are very dependant on outliers and in the global analysis we did not remove outliers.
In Table 5.6 column Hosp – LR all hypotheses and proxies validation values have the indication "n/a" (not available).

5.2.3 Validity of hypotheses and proxies according to the global analyses

In Table 5.6 the degree of validation of hypotheses and proxies according to Partial Least Squares (PLS) and Linear Regression (LR) is represented for Housing Corporations (HC), Municipalities (M) and Hospitals (Hosp).

Table 5.6 Degree of validity of hypotheses and proxies after global analysis

	Type organization	HC		M		Hosp	
Nr	Hypothesis/proxy description	PLS	LR	PLS	LR	PLS	LR
H1	Relation between ICT assets and ICT expenditure negative influenced by ICT policies	75%	30%	75%	70%	75%	n/a
P1	ICT expenditure better estimated by FTE Operations than by total ICT costs	yes	yes	no	no	yes	n/a
P2	Scale of ICT assets better estimated by number of ICT assets than by TIR cost	yes	yes	yes	yes	yes	n/a
P2a	Better number measure by workstations than by combined scale factor	yes	no	no	no	yes	n/a
P3	Efficacy ICT management policies better estimated by IF than by MF	yes	yes	yes	yes	yes	n/a
H2	Relation between ICT assets and Turnover negative influenced by (average) IF	100%	100%	0%	100%	0%	n/a

We can conclude that the LR analysis gives almost the same results as the PLS analysis. The only differences are the HC/PLS/P2a/yes value compared with the HC/LR/P2a/no value and the M/PLS/H2/0% value compared with the M/LR/H2/100% value.

In summary the findings of the global analyses substantially support the hypotheses and proxies, especially for Housing Corporations. In chapter 6.3 we will demonstrate that the internal validity of the research depends highly on the number of organizations. Therefore the results of Housing Corporations (196 measurements) is more important than the result of Municipalities (55 measurements) or Hospitals (37 measurements).

5.3 Results detailed analysis

We will first perform the analyses for the hypotheses H1and H2 separately according to Figure 4.4. In Table 4.1 we can see that for the analyses of hypothesis H1 and proxies P1-P3 there are 10 possible combinations for each of the three cases (Housing Corporations, Municipalities and Hospitals) indicated with "ICT". These 10 combinations will be calculated for the absolute productivity and for the DEA productivity, so we will make 20 calculations for every available benchmark year. If in a certain benchmark year there are only IF data available, then we make 10 calculations.

For the analyses of hypothesis H2 there are 2 combinations, indicated in Table 4.1 with "OP" (Organization Performance), thus in this case we make 2 calculations for every available benchmark year.

After these separate detailed analyses we will perform the analyses for the hypotheses H1 and H2 simultaneously, according to Figure 4.4.

5.3.1 Housing Corporations detailed separate analyses

First the results of the ICT performance (hypothesis H1 and proxies P1-P3) will be presented. Afterwards the results of the business performance (hypothesis H2).

ICT performance

The data of the Housing Corporations are available for IF 6 years (the period 2002-7) and for MF 4 years (the period 2004-7); according to Table 4.1 for hypothesis H1 and proxies P1-P3 we will make 100 calculations (= (5 combinations of variables x 6 years IF x 2 ways productivity determination) + (5 combinations of variables x 4 years MF x 2 ways productivity determination)). For each of the 100 calculations the following steps were executed, as explained in the methodology section (section 4.4.2 step 2):

a) Determination of the productivity (=output/input) of each combination on the basis of:
   Input: the measurement of the ICT expenditure construct.
   Output: the measurement of the ICT assets scale.
b) For each year and for each ICT management policies criterion the organizations were sorted by their policies criterion scores.
c) As a first step, the about 1/2 number of organizations with the highest *policies scores* was compared as a group with the about 1/2 number of organizations with the lowest *policies scores* as a group, with respect to the aspect of *productivity* (at least one organization in the middle was left out of the analysis).
d) For the comparison of the *productivities* of the two groups, Mann Whitney was used (Mann and Whitney 1947) since ANOVA starts from a normal distribution and is therefore not always correct. Because Mann Whitney does not have this requirement, it was more suited for our research study.
e) Given that Mann Whitney p (two sided) < 0,05, a statistically significant difference between the *productivities* in both groups was assumed.
f) If no significant difference was found, a smaller number of organizations in both groups was tried; the smallest number was 4 (so then there were two groups of 4 organizations).
g) If necessary (to attain p-values < 0,05), an outlier was deleted in both groups.

Table 5.7 represents the 100 results of the analyses for both absolute and DEA productivity. The 50 values of **p<0,05** are printed in bold. The 7 values of *p=0,05* are printed italic and underlined (to give the reader a quick impression where statistical significance was almost attained).

Table 5.7 Housing Corporations results of Mann Whitney analyses

Organisations sorted on average infrastructure factor						
year	Prod abs	Prod abs	Prod abs	DEA	DEA	DEA
input	output	output	output	output	output	output
	WS	comb scale	cost HW/SW	WS	comb scale	cost HW/SW
Input: ICT personnel operations						
2002 23 org	**0,021**	**0,002**	0,150	*0,050*	0,199	0,076
2003 24 org	**0,021**	**0,021**	0,149	**0,020**	**0,021**	0,513
2004 35 org	**0,004**	**0,009**	**0,002**	**0,013**	**0,009**	0,324
2005 39 org	**0,028**	**0,037**	**0,004**	**0,010**	**0,027**	0,140
2006 37 org	**0,028**	**0,016**	0,106	*0,050*	*0,050*	0,077
2007 38 org	0,083	**0,021**	0,356	**0,047**	**0,046**	0,565
Input: Total ICT cost						
2002 23 org	0,149	**0,013**	xxx	**0,009**	**0,003**	xxx
2003 24 org	**0,021**	**0,021**	xxx	0,083	0,081	xxx
2004 35 org	**0,037**	*0,050*	xxx	**0,035**	0,306	xxx
2005 39 org	0,076	**0,021**	xxx	**0,039**	**0,044**	xxx
2006 37 org	**0,016**	**0,002**	xxx	**0,003**	**0,028**	xxx
2007 38 org	**0,001**	**0,002**	xxx	**0,002**	**0,006**	xxx
Organisations sorted on maturity factor						
year	Prod abs	Prod abs	Prod abs	DEA	DEA	DEA
input	output	output	output	output	output	output
	WS	comb scale	cost HW/SW	WS	comb scale	cost HW/SW
Input: ICT personnel operations						
2004 35 org	0,127	1,000	0,226	0,121	0,282	0,773
2005 39 org	0,873	1,000	0,729	**0,025**	**0,011**	0,507
2006 37 org	*0,050*	0,127	0,175	**0,014**	**0,003**	**0,025**
2007 38 org	0,475	0,406	0,406	**0,02**	0,121	**0,043**
Input: Total ICT cost						
2004 35 org	*0,050*	0,127	xxx	0,078	**0,013**	xxx
2005 39 org	0,127	0,513	xxx	0,179	0,341	xxx
2006 37 org	0,063	0,386	xxx	**0,016**	**0,003**	xxx
2007 38 org	**0,006**	0,482	xxx	0,127	*0,050*	xxx

Now we continue with step 3 of the methodology (section 4.4.2). To perform a regression analysis the following steps were executed for each allowable combination of scale measurement, policies criterion, and ICT expenditure construct (20 times (= (5 combinations of variables IF x 2 ways productivity determination) + (5 combinations of variables MF x 2 ways productivity determination)), see Table 5.7):

a) Two groups were formed, one of high efficacy policies organizations and one of low efficacy policies organizations, with statistically significant differences. These two groups were composed on the basis of the 50 significant results of Table 5.7.
b) If for a year-scale-policies-expenditure combination there was no statistically significant difference between the high and the low efficacy policies organizations, these organizations were left out (50 not significant results of Table 5.7).

c) Power regression analysis was used to determine the values of a(high), a(low), b(high) and b(low) in the function $y = a.x^b$ with y = ICT expenditure and x = scale of ICT assets.

Table 5.8 represents the results of these analyses for each of the 20 combinations of ICT assets scale measurement, policies criterion, and expenditure construct measurement (for both the absolute as the DEA productivity):

- The periods of available data (2002-2007 and 2004-2007) and the number of organizations. For example, 0 – 0 - 0 - 7 means that only in the year 2007 there were 7 organizations in the group with high MF, and 7 organizations with low MF (because the years 2004-2006 do not contribute). The value 0 - 0 - 0 - 0 means that there is no contribution of any year, so it is not possible to perform a regression analysis.
- The indication ‘low’ or ‘high’ for the low or high efficacy policies group.
- The value of b in the function $y = a.x^b$ (with y = ICT expenditure and x = scale of ICT assets) as a result of the regression analysis.
- The value of the correlations (Rsq) in the regression analyses.
- The percentile of years that contribute to the regression analysis. The resulting curves can be viewed in Appendix 3.
- The curve validation value is dependent on the values of b(low) and b(high):
  If b(low)>1 and b(high)<1, then curve value = 1 (according to Figure 3), or else if b(low)>1 or b(high)<1, then curve value = 0,5, or else curve value=0 (if b(low)>1 and b(high)<1).
  If the ‘low’ curve and ‘high’ curve in Appendix 3 appear to be more or less the same (face validity), then curve value = 0. This is indicated in Appendix 3 and results in the indication “curve” and the number of the Figure in Appendix 3 in Table 5.8.
- The resulting hypothesis H1 validation value is defined as the product of the average Rsq value, the “years” value, and the curve validation value.
- n/a: no data were available to perform a regression analysis.
- The highest validation values per efficacy criterion (in combination with the productivity measurement) are printed in **bold**.

Table 5.8 HC results of the regression analyses and resulting H1 validation

Housing Corporations average IF as efficacy criterion - abs productivity						
2002-7	IF aver.	b	Rsq	years	curve	result
HIR operations - workstations	low	1,02	0,91	0,83	0,50	0,38
4 - 4 - 6 - 5 - 5 - 0	high	1,07	0,93			
HIR operations - combined scale	low	1,50	0,82	1,00	0,50	0,37
7 - 4 - 8 - 6 - 5 - 4	high	1,43	0,68			
HIR operations - TIR cost average	low	1,01	0,89	0,33	0,00	0,00
0 - 0 - 7 - 6 - 0 - 0	high	1,27	0,79		curve	A3.3
Total ICT cost - workstations	low	1,00	0,93	0,67	1,00	**0,60**
0 - 4 - 6 - 0 - 6 - 8	high	0,94	0,87			
Total ICT cost - combined scale	low	1,20	0,74	0,83	0,50	0,31
7 - 4 - 0 - 4 - 7 - 7	high	1,30	0,76			
Housing Corporations average IF as efficacy criterion - DEA productivity						
2002-7	IF aver.	b	Rsq	years	curve	result
HIR operations - workstations	low	1,08	0,82	0,50	0,50	0,21
0 - 4 - 11 - 15 - 0 - 0	high	1,11	0,88			
HIR operations - combined scale	low	1,71	0,82	0,67	0,50	0,27
0 - 4 - 10 - 13 - 0 - 3	high	1,85	0,79			
HIR operations - TIR cost average	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0 - 0 - 0 - 0	high	n/a	n/a			
Total ICT cost - workstations	low	1,00	0,90	0,83	1,00	**0,74**
7 - 0 - 13 - 14 - 16 - 7	high	0,88	0,87			
Total ICT cost - combined scale	low	1,32	0,80	0,67	0,00	0,00
7 - 0 - 0 - 17 - 15 - 8	high	1,63	0,81		curve	A3.9
Housing Corporations Maturity Factor as efficacy criterion - absolute productivity						
2004-7	MF	b	Rsq	years	curve	result
HIR operations - workstations	low	n/a	n/a	n/a	n/a	0,00
0 - 0 - 0 - 0	high	n/a	n/a			
HIR operations - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0 - 0	high	n/a	n/a			
HIR operations - TIR cost	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0 - 0	high	n/a	n/a			
Total ICT cost - workstations	low	0,90	0,69	0,25	0,50	**0,10**
0 - 0 - 0 - 7	high	0,89	0,96			
Total ICT cost - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0 - 0	high	n/a	n/a			
Housing Corporations Maturity Factor as efficacy criterion - DEA productivity						
2004-7	MF	b	Rsq	years	curve	result
HIR operations - workstations	low	0,99	0,79	0,75	0,00	0,00
0 - 7 - 6 - 4	high	1,25	0,8			
HIR operations - combined scale	low	1,68	0,81	0,50	0,00	0,00
0 - 8 - 8 - 0	high	1,9	0,92		curve	A3.11
HIR operations - TIR cost	low	1,15	0,74	0,50	0,50	**0,17**
0 - 0 - 7 - 12	high	1,09	0,62			
Total ICT cost - workstations	low	1,06	0,88	0,25	0,50	0,11
0 - 0 - 6 - 0	high	1,07	0,95			
Total ICT cost - combined scale	low	1,32	0,65	0,50	0,00	0,00
5 - 0 - 8 - 0	high	1,39	0,83		curve	A3.14

The 20 entries in Table 5.8 have resulted in 14 Figures in Appendix 3; in 5 cases there were no results available (n/a); in 1 case b(low)<1 and b(high)>1, which results in a curve value = 0. The 14 Figures were rejected in 4 cases (indication "curve" in Table 5.8), so eventually there are 12 situations left with resulting H1 validation value > 0.

Business performance

For hypothesis H2 the same calculations have been performed for the 2 possible combinations of measurements of constructs, for absolute and DEA productivity. The results are presented in Table 5.9.

Table 5.9 HC Business productivity Mann Whitney analysis

HC year input ICT assets	Prod abs IF average WS	Prod abs IF average Comb	DEA IF average WS	DEA IF average Comb
2002 23 org	0,149	0,083	**0,021**	0,275
2003 24 org	0,150	0,050	0,078	**0,047**
2004 35 org	**0,046**	0,127	**0,016**	**0,025**
2005 39 org	**0,021**	**0,002**	**0,020**	0,057
2006 37 org	**0,016**	**0,003**	0,121	0,487
2007 38 org	**0,009**	0,050	**0,005**	**0,009**

Table 5.10 represents the results of the regression analyses, according to step 3 of the methodology, for both the absolute as the DEA productivity.

Table 5.10 HC results of the regression analyses and resulting H2 validation

Housing Corporations - Infrastructure Factor - absolute productivity						
2002-7	IF	b	Rsq	years	curve	result
av. IF - Turnover - workstations	low	1,05	0,95	0,67	1,00	**0,63**
0 - 0 - 8 - 8 - 6 - 9	high	0,93	0,94			
av. IF - Sales - combined scale	low	1,43	0,80	0,33	0,50	0,13
0 - 0 - 0 - 8 - 7 - 0	high	1,38	0,83			
Housing Corporations - Infrastructure Factor - DEA productivity						
2002-7	IF	b	Rsq	years	curve	result
av. IF - Turnover - workstations	low	1,04	0,95	0,67	0,50	**0,31**
4 - 0 - 8 - 11 - 0 - 9	high	0,92	0,92			
av. IF - Turnover - combined scale	low	1,53	0,81	0,50	0	0
0 - 5 - 7 - 0 - 0 - 7	high	1,49	0,78		curve	A3.18

The 4 entries in Table 5.10 have resulted in 4 Figures in Appendix 3. One of these Figures was rejected (indication "curve" in Table 5.10), so eventually there are 3 situations left with resulting H2 validation value > 0.

5.3.2 Municipalities detailed separate analyses

First the results of the ICT performance (hypothesis H1 and proxies P1-P3) will be presented. Afterwards the results of the business performance (hypothesis H2).

ICT performance

The data of the Municipalities are available for IF 4 years (the period 2004-7) and for MF 3 years (the period 2005-7); according to Table 4.1 we will make 70 calculations for hypothesis H1 and proxies P1-P3 (to determine absolute and DEA productivity). Table 5.11 shows the 70 results of step 2 of the methodology. The 16 values of **p < 0,05** are printed in bold**.** The 3 values of <u>*p=0,05*</u> are printed italic and underlined.

Table 5.11 Municipalities results of Mann Whitney analyses

Organisations sorted on average infrastructure factor						
year input	Prod abs output WS	Prod abs output comb scale	Prod abs output cost HW/SW	DEA output WS	DEA output comb scale	DEA output cost HW/SW
Input: ICT personnel operations						
2004 13 org	**0,021**	**0,029**	0,127	**0,021**	**0,021**	0,352
2005 15 org	0,109	0,564	0,564	0,420	0,420	0,827
2006 13 org	**0,028**	0,076	0,083	**0,026**	**0,013**	0,131
2007 14 org	0,117	0,465	0,050	**0,028**	**0,028**	**0,009**
Input: Total ICT cost						
2004 13 org	0,127	**0,021**	xxx	0,127	0,275	xxx
2005 15 org	0,749	0,773	xxx	0,173	0,121	xxx
2006 13 org	**0,047**	0,117	xxx	**0,047**	**0,047**	xxx
2007 14 org	**0,028**	1,000	xxx	0,121	0,268	xxx
Organisations sorted on maturity factor						
year input	Prod abs output WS	Prod abs output comb scale	Prod abs output cost HW/SW	DEA output WS	DEA output comb scale	DEA output cost HW/SW
Input: ICT personnel operations						
2005 15 org	1,000	1,000	0,200	0,275	0,827	0,275
2006 13 org	1,000	0,827	<u>*0,050*</u>	**0,047**	1,000	<u>*0,050*</u>
2007 14 org	0,513	1,000	0,513	0,376	0,376	0,149
Input: Total ICT cost						
2005 15 org	1,000	1,000	xxx	0,275	0,513	xxx
2006 13 org	1,000	1,000	xxx	0,083	1,000	xxx
2007 14 org	<u>*0,050*</u>	0,412	xxx	0,117	0,275	xxx

Table 5.12 represents the results of the regression analyses, according to step 3 of the methodology, for each of the 20 combinations of ICT assets scale measurement, policies criterion, and expenditure construct measurement (for both the absolute as the DEA productivity).

Table 5.12 M results of the regression analyses and resulting H1 validation

Municipalities average Infrastructure Factor as quality criterion - absolute productivity						
2004-7	IF	b	Rsq	years	curve	result
HIR operations - workstations	low	0,98	0,93	0,50	0,50	0,23
4 - 0 - 5 - 0	high	0,96	0,88			
HIR operations - combined scale	low	1,32	1,00	0,25	0,50	0,11
4 - 0 - 0 - 0	high	1,05	0,82			
HIR operat. - cost TIR (HW/SW)	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0 - 0	high	n/a	n/a			
Total ICT cost - workstations	low	0,84	0,94	0,50	0,50	**0,24**
0 - 0 - 5 - 5	high	0,87	0,97			
Total ICT cost - combined scale	low	0,77	0,67	0,25	0,00	0,00
4 - 0 - 0 - 0	high	1,34	0,85		curve	A3.22
Municipalities average Infrastructure Factor as quality criterion - DEA productivity						
2004-7	IF	b	Rsq	years	curve	result
HIR operations - workstations	low	1,00	0,77	0,75	0,50	**0,29**
4 - 0 - 5 - 5	high	0,83	0,77			
HIR operations - combined scale	low	1,94	0,75	0,75	0,50	0,29
4 - 0 - 5 - 5	high	1,21	0,78			
HIR operat. - cost TIR (HW/SW)	low	0,76	0,48	0,25	0,00	0,00
0 - 0 - 0 - 5	high	1,25	0,74			
Total ICT cost - workstations	low	0,91	0,88	0,25	0,50	0,11
0 - 0 - 5 - 0	high	0,93	0,93			
Total ICT cost - combined scale	low	2,03	0,91	0,25	0,00	0,00
0 - 0 - 5 - 0	high	1,37	0,86		curve	A3.26
Municipalities Maturity Factor as quality criterion - absolute productivity						
2005-7	MF	b	Rsq	years	curve	result
HIR operations - workstations	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
HIR operations - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
HIR operat. - cost TIR (HW/SW)	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Total ICT cost - workstations	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Total ICT cost - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Municipalities Maturity Factor as quality criterion - DEA productivity						
2005-7	IF	b	Rsq	years	curve	result
HIR operations - workstations	low	1,01	0,91	0,33	0,00	0,00
0 - 5 - 0	high	0,91	0,90		curve	A3.27
HIR operations - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
HIR operat. - cost TIR (HW/SW)	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Total ICT cost - workstations	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Total ICT cost - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			

The 20 entries in Table 5.12 have resulted in 9 Figures in Appendix 3; in 10 cases there were no results available (n/a); in 1 case b(low)<1 and b(high)>1, which results in a curve value = 0. The 9 Figures were rejected in 3 cases (indication "curve" in Table 5.12), so eventually there are 6 situations left with resulting H1 validation value > 0.

Business performance

For hypothesis H2 the same calculations have been performed for the 2 possible combinations of measurements of constructs, for absolute and DEA productivity. The results are presented in Table 5.13.

Table 5.13 Municipalities Business productivity Mann Whitney analysis

M year input ICT assets	Prod abs IF average WS	Prod abs IF average Comb	DEA IF average WS	DEA IF average Comb
2004 13 org	0,050	0,275	0,139	0,321
2005 15 org	0,773	0,564	0,245	0,107
2006 13 org	0,149	0,083	0,827	1,000
2007 14 org	0,827	1,000	0,147	0,245

Table 5.14 represents the results of the regression analyses, according to step 3 of the methodology, for both the absolute as the DEA productivity.

Table 5.14 M results of the regression analyses and resulting H2 validation

Municipalities - Infrastructure Factor - absolute productivity						
2004-7	IF	b	Rsq	years	curve	result
av. IF - Turnover - workstations	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
av. IF - Turnover - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Municipalities - Infrastructure Factor - DEA productivity						
2004-7	IF	b	Rsq	years	curve	result
av. IF - Turnover - workstations	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
av. IF - Turnover - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			

The 4 entries in Table 5.14 have resulted in no Figure in Appendix 3.

5.3.3 Hospitals detailed separate analyses

First the results of the ICT performance (hypothesis H1 and proxies P1-P3) will be presented. Afterwards the results of the business performance (hypothesis H2).

ICT performance

The data of the Hospitals are available for 3 years (the period 2006-8); according to Table 4.1 we will make 60 calculations for hypothesis H1 and proxies P1-P3 (to determine absolute and DEA productivity). Table 5.15 shows the 60 results of step 2 of the methodology. The 9 values of **p < 0,05** are printed in bold**.** The 14 values of *p=0,05* are printed italic and underlined.

Table 5.15 Hospitals results of Mann Whitney analyses

Organisations sorted on average infrastructure factor						
year input	Prod abs output WS	Prod abs output comb scale	Prod abs output cost HW/SW	DEA output WS	DEA output comb scale	DEA output cost HW/SW
Input: ICT personnel operations						
2006 14 org	0,184	0,127	*0,050*	0,275	0,275	0,127
2007 12 org	0,513	0,083	0,275	0,245	0,146	0,139
2008 11 org	**0,021**	*0,050*	*0,050*	**0,046**	**0,046**	**0,046**
Input: Total ICT cost						
2006 14 org	0,827	1,000	xxx	*0,050*	*0,050*	xxx
2007 12 org	0,083	*0,050*	xxx	0,191	0,237	xxx
2008 11 org	**0,009**	**0,021**	xxx	**0,020**	0,081	xxx
Organisations sorted on maturity factor						
year input	Prod abs output WS	Prod abs output comb scale	Prod abs output cost HW/SW	DEA output WS	DEA output comb scale	DEA output cost HW/SW
Input: ICT personnel operations						
2006 14 org	*0,050*	*0,050*	0,275	*0,050*	**0,046**	0,275
2007 12 org	0,127	1,000	**0,021**	1,000	1,000	0,139
2008 11 org	*0,050*	0,127	*0,050*	*0,050*	*0,050*	*0,050*
Input: Total ICT cost						
2006 14 org	0,275	0,275	xxx	1,000	1,000	xxx
2007 12 org	0,275	1,000	xxx	1,000	1,000	xxx
2008 11 org	1,000	1,000	xxx	1,000	1,000	xxx

Table 5.16 represents the results of the regression analyses, according to step 3 of the methodology, for each of the 20 combinations of ICT assets scale measurement, ICT management policies criterion, and expenditure construct measurement (for both the absolute as the DEA productivity).

Table 5.16 Hosp results of regression analyses and resulting H1 validation

Hospitals average Infrastructure Factor as quality criterion - absolute productivity						
2006-8	IF	b	Rsq	years	curve	result
HIR operations - workstations	low	0,93	0,84	0,33	0,50	0,10
0 - 0 - 4	high	0,99	0,34			
HIR operations - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
HIR operat. - cost TIR (HW/SW)	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Total ICT cost - workstations	low	0,98	0,98	0,33	0,50	0,13
0 - 0 - 5	high	0,99	0,56			
Total ICT cost - combined scale	low	0,92	0,96	0,33	0,50	**0,14**
0 - 0 - 4	high	1,10	0,73			
Hospitals average Infrastructure Factor as quality criterion - DEA productivity						
2006-8	IF	b	Rsq	years	curve	result
HIR operations - workstations	low	1,44	0,90	0,33	0,50	0,14
0 - 0 - 3	high	2,31	0,82			
HIR operations - combined scale	low	1,01	0,82	0,33	0,50	0,12
0 - 0 - 3	high	1,62	0,69			
HIR operat. - cost TIR (HW/SW)	low	1,07	0,74	0,33	0,50	**0,14**
0 - 0 - 3	high	1,84	0,99			
Total ICT cost - workstations	low	0,88	0,99	0,33	0,00	0,00
0 - 0 - 4	high	1,60	0,84			
Total ICT cost - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Hospitals Maturity Factor as quality criterion - absolute productivity						
2006-8	MF	b	Rsq	years	curve	result
HIR operations - workstations	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
HIR operations - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
HIR operat. - cost TIR (HW/SW)	low	1,04	0,15	0,33	0,50	**0,09**
0 - 4 - 0	high	1,69	0,98			
Total ICT cost - workstations	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Total ICT cost - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Hospitals Maturity Factor as quality criterion - DEA productivity						
2006-8	IF	b	Rsq	years	curve	result
HIR operations - workstations	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
HIR operations - combined scale	low	0,73	0,59	0,33	0,50	**0,10**
3 - 0 - 0	high	0,95	0,59			
HIR operat. - cost TIR (HW/SW)	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Total ICT cost - workstations	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Total ICT cost - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			

The 20 entries in Table 5.16 have resulted in 8 Figures in Appendix 3; in 11 cases there were no results available (n/a); in 1 case b(low)<1 and b(high)>1, which results in a curve value=0. The 8 Figures were in no case rejected, so eventually there are 8 situations left with resulting H1 validation value > 0.

Business performance

For hypothesis H2 the same calculations have been performed for the 2 possible combinations of measurements of constructs, for absolute and DEA productivity. The results are presented in Table 5.17.

Table 5.17 Hospitals Business productivity Mann Whitney analysis

Hosp year input ICT assets	Prod abs IF average WS	Prod abs IF average Comb	DEA IF average WS	DEA IF average Comb
2006 14 org	0,827	1,000	0,275	0,127
2007 12 org	0,149	0,149	0,139	0,139
2008 11 org	0,127	0,127	**0,037**	**0,037**

Table 5.18 represents the results of the regression analyses, according to step 3 of the methodology, for both the absolute as the DEA productivity.

Table 5.18 Hosp results of regression analyses and resulting H2 validation

Hospitals - Infrastructure Factor - absolute productivity						
2006-8	IF	b	Rsq	years	curve	result
av. IF - Turnover - workstations	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
av. IF - Turnover - combined scale	low	n/a	n/a	0,00	0,00	0,00
0 - 0 - 0	high	n/a	n/a			
Hospitals - Infrastructure Factor - DEA productivity						
2006-8	IF	b	Rsq	years	curve	result
av. IF - Turnover - workstations	low	1,47	0,96	0,33	0,50	**0,12**
0 - 0 - 3	high	1,06	0,48			
av. IF - Turnover - combined scale	low	1,25	0,96	0,33	1,00	0,00
0 - 0 - 3	high	0,90	0,59		curve	A3.36

The 4 entries in Table 5.18 have resulted in 2 Figures in Appendix 3. One of the 2 Figures was rejected (indication "curve" in Table 5.18), so eventually there is 1 situation left with resulting H5 validation value > 0.

5.3.4 Validity of hypotheses/proxies according to the detailed separate analyses

In this section we will derive the (degree of) validity of the hypotheses and proxies, as represented in the research model (Figure 3.10). We established a base hypothesis (H1) about the effect of the efficacy of ICT management policies with respect to economies of scale in the operational ICT conversion process, defined as a relation between the ICT expenditure and the scale of ICT assets. Furthermore additional proxies are defined, concerning the best way to measure ICT expenditure (P1), scale of ICT assets (P2 and P2a) and efficacy of ICT management policies (P3). Finally we defined a hypothesis (H2) about the effect of the infrastructure factor with respect to economies of scale in the business processes, defined as a relation between the scale of ICT assets and the organizational performance. First the results of the ICT performance (hypothesis H1 and proxies P1-P3) will be presented. Afterwards the results of the business performance (hypothesis H2).

ICT performance

In this section the validity of hypothesis H1 and proxy assumptions P1-P3 will be determined. Table 5.19 gives a summary of the results for Housing Corporations (Table 5.8), Municipalities (Table 5.12) and Hospitals (Table 5.16):

- The first 5 rows for Housing Corporations (HC), Municipalities (Mun) and Hospitals (Hosp) are the average values of the results of Tables 5.8, 5.12 and 5.16.
- The first 2 columns are the average values of IF average and MF; the third column is the average value of first 2 columns which is also the average of the fourth and fifth columns; the fourth and fifth columns are the average values of the absolute productivity and DEA productivity.
- **H1, P3**: The sixth row shows the average values of the first 5 rows. IF average values (column 1) are higher than MF values (column 2) for HC, M and Hosp, which means that proxy assumption P3 is validated. The overall average (0,16) for HC is higher than for M (0,06), which is higher than for Hosp (0,05). This implies that hypothesis H1 is on average best validated for HC and worst for Hosp.
- **P1**: The seventh and eighth rows give the results for proxy P1 (lines number 1 and 2 in the research model in Figure 3.10): row 7 gives the average values of rows 1 and 2; row 8 gives the average values of rows 4 and 5. We can see that for HC/IF and for HC/MF row 8 has higher values than row 7; for M/IF, Hosp/IF and Hosp/MF row 7 has the highest value; for M/MF both values are zero. This implies that proxy assumption P1 is validated for M/IF, Hosp/IF and Hosp/MF, not for HC/IF and HC/MF, and for M/MF it is undecided.
- **P2a**: The ninth row gives the average values of rows 1 and 4; the tenth row gives the average of rows 2 and 5. Workstations (row 9) are a better measurement of the scale of ICT assets than the combined scale (row 10) for HC/IF, HC/MF, M/IF and Hosp/IF (which validates P2a). For Hosp/MF the Combined scale is a better measure, which contradicts proxy assumption P2a. For M/MF this is undecided, as the values of both row 9 and 10 are zero.
- **P2**: The eleventh and twelfth rows show the results for proxy P2 (lines number 2 and 3 in the research model in Figure 3.10): row 11 gives the values of row 3; row 12 gives the average values of rows 1 and 2. The number of ICT assets (row 12) is a better measurement of the scale of ICT assets than the TIR cost (row 11) for HC/IF, M/IF and Hosp/IF, which confirms proxy assumption P2. For HC/MF and Hosp/MF proxy assumption P2 must be rejected. In the case of M/MF proxy P2 could not be evaluated, as the values of both row 9 and 10 are zero.

Table 5.19 Overview of the results for hypothesis H1 and proxies P1-P3

Average values of IF / MF - abs / DEA prod	col.1	col.2	col.3	col.4	col. 5
Housing Corporations	2002-7	2004-7			
	IF av	MF	average	abs prod	DEA
1. HIR operations - workstations	0,30	0,00	0,15	0,19	0,11
2. HIR oper - combined scale	0,32	0,00	0,16	0,19	0,13
3. HIR operations - TIR cost	0,00	0,09	0,04	0,00	0,09
4. Total ICT cost - workstations	0,67	0,11	0,39	0,35	0,43
5. Total ICT cost - combined scale	0,16	0,00	0,08	0,16	0,00
6. Average all **H1 + P3**	**0,29**	0,04	**0,16**	0,18	0,15
7. Average HIR oper (ws,cs) **P1/2**	0,31	0,00	0,15	0,19	0,12
8. Average ICT cost (ws,cs) **P1/1**	**0,41**	**0,05**	0,23	0,25	0,21
9. Average ws (HIR op, ICT cost) **P2a**	**0,48**	**0,05**	0,27	0,27	0,27
10. Average cs (HIR op, ICT cost) **P2a**	0,24	0,00	0,12	0,17	0,07
11. HIR operations - TIR cost **P2/3**	0,00	**0,09**	0,04	0,00	0,09
12. Average HIR oper (ws,cs) **P2/2**	**0,31**	0,00	0,15	0,19	0,12
Municipalities	2004-7	2005-7			
	IF av	MF	average	abs prod	DEA
1. HIR operations - workstations	0,26	0,00	0,13	0,11	0,14
2. HIR oper - combined scale	0,20	0,00	0,10	0,06	0,14
3. HIR operations - TIR cost	0,00	0,00	0,00	0,00	0,00
4. Total ICT cost - workstations	0,18	0,00	0,09	0,12	0,06
5. Total ICT cost - combined scale	0,00	0,00	0,00	0,00	0,00
6. Average all **H1 + P3**	**0,13**	0,00	**0,06**	0,06	0,07
7. Average HIR oper (ws,cs) **P1/2**	**0,23**	0,00	0,11	0,09	0,14
8. Average ICT cost (ws,cs) **P1/1**	0,09	0,00	0,04	0,06	0,03
9. Average ws (HIR op, ICT cost) **P2a**	**0,22**	0,00	0,11	0,12	0,10
10. Average cs (HIR op, ICT cost) **P2a**	0,10	0,00	0,05	0,03	0,07
11. HIR operations - TIR cost **P2/3**	0,00	0,00	0,00	0,00	0,00
12. Average HIR oper (ws,cs) **P2/2**	**0,23**	0,00	0,11	0,09	0,14

Hospitals	2006-8 IF av	2006-8 MF	average	abs prod	DEA
1. HIR operations - workstations	0,12	0,00	0,06	0,05	0,07
2. HIR oper - combined scale	0,06	0,05	0,06	0,00	0,11
3. HIR operations - TIR cost	0,07	0,05	0,06	0,05	0,07
4. Total ICT cost - workstations	0,06	0,00	0,03	0,06	0,00
5. Total ICT cost - combined scale	0,07	0,00	0,03	0,07	0,00
6. Average all **H1 + P3**	**0,08**	0,02	**0,05**	0,05	0,05
7. Average HIR oper (ws,cs) **P1/2**	**0,09**	**0,02**	0,06	0,02	0,09
8. Average ICT cost (ws,cs) **P1/1**	0,07	0,00	0,03	0,07	0,00
9. Average ws (HIR op, ICT cost) **P2a**	**0,09**	0,00	0,05	0,06	0,04
10. Average cs (HIR op, ICT cost) **P2a**	0,07	**0,02**	0,05	0,03	0,06
11. HIR operations - TIR cost **P2/3**	0,07	**0,05**	0,06	0,05	0,07
12. Average HIR oper (ws,cs) **P2/2**	**0,09**	0,02	0,06	0,02	0,09

Business performance

In this section the validity of hypothesis H2 will be determined. Table 5.20 gives a summary of the results for Housing Corporations (Table 5.10), Municipalities (Table 5.14) and Hospitals (Table 5.18). The "average" column in Table 5.20 is average for a) the "abs prod" and "DEA" column and b) the "WS" and "Comb" column.

Table 5.20 Overview of the results for hypothesis H2

	abs prod	DEA	average	WS	Comb
Housing Corporations	0,38	0,16	0,27	0,47	0,07
Municipalities	0,00	0,00	0,00	0,00	0,00
Hospitals	0,00	0,06	0,03	0,06	0,00

Validity of the hypotheses H1 and H2 separately

Table 5.21 gives an overview of the (degree of) validity of the hypotheses H1 and H2 separately.

Table 5.21 Degree of validity of hypotheses H1 and H2 separately

	Type organization	HC		M		Hosp	
Nr	Hypothesis/proxy description / ICT management policy	IF	MF	IF	MF	IF	MF
H1	Relation between ICT assets and ICT expenditure influenced by ICT policies	0,29	0,04	0,13	0,00	0,08	0,02
P1	ICT expenditure better estimated by FTE Operations than by total ICT costs	no	no	yes	n/a	yes	yes
P2	Scale of ICT assets better estimated by number of ICT assets than by TIR cost	yes	no	yes	n/a	yes	no
P2a	Better number measure by workstations than by combined scale factor	yes	yes	yes	n/a	yes	no
P3	Efficacy ICT management policies better estimated by IF than MF	yes		yes		yes	
H2	Relation between ICT assets and Sales influenced by IF	0,27		0,00		0,03	

The results in Table 5.19 for the Maturity Factor in the case of Municipalities are all zero, so the proxy assumptions P1, P2 and P2a in Table 5.21 could not be evaluated (n/a). If we compare Table 5.21 with Table 5.6 (global analysis), then we can conclude that the degree of validation is lower in the detailed analysis, according to our expectation. Comparing the most important results, the Housing Corporations measured by IF (first column in Table 5.21) with HC measured by LR (second column in Table 5.6) then we see the following differences:

- In the global analysis there is a "no" for P2a, versus a "yes" in the detailed analysis.
- In the detailed analysis there is a "no" for P1, versus a "yes" in the global analysis.
- In the detailed analysis the validation values for H1 and H2 are lower than in the global analysis, but these values are not comparable.

As stated before, we consider the results of the detailed analysis as more valuable than the results of the global analysis and in the discussion (chapter 6.2) we will explain what is the possible cause of the HC/IF-invalidation of P1.

In Appendix 4 we determined until what extent proxy P3 is supported by the cybernetic view on ICT management policies. We can conclude that proxy P3 is completely supported by the cybernetic view on ICT management policies in the case of the Housing Corporations. This is only partly the case for Municipalities and for Hospitals.

5.3.5 Determination of H1 and H2 simultaneously

In this section the hypotheses H1 and H2 will be validated simultaneously in the case of the Housing Corporations and Hospitals. Afterwards we will demonstrate that there are insufficient significant results in the case of the Municipalities to perform this type of analysis.

This type of analysis is explained in section 4.4.2, Figure 4.7. We will start with Housing Corporations and as an example we take the combination IF – workstations – absolute productivity. These results are represented in Figure 5.1 (as an example of Graph 1 in Figure 4.7) and Figure 5.2 (see Graph 2 in Figure 4.7).

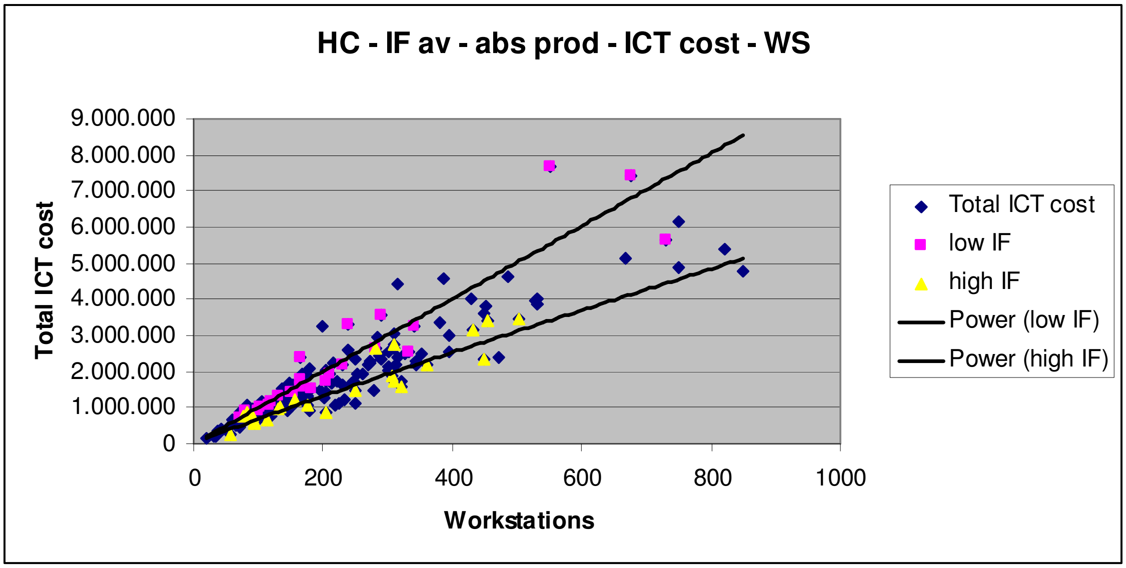


Figure 5.1 HC ICT productivity (see Graph 1 in Figure 4.7)

In Figure 5.1 the 24 low IF points are represented in purple (squares) and the 24 high IF points in yellow (triangles). The same for the 31 low and high IF points in Figure 5.2. However, we have to check whether these two analyses, performed separately for the ICT conversion process and the Business processes, are the results of the data of the same organizations.

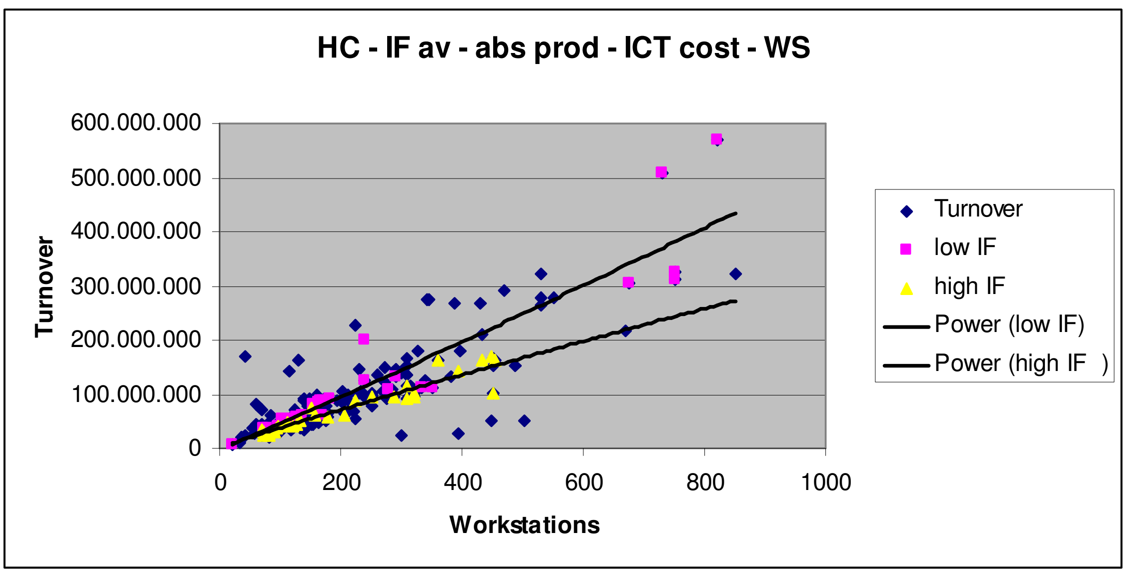


Figure 5.2 HC Business productivity (see Graph 2 in Figure 4.7)

The answer on this question is demonstrated in Figure 5.3 which shows that only 16 “low IF” organizations are the same as output of the ICT conversion process and as input for the Business processes. And only 15 of the “high IF” organizations are the same.

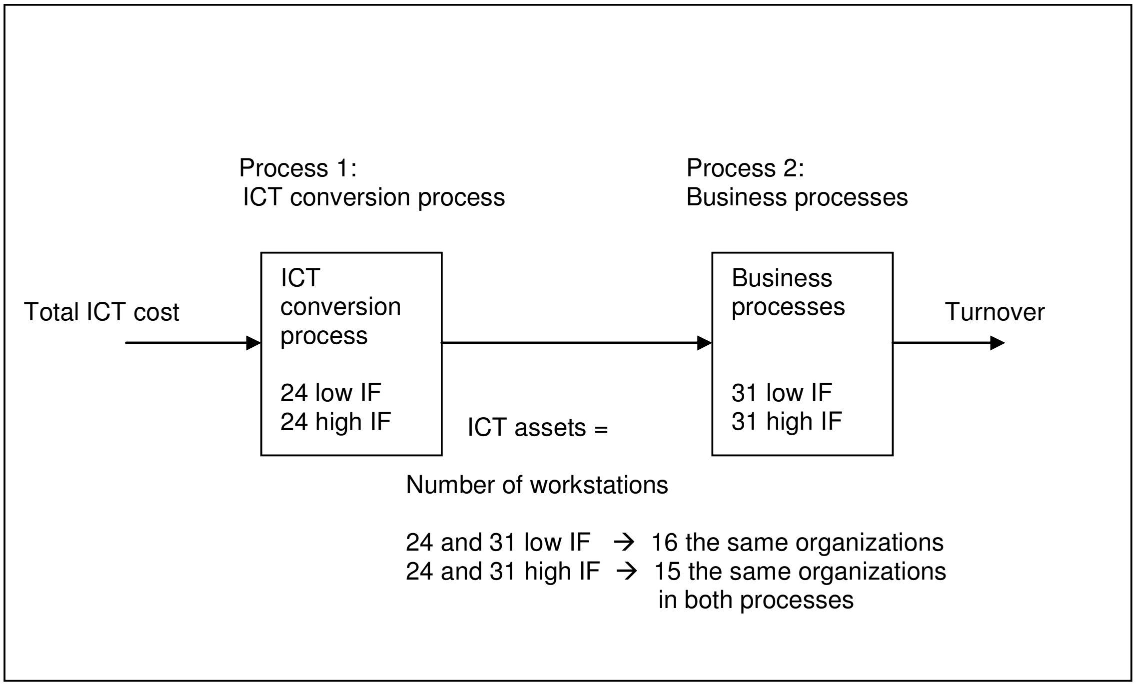


Figure 5.3 HC ICT assets as output process 1 and as input process 2

We will now validate H1 and H2 simultaneously and the results are presented in Table 5.22. In the second and third column the number of organizations with low IF and high IF are copied from Table 5.8 and Table 5.10. In the fourth column the average H1 and H2 validation results of Table 5.8 and Table 5.10 are represented. In the fifth column we see the sum of the number of IF low and IF high organizations, for example 31 in the first row, which is copied from Figure 5.3. The sixth column is the product of the average validation value in column 4 with the percentile of organizations in column 5 (for example 0,62 x (31 / (24 + 31)) = 0,35 in the first row). In the seventh column the minimum IF value (“Min” in Figure 3.7 and in Figure 4.7) is represented. In the first row this is the maximum IF value of the conjunction of “low IF” values (16 organizations) in Figure 5.1 and in Figure 5.2. In the eighth column the maximum IF value (“Max” in Figure 3.7 and in Figure 4.7) is represented. In the first row this is the minimum IF value of the conjunction of “high IF” values (15 organizations) in Figure 5.1 and in Figure 5.2.

Table 5.22 HC validity of hypotheses H1 and H2 simultaneously

HC - abs productivity	col. 2	col. 3	col. 4	col. 5	col. 6	col. 7	col. 8
2002-7	H1 org	H2 org	av val	H1+H2 org	corr val	Min	Max
av. IF - workstations	24	31	**0,62**	31	**0,35**	**0,38**	**0,53**
av. IF - combined scale	29	15	0,22	20	0,10	0,38	0,56
HC - DEA productivity							
2002-7	H1 org	H2 org	av val	H1+2 org	corr val	Min	Max
av. IF - workstations	57	32	0,53	56	0,33	0,42	0,54
av. IF - combined scale	47	19	0,00	12	0,00	0,37	0,56

The highest corrected validation value (0,35) of H1 and H2 simultaneously in Table 5.22 is realized by the combination average IF – workstations – absolute productivity. This is also the highest average value (“av val”): 0,62 and confirms the results in Table 5.21. The corresponding Min-Max segment of Figure 3.7 is 0,38-0,53. The other 2 combinations in Table 5.22 (with corrected validation value > 0) have Min-Max segments 0,38-0,56 and 0,42-0,54. It seams reasonable (from the point of view of robustness) to use the maximum value of the minimum values (0,42) and the minimum value of the maximum values (0,53). Thus we might advice for Housing Corporations that the optimal IF value must be in the segment 0,42-0,53.

We are not able to perform a simultaneous analysis of H1 and H2 for Municipalities, as there are no H5 validation results (see Table 5.20). Therefore we are not able to advice an optimal IF value for Municipalities.

In the case of Hospitals we performed a simultaneous analysis of H1 and H2 and the results are showed in Table 5.23. There is one situation with positive results, realized by the combination average IF – workstations – DEA productivity. This confirms in general the results in Table 5.21.The corresponding Min-Max segment of Figure 3.7 is 0,54-0,58. So it seems reasonable to advice for Hospitals that the optimal IF value must be in the segment 0,54-0,58.

Table 5.23 Hosp validity of hypotheses H1 and H2 simultaneously

Hosp - abs productivity							
2006-8	H1 org	H2 org	av val	H1+2 org	corr val	Min	Max
av. IF - workstations	5	0	0,06	0	0,00	n/a	n/a
av. IF - combined scale	4	0	0,07	0	0,00	n/a	n/a
Hosp - DEA productivity							
2006-8	H1 org	H2 org	av val	H1+2 org	corr val	Min	Max
av. IF - workstations	4	3	0,09	2	**0,03**	**0,54**	**0,58**
av. IF - combined scale	0	0	0,00	0	0,00	n/a	n/a

5.4 Conclusion

In this chapter the results of the calculations are presented, based on the available data and according to the methodology. The most global and holistic analysis is according to the Partial Least Squares. Linear regression makes it possible to better determine the validity of H1 and H2. In the detailed analysis hypothesis H1 has been tested in 20 different ways for Housing Corporations (Table 5.8), Municipalities (Table 5.12) and Hospitals (Table 5.16). Hypothesis H2 has been tested in 4 different ways for Housing Corporations (Table 5.10), Municipalities (Table 5.14) and Hospitals (Table 5.18). The graphical results can be viewed in Appendix 3. Both hypotheses H1 and H2 have been tested simultaneously in 4 different ways for HC (Table 5.22) and Hosp (Table 5.23). In general the hypotheses are supported by the findings, as far as the infrastructure factor is concerned. A positive relation between ICT expenditure and the maturity of the ICT organization could, however, hardly be validated.

6 DISCUSSION, LIMITATIONS AND CONCLUSION

6.1 Introduction

In this section we first discuss the research findings. Then the limitations of this research are analyzed in terms of different validity aspects. Finally we address the implications of the research findings in a concluding section.

6.2 Discussion

In summary, our findings substantially support our research model. They provide evidence which is consistent with the hypotheses **H1** and **H2** about (dis)economies of scale in ICT respectively business processes; this holds especially for Housing Corporations in combination with the Infrastructure Factor. In this research we performed a global and a detailed analysis concerning the validity of the hypotheses, all based on least squares. The *global* analysis consists of Partial Least Square (PLS) regression and linear regression to obtain a global view regarding the validity of the hypotheses; we assumed linear relations between the inputs and outputs of the ICT respectively business processes. In the *detailed* analysis we assumed functions of the form $y = a.x^b$ with y = output and x = input of the ICT respectively business processes. We determined the absolute productivity (y/x) and the relative productivity using Data Envelopment Analysis. The discussion below is based on the results of the detailed analysis.

The measurement of ICT expenditure has only for Municipalities and Hospitals resulted in higher validation values for FTE Operations than for Total ICT costs (see Table 5.21), which partly confirms proxy assumption **P1**. However, for Housing Corporations the opposite holds; a possible explanation could be that the measurement of the FTE for operations and maintenance is insufficiently accurate, and that part of the workforce is spent on projects rather than on operations and regular maintenance. This is always a difficult distinction: for example, what about maintenance projects? Housing Corporations are relatively small organizations, using on average only 7 FTE for operations and maintenance, so there is in general no clear separation of functions.

We supposed in proxy assumption **P2** that the number of ICT assets would be a better approximation of the scale of ICT assets than the cost of hardware/software. Furthermore we expected in **P2a** that the number of workstations gives higher validation values than the combined scale measurement. In general both P2 and P2a are validated, with two exceptions: in the situation of Housing Corporations (P2) and Hospitals (P2 and P2a), with the Maturity Factor as efficacy criterion (see Table 5.21). Below we will discuss that the Maturity Factor has a low H1-validation value compared with the Infrastructure Factor, which makes the rejection of P2 and P2a in this case more explainable and less important.

The COBIT Maturity Factor as an ICT management policies criterion has an average H1-validation value of just about 11 % of the average Infrastructure Factor validation value (see Table 5.19). The validation of H1 could not be improved by using subsets of the 17 maturity criteria (Figure 4.3). These results are in line with proxy assumption **P3**, which states that the maturity of the ICT organization is less important for the productivity of the ICT organization. As the COBIT maturity factor leads to very low H1-validation values, we can state that the results in the "MF" columns in Table 5.21 are less relevant than those in the "IF" columns.

Why are the Housing Corporations' validation values higher than those of Municipalities and Hospitals? Note that only 16 of the 70 entries (23%) in Table 5.11 (Municipalities) show a statistically significant ($p < 0,05$) difference between the high and the low efficacy ICT management policies groups of Municipalities. For Hospitals this value is even lower: only 9 of the 60 entries (15%) in Table 5.15 show a statistically significant ($p < 0,05$) difference. These values are lower than the results for the Housing Corporations in Table 5.7, where 50 of the 100 entries (50%) show a statistically significant difference. The distinction between Housing Corporations, Municipalities and Hospitals is also demonstrated in Table 5.19, which shows an overall H1-validation value of 0,16 for the Housing Corporations versus 0,06 for the Municipalities and 0,05 for the Hospitals. Another difference between Housing Corporations, Municipalities and Hospitals can be found in Appendix 4, where the Housing Corporations could better be divided in groups based on the cybernetic view on ICT management policies (according to Figure 2.17) than the Municipalities and the Hospitals.
The explanation can probably be found in the following differences, which will be analyzed in more detail in section 6.3 (Limitations):

1) The Housing Corporations hardly show any variety in their business processes and are more mutually comparable than the Municipalities and the Hospitals, whose business processes show a larger variety.
2) The size of the benchmark: a number of 196 measurements (Housing Corporations) provides better statistical results than 55 (Municipalities) or 37 (Hospitals).

In Table 5.19 we can see that the H1-validation values calculated with Data Envelopment Analysis (DEA) are on average the same as those calculated with the absolute productivity analysis. For Housing Corporations the average DEA value is lower than the absolute productivity value (0,15 versus 0,18). For Municipalities on the contrary the average DEA value is somewhat higher than the absolute productivity value (0,07 versus 0,06). For Hospitals the average DEA value is the same as the absolute productivity value (0,05). A possible explanation for the differences between both techniques could be that DEA is sensible for measurement errors (Kitchenham 2002).

In this research a positive relation between ICT expenditure and the maturity of the ICT organization could hardly be validated. It is however likely that in organizations with a higher ICT budget the maturity of the ICT organization has more influence on the productivity of the ICT organization. In general can be stated that the higher the ICT budget, the higher the level of maturity of the ICT organization, the better the ICT organization is under control, the less errors are made and, the higher the level of productivity of the ICT labour is (Juran 1979). On the other hand, a higher level of COBIT maturity usually involves costs which could be equivalent to or even supersede possible savings (see Figure 2.16 for these opposing views). Further research is therefore required to analyze the effects at higher COBIT maturity levels.

In this research we have primarily analyzed the productivity of the ICT conversion process and secondarily the productivity of the business processes. In order to realize economies of scale in ICT and in business, the spending in infrastructure and applications must both be sufficient. In Figure 3.7 the relation between the average Infrastructure Factor (IF) and Costs of ICT processes is represented: we assume that these costs decrease with increasing IF. On the other hand the Costs of Business Processes increase with increasing IF (and decreasing application spending, thus decreasing application functionality). Therefore there must be a minimum for the total costs (the sum of business and ICT) at a certain value of IF. We suppose there is a minimum value (Min) for IF below which the ICT expenditures rise more steeply and a maximum (Max) above which the business expenditures rise more steeply. Then there must be an area between Min and Max where total costs are more or less the same. We found for Housing Corporations that Min=0,42 and Max=0,53. For Hospitals these values are Min=0,54 and Max=0,58. In this research we could not determine a percentage for Municipalities, as the available data did not permit us to draw a conclusion. The above mentioned percentage should however be considered with care, as the individual situation of an organization may require specific investments in necessary functionalities. Besides, these percentages will change over time. Further research is required, in particular in the contribution of ICT to the performance of business processes (Brynjolfsson and Hitt 2003).

In this research we did not analyze the relation between the Maturity factor and the productivity of business processes, as the ICT/Business alignment is outside the scope of this research. As stated above the focus is primarily on the productivity of the ICT conversion process. We analyzed the business productivity only from the point of view of the upper limit of the infrastructure factor, to be sure that the organizations with *high* IF values that contribute to the *high* ICT productivity curve (Figure 4.7 graph 1), are the same organizations that contribute to the *low* business productivity curve (Figure 4.7 graph 2). We also found however that that the organizations with *low* IF values that contribute to the *low* ICT productivity curve, are the same organizations that contribute to the *high* business productivity curve. As the simultaneous analysis of **H1 and H2** gives the same results as the separate analysis of H1 and H2, we can state that we reach a higher level of internal validity: we exclude the possibility that high / low ICT productivity is reached by other organizations than those that realize low / high business productivity. Validity aspects will be analyzed in more detail in the next chapter.

6.3 Limitations

In this section the validity of this research will be elaborated. First we will define the different validity aspects. Then we treat the question concerning the independency of the measurement variables of the constructs. Afterwards the influence of the quality of the empirical dataset on the different validity aspects will be investigated. Finally we will apply these ideas to this study, to determine the limitations of this PhD research.

6.3.1 Definitions validity aspects

In Figure 6.1 the different elements in the research process are represented. The starting point is made up be the phenomena in *reality* which are studied in the research, which determines the scope of the research. This is in terms of Popper (1972) part of World I. The *Research model* consists of the definitions of the constructs (efficacy of ICT management policies, ICT expenditure, scale ICT assets, organization performance), the hypotheses H1–H2 and proxy assumptions P1-P3. In Figure 3.10, Research model, we can see that the approximation of constructs by variables is determined by the proxies P1-P3. The research model is in terms of Popper World II, as these are descriptions of the phenomena in reality. These constructs and hypotheses are based upon *theories*, e.g. Cobb and Douglas for economies of scale, which can be considered as a point of view to "look" at reality (see also Figure 2.12). These theories are in terms of Popper World III. In the *Measurement model* the constructs are represented by variables that are measured in reality with certain reliability. The Measurement model can be considered as a specification of the Research model. In the measurement model the measured variables fill in the ("specified") hypotheses and proxies. On the other hand, by the use of the M&I dataset as secondary data source the measurement model imposes a restriction on the researchmodel. The measurement model is in terms of Popper also part of World II.

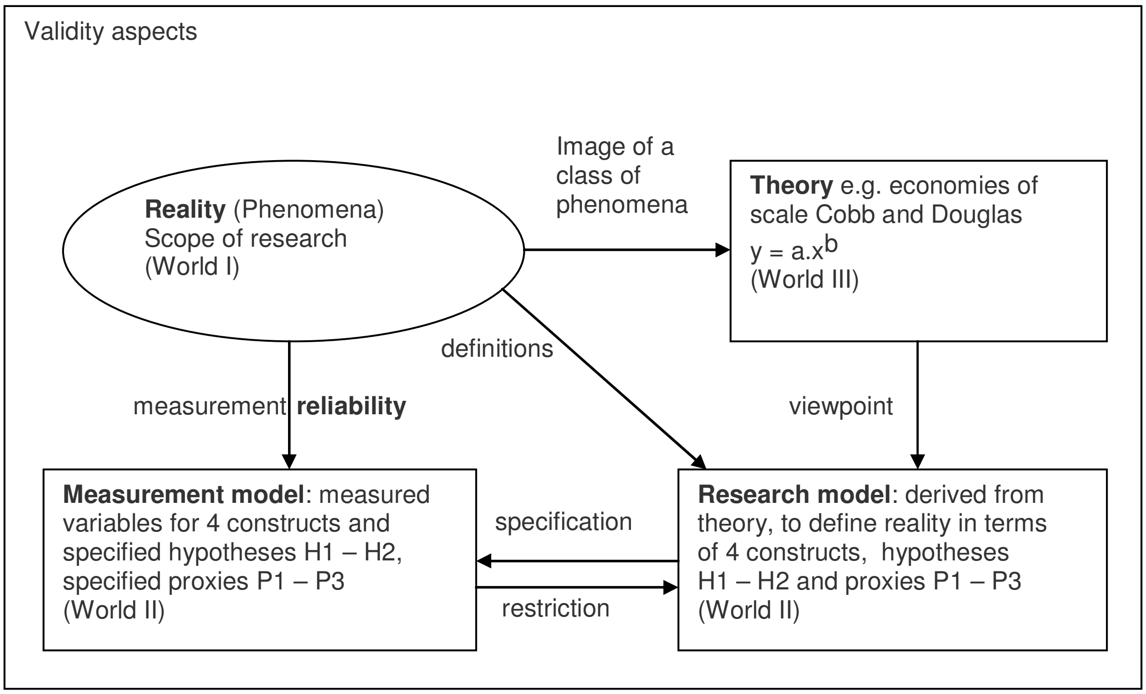


Figure 6.1 Relation between reality, theory and models

Content validity is the degree to which items in an instrument reflect the content universe to which the instrument will be generalized (Cronbach 1971; Rogers 1995; Boudreau et al 2001). This validity is generally established through literature reviews and expert judges or panels. The content validity can in terms of Figure 6.1 be defined as the degree until which the research model (consisting of definitions, hypotheses and proxies) is a good representation of the (perceived) reality (Leeuw 1996; Baarda and de Goede 2001). This type of validity can only be made plausible by the usage of general theories. For example the laws of gravitation cannot be proved to be valid, but every day again everybody is taking them into account as a well corroborated theory (Popper 1934). This is for hypotheses H1 and H2 determined by the question whether the theory of economies of scale according to the Cobb-Douglas function is an adequate representation of the reality in this case. For proxy assumptions P1-P3 there is no general theory to support the validity question. However, the cited references in this research should support the content validity of the proxies.

Construct validity is the extent to which an operationalization measures the concepts that it purports to measure (Straub 1989; Boudreau et al 2001). It asks whether the measures chosen are true constructs describing the event or merely artifacts of the methodology itself (Campbell and Fiske 1959; Cronbach 1971).The construct validity can in terms of Figure 6.1 be defined as the degree until which the measurement model (consisting of measured variables) is a good representation of the research model, given the measurement conditions (Leeuw 1996; Baarda and de Goede 2001). Within the scope of the measurement model the analysis of the empirical data is performed, which leads to the determination of the degree of validity of the hypotheses and of the proxy assumptions. For example hypothesis H1 has in Table 5.19 an average validation value of 0,16 for Housing Corporations. That means that the *construct validity of this hypothesis* has a value of 0,16, given the measurement conditions. The validation values as such depend on the *definition* of the validation value (which depends upon the values of b, Rsq and the number of years, see for example Table 5.8). The following remarks can be made concerning the construct validity:

- In section 4.3.1 we explained that the measurement according to the M&I cost model is based on a different definition of "Infrastructure" as a collection hardware components instead of a collection services including the integrative software. We concluded however that the M&I definition is better at the current level of data granularity. Only if more detailed data is available about the implementation of integrative infrastructural software, then it is worthwhile to measure the infrastructural software separately.
- The measurement model is "loaded" with data which is the result of measurement of reality with a certain reliability (see Figure 6.1).The validation values in Table 5.19 are based on the validation values in other Tables which all can be considered as *construct* validation values. High construct validation values are dependant on high *reliability* values in the Mann Whitney Tables; these values are ultimately based upon the reliability of the measurements of reality, which will be treated below.
- An important question regarding construct validity is (Straub 1989): "are the data a reflection of true scores or artefacts of the kind of instrument chosen"? In section 6.3.2 this will be elaborated in more detail.

Reliability is essentially an evaluation of measurement accuracy, for example the extent to which the respondent can answer the same or approximately the same questions the same way each time (Cronbach 1951). The measurement of the data in this research is already explained in Section 1.4.3: the measurements that are based on maturity data and on application availability data have the lowest reliability. The measurements with the highest reliability are based upon the cost data. This difference is also reflected in the validation value of the hypotheses: for example the IF-based analyses lead to higher validation values than the MF-based analyses. So we can state that the quality of an IF-based measurement model is higher than an MF-based model: an IF-based model is a better representation of reality than a MF-based model.

Internal validity raises the question of whether the observed effects could have been caused by or correlated with a set of unhypothesized and/or unmeasured variables (Straub 1989**).** In short, are there viable, rival explanations for the findings other than the single explanation offered by the researcher's hypotheses? The internal validity can in terms of Figure 6.1 be defined as the degree until which the measurement model is a good representation of the reality. Indeed, there could be an alternative explanation for high construct validation values, which are based upon a solid theoretical foundation that implies a high content validity. For example high investments in infrastructure can lead to neglecting investments in applications, which can lead to insufficient functionality for users. We found that the simultaneous analysis of H1 and H2 gives the same results as the separate analysis of H1 and H2, so the possibility is excluded that high ICT productivity is reached by *other* organizations than those that realize low business productivity (and vice versa). By analyzing H1 and H2 simultaneously we realized a higher internal validity than by the separate analysis of H1 and H2.

External validity refers to generalizing across times, settings, and individuals (Cook and Campbell 1976; Sackett and Larson 1990). Sackett and Larson state that "external validity is the type of validity closest to our definition of generalizability". The external validity can in terms of Figure 6.1 be defined (just as the internal validity) as the degree until which the measurement model is a good representation of the reality. In this case the focus is extending the scope of the investigated reality. We think that the results of this research are applicable to organizations with a low ICT budget, with a "utility" function of ICT (Weill and Broadbent 1998), that run the risk of neglecting investments in ICT infrastructure (caused by the rapidity of technological aging in ICT). Therefore the results of hypotheses H1 and H2 might be generalized for low ICT budget organizations. According to Lee and Baskerville (2003) generalization is however never possible without empirical verification, so we have to be very careful with this statement. The results of the other hypotheses (see Table 5.21) depend too much on the type of organization and therefore generalization is impossible.

Content validity, construct validity and reliability are necessary conditions for internal and external validity. In terms of Figure 6.1 we can state that the product of *content validity* (derivation of the research model from reality) and *construct validity* (derivation of the measurement model from the research model) and *reliability* (measurement of data in reality) determines the quality of the measurement model as a representation of reality. However, this is not a sufficient condition; in the concept of internal validity there is also an alternative modelling possible (see Figure 2.12, based on a different representation of reality); in the case of external validity we are dependant of the extension of the scope of the reality that is covered by the model (in terms of Figure 2.12 we could also speak of the scope of the representation of the reality).

6.3.2 Construct validity and the measurements of the constructs

In this section we will analyze some aspects of construct validity in more detail. The measurement model as defined in the foregoing section should ideally consist of variables that are orthogonal *between* different constructs. In Figure 6.2 the dimensions of the measurement variables of the 3 constructs of hypothesis H1 are represented on orthogonal axes X, Y and Z. Theoretically the correlation values of the inter-construct measures should be zero. However, in practice inter-construct correlation values up to 0,4 are considered acceptable (Bollen and Lennox 1991). There are in Figure 6.2 some combinations of inter-construct measurement variables that have to be considered with care:

- If Y is measured by Total ICT cost in year N and Z is measured by the average Infrastructure Factor, then Z contains cost factors of year N, that are also part of Y. However the correlation values between Y(ICT cost) and Z(IF), see Table 5.1, are -0,28 (HC), 0,18 (M) and 0,57 (Hosp). Only in the case of Hospitals this value is higher than 0,4 but the H1-validation values of Hospitals are lower than those of Housing Corporations and Municipalities, see Table 5.21. We discussed already in section 5.2 the possible reasons why there is in the case of Hospitals a high correlation between IF and scale related variables.

- If X is measured by Cost of hardware/software in year N and Z is measured by the average Infrastructure Factor, then Z contains cost factors of year N, that are also part of X. In this case the correlation values between X(Cost HW/SW) and Z(IF), are -0,23 (HC), 0,19 (M) and 0,59 (Hosp), which is comparable with the situation described above.
- Note that we did already exclude the combination of Y(Total ICT cost year N) and X(Cost of hardware/software year N) in the research model, see Figure 3.10. In this case the correlation values between both variables are between 0,97 and 0,99.
- In section 4.4.1 we mentioned for Housing Corporations a correlation value of 0,51 between Z(MF) and X(Applications), which was explained by a subjective measurement procedure. However, the correlation between Z(MF) and X(Combined scale) has the value 0,25 (see Table 5.1) which is lower than 0,4.

The intra-construct variables should ideally be highly correlated in the case of “reflective” variables: in section 4.4.1 we already discussed this point and calculated a value of Cronbach’s alpha of 0,94 for Y(ICT cost) and Y(FTE Operations). The other intra-construct variables (in case of more than one variable per construct) are “formative” which does not demand a high level of correlation. Indeed, in Figure 6.2 there are 2 alternative measurement variables for each dimension, which are treated independently. Only in the situation of the composite variable (see section 4.3.2) scale ICT assets = f(workstations, FTE, applications), the correlation between these 3 variables is important. For Housing Corporations the value of Cronbach alpha appears to be 0,75 (N=196, N of items is 3).

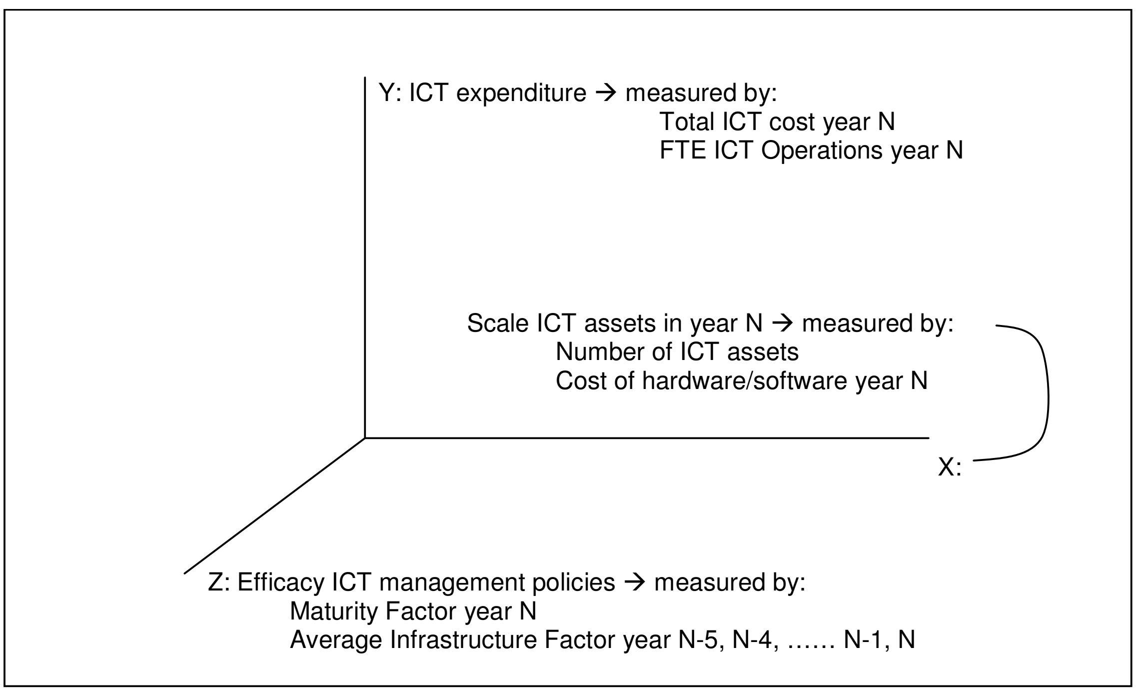


Figure 6.2 Dimensions constructs measurement hypothesis H1

Note that in the case of hypothesis H2 we do not have these problems with cost factors that are part of measurement variables of different constructs. In Table 5.1 we can see that the correlation values of inter-construct measures between Turnover and the other variables are comparable with the correlation values of inter-construct measures between ICT cost and the other variables, which was already discussed above.

6.3.3 Statistical power and validity aspects

In this section we will relate the different validity aspects with the concept of statistical power. The power of any statistical test of a null hypothesis is a function of the following three parameters (Baroudi and Orlikowski 1989):

1. The significance criterion (a), which is the chosen risk of incurring a Type I error, and whether the test is directional (one-sided) or non-directional (two-sided). Power increases with larger a and with directional hypothesis tests. In this research Mann Whitney was used since ANOVA starts from a normal distribution and is therefore not always correct. Because Mann Whitney does not have this requirement, it was more suited for our research study. A statistically significant difference between the *productivities* in two groups was assumed when Mann Whitney p (two sided) < 0,05.

2. The precision of sample estimates, which is primarily influenced by the sample size n. The larger the n, all else being equal, the smaller the error, and the greater the precision, which increases the probability of rejecting the false null hypothesis. In this research the biggest sample size was realized by the dataset of the Housing Corporations. However, the datasets of Municipalities and Hospitals achieve additional statistical power.

3. The effect size, which represents the magnitude or strength of the relationship among the variables in the population. If other factors are controlled, the larger the effect size, the greater the degree that a phenomenon manifests itself, and the greater the probability that it will be detected and the null hypothesis rejected. In this research we have a limited number of variables and relations to describe a complex phenomenon in reality. We will analyze this problem in more detail below and relate this to the different validity aspects.

The quality of the measurement model as a representation of reality depends on the quality of the empirical dataset. In an ideal situation the dataset would contain data of all relevant variables (Z2 in Figure 6.3) of some phenomenon, for example economies of scale in low ICT budget organizations. Then all organizations of this type would be for example the organizations with low ICT cost (for example < 10% of total cost). We would be able to construct an isomorphic model of the relevant part of reality that is able to explain completely this part of reality. The dataset would contain data of enough organizations (X2 in Figure 6.3), measured with a sufficient level of reliability (Y2 in Figure 6.3). However, we are limited to a dataset that contains data of a limited number of organizations (X1) concerning a limited number of variables (Z1), measured with a limited level of reliability (Y1).

In the "ideal" situation (X2, Y2, Z2) the *content* validity is 100%, as the research model is an isomorphic model of the relevant part of reality (there is no relevant ignorance at a conceptual level). The *construct* validity is 100%, as the measurement model is an isomorphic model of the relevant part of reality (all variables are mutual independant and there is no relevant ignorance at the data level). The *internal* validity is 100%, as there are no competing theories that can explain the phenomenon in reality, because the measurement model is perfect (there is no relevant ignorance about economies of scale in ICT in low ICT budget organizations). The *external* validity is 100%, as the measurement model can explain perfectly the behaviour of the phenomenon in all relevant organizations (organizations with low ICT cost). Therefore we can define the quality of the ideal dataset as being 100%. In Figure 6.3 this can be visualized by stating that the quality of 100% belongs to point (X2, Y2, Z2).

In situation 1 (limited dataset) the *content* validity is less than 100%, as the research model is an incomplete model of the relevant part of reality. There is an amount of relevant ignorance at a conceptual level: in our situation we have only a Cobb-Douglas function, which is an incomplete model of the phenomenon of economies of scale in ICT. The *construct* validity is less than 100%, as the measurement model is an incomplete model of the relevant part of reality. The measured variables are determined by the definitions of the variables in the secondary dataset of M&I/Partners, that are just approximations of the defined constructs. These constructs cannot be completely measured, for example there is no definition of the level of knowledge of the users in the M&I dataset. The *internal* validity is less than 100%, as there are possibly competing theories that can partly explain the phenomenon in reality, because the measurement model is incomplete (there is an amount of relevant ignorance about economies of scale in ICT in low ICT budget organizations). The *external* validity is less than 100%, as the measurement model can only partly explain the behaviour of the phenomenon in a limited number of organizations (a number of Housing Corporations, Municipalities and Hospitals with ICT cost less than 10% of total cost). We can determine the quality of the limited dataset in Figure 6.3 the point (X1,Y1,Z1). A value of the quality of the limited dataset might for example be defined as the quotient 100%*(X1*Y1*Z1)/(X2*Y2*Z2).

An example will elucidate these concepts. The efficacy of ICT management policies as construct is defined by the variables Infrastructure Factor (IF) and Maturity Factor (MF), as part of the research model. These variables are measured in a certain way as part of the measurement model.

Suppose firstly that we find an alternative way to measure MF. This leaves the research model unchanged, as the definition of the construct and the variables is the same. The measurement model is changed, as there is an alternative way of measurement of a variable. In this example the content validity remains the same, as the constructs and variables are unchanged. The construct validity is higher when this appears to be a better way to measure this variable. The internal validity is higher, as there is less room for alternative models. The external validity is higher if the behaviour of more organizations can be explained correctly.

Suppose secondly there would be another variable to define efficacy of ICT management policies, besides IF and MF, for example an independent Skill Factor (SF), which enriches the research model. Also the measurement model would be more complete, provided that SF can be measured correctly. In this example the content validity is higher, as the definition of the constructs is changed. The construct validity is higher, as there are more variables to measure this construct. The internal validity is higher, as there is less room for alternative models. The external validity is higher if the behaviour of more organizations can be correctly explained.

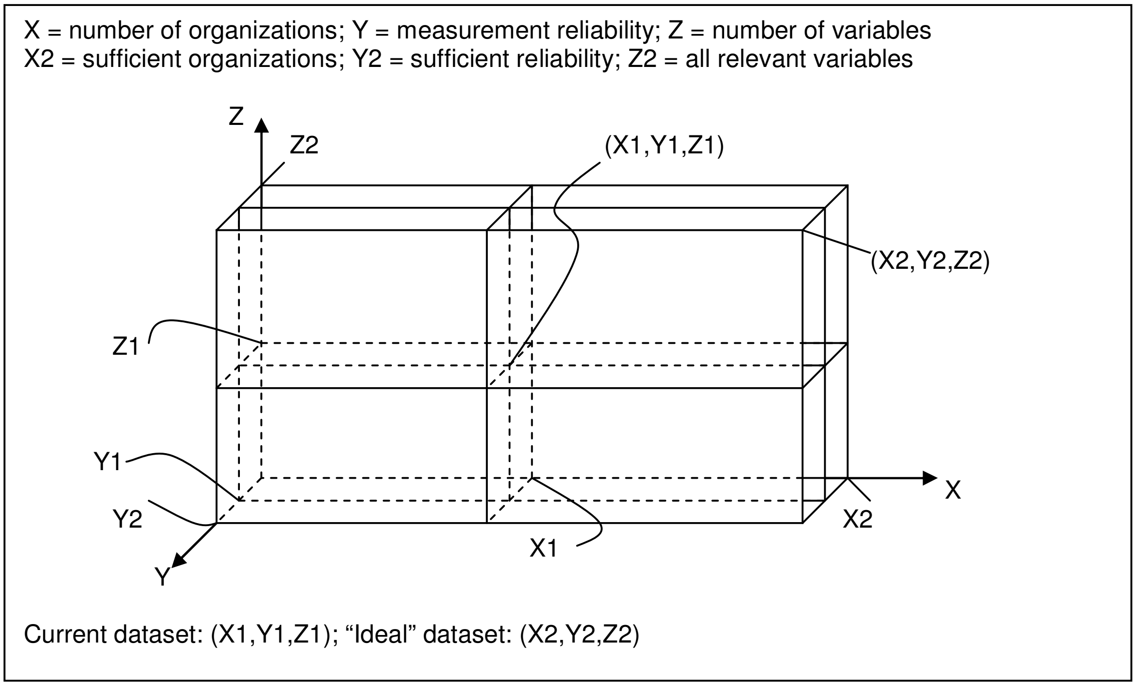


Figure 6.3 Quality of the empirical dataset

Summarizing we can state that the *content* validity depends upon the validity of the research model. The more variables (representing constructs) are defined in the research model, the better the research model should represent reality (provided that these variables are relevant). So content validity = f (Z).
The *construct* validity depends upon the validity of the measurement model. The more variables are defined in the measurement model and the higher the reliability of the measurement, the better the constructs can be measured (provided that the variables are relevant and independent). Furthermore, the more organizations are available in the dataset, the higher the probability to attain statistical significance and the better the validity of the measurement model. Therefore construct validity = f (X,Y,Z).
The *internal* validity depends both on the validity of the construct model and the measurement model.. Therefore internal validity = f (X,Y,Z).
The *external* validity depends both on the validity of the construct model and the measurement model. Therefore external validity = f (X,Y,Z).

6.3.4 Validity aspects of this PhD research

We will apply the model in Figure 6.3 on this research. First we will evaluate the definition of constructs and the measurement of variables related to these constructs (corresponding with the dimensions Y and Z in section 6.3.3):

The efficacy of ICT management policies is defined in two ways:

- The infrastructure policy is measured by just one financial indicator, the *Infrastructure Factor (IF)*. More infrastructure variables would raise construct validity.

- The maturity of the organization is measured in a subjective way by a compound measurement, the *Maturity Factor (MF).* A more objective measurement of this variable would raise reliability.

The ICT expenditure, the input of the ICT conversion process, is measured in two ways:

- The number of ICT *personnel* for operations and maintenance. Determination of this number can be executed objectively, provided that also the decentralized personnel is counted and that innovation hours are not counted as operations. Solving this problem in small organizations like Housing Corporations (as discussed in section 6.2) would raise reliability.
- The *total ICT costs* can be determined objectively and in a reliable way, provided that the accounting procedures are correctly executed by the accounting department.

The *Turnover*, the output of the Business processes, can be determined objectively and in a reliable way, provided that the accounting procedures are correctly executed by the accounting department.

The scale of ICT assets, the output of the ICT conversion process, is measured in three ways:

- The *number of workstations* as a representation of the scale of the infrastructure and the scale of the users, based on the assumption that the application variety is equal for all organizations of the same type:

  Scale ICT assets = number of workstations

  This measurement gives on average the highest hypotheses validation values.
- *Combined scale factor:* A combination of the number of workstations (scale infrastructure), the weighted number of application types (the variety of applications in the test environment determines the scale of applications on the desktop), and the number of FTE of the organization (scale users). Formally defined, according to the distance-based approach a compound measurement is conducted as follows (Poels and Dedene 2000):

  $$Scale\ ICT\ assets = \sqrt{workstations^2 + FTE^2 + applications^2}$$

  The statistical significance appears to be lower than in the foregoing approach (with only the number of workstations as scale of ICT assets). A better measurement of the variety and scale of applications and the number of users with knowledge would raise construct validity.
- The *TIR cost* (the cost of hardware / software) as a measurement of the scale of ICT assets. This approach gives lower levels of statistical significance in the analyses, compared with the number approach of ICT assets. The difference between the "ontological" (based on numbers) and the "descriptive" (based on cost HW/SW) approach is discussed in considerable detail in section 3.4.3: this explains the lower level of validity of the descriptive approach.

The number of variables in the research model is the same for Housing Corporations (HC), Municipalities (M) and Hospitals (Hosp). However, HC are less complex organizations than M and Hosp. Therefore the "ideal" description of HC needs fewer variables than M and Hosp. Thus the value of Z for HC is greater than the value of Z for M or Hosp. Formally written: Z(HC) > Z(M) and Z(HC) > Z(Hosp). In Table 6.1 Z(HC) = "low" and Z(M) = "very low" , which also holds for Z(Hosp).

The measurement reliability is the same for HC, M and Hosp. Formally written: Y(HC) = Y(M) = Y(Hosp). In Table 6.1 this is indicated as "comparable".

The number of measurements of Housing Corporations X(HC) = 196. For the other organization types: X(M) = 55 and X(Hosp) = 37. These numbers are represented in Table

6.1. The value of X(HC)*Y(HC)*Z(HC) is indicated as "high", to differentiate it from the value for M ("low") and Hosp ("very low").

The value "p<0,05" in Table 6.1 is an indication of the percentile of measurements with p<0,05 in the Tables 5.7 (HC), 5.11 (M) and 5.15 (Hosp) concerning the statistically significant difference between the high and low efficacy ICT management policies groups. The relation in Table 6.1 between "X*Y*Z" and "P<0,05" is straightforward, given the explication of the statistical power model in the foregoing section. The same holds for the ultimate H1 validation "H1 val" in Table 6.1.

Table 6.1 Relation between statistical power model and H1 validation

	X	Y	Z	X*Y*Z	p < 0,05	H1 val
HC	196	low	comparable	high	0,50	0,16
M	55	very low	comparable	low	0,23	0,06
Hosp	37	very low	comparable	very low	0,15	0,05

We can consider "H1 val" as a measure of the internal validity of this research, which can be described as "low" for HC and "very low" for M and Hosp, as there are very much alternative explanations possible caused by variables that are not measured in this research. Therefore the external validity is limited to Housing Corporations, Municipalities and Hospitals.

6.4 Conclusion

This study offers new evidence for and insights into the economies of scale of ICT departments with low ICT budgets and a "utility view" on ICT (Weill and Broadbent 1998). We have concluded that these lower ICT spending organizations should spend a certain minimum of their ICT expenditure on infrastructure in order to attain economies of scale in the ICT conversion process. The measured economies between low and high infrastructure spending organizations are on average more than 20% for operational ICT labour and for Total ICT costs.

In this research the relationships between *the efficacy of ICT management policies, ICT expenditure,* and *the scale of the ICT assets* have been analyzed. The efficacy of ICT management policies has been defined as the ability of ICT management to govern an efficient and effective conversion from operational ICT expenditure to ICT assets. This implies that effective policies create the conditions for an efficient and effective ICT conversion process. Efficacy therefore refers to the optimal utilization of both technological resources and labour (or skills), which is increasingly important in order to leverage commodities. Our basic hypothesis is that a higher efficacy of organizations' ICT management policies results in lower levels of ICT expenditure, given a similar scale of ICT assets. Using empirical data on 74 Housing Corporations, 22 Municipalities and 36 Hospitals, support has been found to demonstrate economies of scale with respect to ICT assets for (comparable) organizations with a high efficacy of ICT management policies. Furthermore, we have demonstrated diseconomies of scale for organizations with a low efficacy of ICT management policies. The theoretical contribution of this research lies in the presentation of a definition of the efficacy of ICT management policies and the measurement of this efficacy.

In addition, a new methodology has been introduced to analyze the relation between the efficacy of ICT management policies and cost savings in ICT by economies of scale.

In this research study infrastructure expenditure appears to be the most important ICT management policies criterion. The organizations investigated in this research (Housing Corporations, Municipalities and Hospitals) have low ICT budgets and have a "utility" view on ICT. According to Weill and Broadbent these organizations should concentrate on infrastructure and transactional applications to attain economies of scale. This confirms the general notion that a certain level of ICT infrastructure is a necessary condition for an efficient ICT management. This study demonstrated that ICT expenses grow at a higher rate compared to the scale of the ICT assets whenever the level of infrastructure expenses is insufficient.

The maturity of the ICT organization formed the second ICT management policies criterion investigated in this research. However, a positive relation between the productivity of the ICT organization and the maturity of the ICT organization, as measured according to COBIT 4.0 (2005), could hardly be validated. This means that for the organizations investigated, the COBIT maturity concept cannot serve as a real differentiator between low or high efficacy of ICT management policies in the sense of the level of ICT expenses at a certain scale of ICT assets. The conclusion of this study is that (for organizations with a low level of ICT spending) a minimum level of ICT infrastructure is more important than COBIT maturity. It is suggested that further research is conducted to find out the percentage of ICT spending as part of the total costs above which a higher COBIT maturity would result in lower ICT expenses, given a similar scale of ICT assets.

We suggest that managers of ICT departments in lower ICT spending organizations start considering ICT-infrastructure investments as a prerequisite for achieving economies of scale in ICT management. There should be equilibrium between the business demand for more applications and the necessary infrastructure for the integration of these applications into the whole ICT architecture. In a situation where ICT is hardly more than just a utility, and where the authority of the ICT manager is generally only limited, the findings of this study may help the ICT manager convince the other managers in the organization to start focusing on infrastructure and transactional applications (Enns et al 2001; Enns et al 2003).

In this research we have primarily analyzed the productivity of the ICT conversion process and secondarily the productivity of the business processes. In order to realize economies of scale in ICT and in business, the spending in infrastructure and applications must both be sufficient. Thus there must be not only a lower limit but also an upper limit for the spending in ICT infrastructure. We found for Housing Corporations a lower limit of 42% of total ICT costs and an upper limit of 53%. For Hospitals these values are 54% and 58%. For Municipalities the available data did not permit us to determine these percentages. These values should be considered with care, as they change over time and for individual organizations it can on a certain moment be necessary to invest in infrastructure or applications.

Weill and Broadbent (1998) argue that lower ICT spending organizations with a "utility view" on ICT should spend relatively more on their ICT infrastructure. This study confirms their view and quantifies their ICT infrastructure findings. Furthermore, this is the first study that applies in-company firm data, which are superior to stock data, to this type of analysis.

Moreover, our study contradicts Carr's notion of ICT as a commodity: even in our lower ICT expenditure level organizations there appear to be significant differences in the application and competitive use of ICT. It would be worthwile to benchmark organizations in other sectors based on the Infrastructure Factor. Besides it would be interesting to compare the (results of) Infrastructure Factor benchmarking with other benchmark methods.

The degree of validity of hypothesis H1 is higher in the case of the Infrastructure Factor than in the case of the Maturity Factor based on 17 COBIT/ITIL aspects. Furthermore, we have seen that a subset of these aspects does not lead to a higher degree of validity. It would be worthwhile to investigate how another definition and measurement of the Maturity Factor could lead to a stronger validity.

In this research we demonstrated that standardization of ICT components and ICT processes is from a theoretical point of view the most important management policy to realize economies of scale in ICT conversion process. We did not analyze the effect of standardization of ICT assets on the productivity of business processes. We believe however that business process redesign, based on standardized applications has a positive effect on economies of scale in business processes. It would be worthwhile to investigate the combined effect of standardized ICT assets on economies of scale in the ICT conversion process and in the business processes.

Although in many respects ICT has proven to be a commodity to the organizations investigated in this research, its effective deployment is by no means straightforward. In this study the efficacy of ICT management policies appeared to be highly dependent on the percentage of ICT infrastructure investments. In other words, large scale infrastructure investments are a prerequisite for the efficient use of ICT (and not vice versa). The analysis presented in this study has clearly produced new and valuable insights into the realization of effective ICT management policies.

APPENDIXES

Appendix 1: Benchmark M&I/Partners

The Dutch consultancy firm M&I/partners is carrying out since 2002 a yearly investigation concerning the cost and quality of the ICT in about 33 *Dutch Housing Corporations* (in total 20% of the sector). Organizations are sorted by size (the largest organization has about 40 times the turnover of smallest one) and the ICT cost per workstation are made up by 6 categories: workstation, LAN, WAN, applications, speech and ICT management. Every cost category contains the relevant hardware, software and cost of personnel. The average total ICT cost per workstation appears not to vary significantly with of the size of the organization. This also holds for the other years in the period 2002-2007.

A similar investigation has been held since 2004 to review the costs and maturity of ICT in *Dutch Municipalities*. The investigation was conducted yearly in about 14 Municipalities, representing around 5% of this sector. The research data used cover the period 2004-2007. The collection of the ICT data gathered in the Municipalities took place in a similar way as described for Housing Corporations.

A similar investigation has been held since 2006 to review the costs and maturity of ICT in *Dutch Hospitals*. The investigation was conducted yearly in about 12 Hospitals, representing around 12% of this sector. The research data used cover the period 2006-2008. The collection of the ICT data gathered in the Hospitals took place in a similar way as described for Housing Corporations.

Available data

Data of *Housing Corporations* are available for the following years:
23 organisations 2002, 24 organisations 2003, 35 organisations 2004, 39 organisations 2005, 37 organisations 2006, 38 organisations 2007
Of all years (2002-2007) the following general and cost data are available:

- Turnover in €
- Personnel in number of Full Time Equivalents (FTE)
- Number of workstations
- Personnel for operation and maintenance (without (innovation) projects)
- ICT cost (hardware, software and personnel)
    - ICT management
    - Workstation
    - LAN (Local Area Network)
    - WAN (Wide Area Network)
    - Applications
    - Speach

Only for the period 2004-2007: Maturity (17 COBIT/ITIL processes)

General and cost data of *Municipalities* are available for the following years:
13 organisations 2004, 15 organisations 2005, 14 organisations 2006, 14 organisations 2007
Maturity data are only available for the period 2005-2007.

General and cost data of *Hospitals* are available for the following years:
14 organisations 2006, 12 organisations 2007, 11 organisations 2008.

ICT benchmark questions

General questions

- Size of the organization
- Number of locations
- Cooperation with organizations (important related to scoping)
- Degree of centralization of ICT functions
- Degree of outsourcing
- General questions related to scope of ICT in the organization

TIR (Technical Information Resources, or Hardware/Software (HW/SW) in €)

Infrastructure:

- Workstations types, cost and quantities
    - A desktop, laptop or notebook, including additional built-in hardware and the client OS (e.g. Windows XP).
- Peripherals types, cost and quantities
    - Printer, scanner, camera, beamer, fax or PDA.
- Infrastructure data communications, cost
    - Internal and external connections (LAN, WAN and internet connections): costs of active (routers, switches) and passive components (physical connections) plus external costs for commutations and connections.
- Servers and storage, cost
    - Hardware for storage, back-up, firewalls and applications: web servers, application servers, database servers, fileservers, thin client servers.
- Communications speech and video, cost
    - Facilities for telephony (fixed and mobile): costs for hardware and software plus external costs for commutations and connections.
    - Facilities for video conferencing: costs for hardware and software (like cameras, monitors and special routers or switches) plus external costs for commutations and connections.
- Facilities, cost
    - Equipment rooms with climate facilities, fire extinguish equipment, power supply and furnishing.
- Infrastructure software (server operating systems and middleware) is included in "Applications" in the cost model of M&I/Partners.

Applications:

- Software and software services, including cost of interfaces between applications, and the corresponding databases.
    - All software and software services, excluded client OS and included costs of outsourced applications

- o NB Infrastructure software (server operating systems and middleware) is included.

HIR (Human Information Resources in Full Time Equivalent (FTE))
- Projects (=innovation: to be excluded in the Measurement of relevant quantity of operational ICT labor)
- Personnel, quantity, cost (central and local)

Maturity (17 COBIT/ITIL processes see Figure 4.5)
- Two or three critical performance indicators for every process
- The level of maturity for every process, which varies from 0 (process is not organized) to 5 (process is completely and formal organized and could serve as best practice)

Availability and importance application types: the weighted number of application types is determined by the product of two factors:
- The availability of the application type: 0 (no applications), 1 (application in development) or 2 (applications operational).
- The importance of the application type for the concerning business process: 1 (not critical for the business, can be unavailable for eventually a few weeks), 2 (important for the business, but can be unavailable for maximum one day) or 3 (critical for the business, must always be available).

Appendix 2: Benchmarking with DEA

Within the scope of this research productivity is defined as:
- Input: ICT expenditure
- Output: scale ICT assets
- Productivity = output / input (in DEA this quotient is called 'efficiency').

The DEA model (maximisation of efficiency of Decision Making Units - DMU's) has the following form (Stensrud and Myrtveit 2003):

Maximize (sum of weighted outputs) / (sum of weighted inputs)

The higher this ratio, the more efficient the DMU. Hereby, DEA evaluates n different, independent DMU's acting under the same technology. The efficiency of each DMU is measured relative to the other DMU's. All DMU's are below or on the efficiency frontier. In Figure A.2.1 the broken line is an efficiency frontier that is based on Albrecht-Gaffney projects (Albrecht and Gaffney 1983). DMU's 21 and 22 form part of the efficiency frontier and have efficiency value 1.

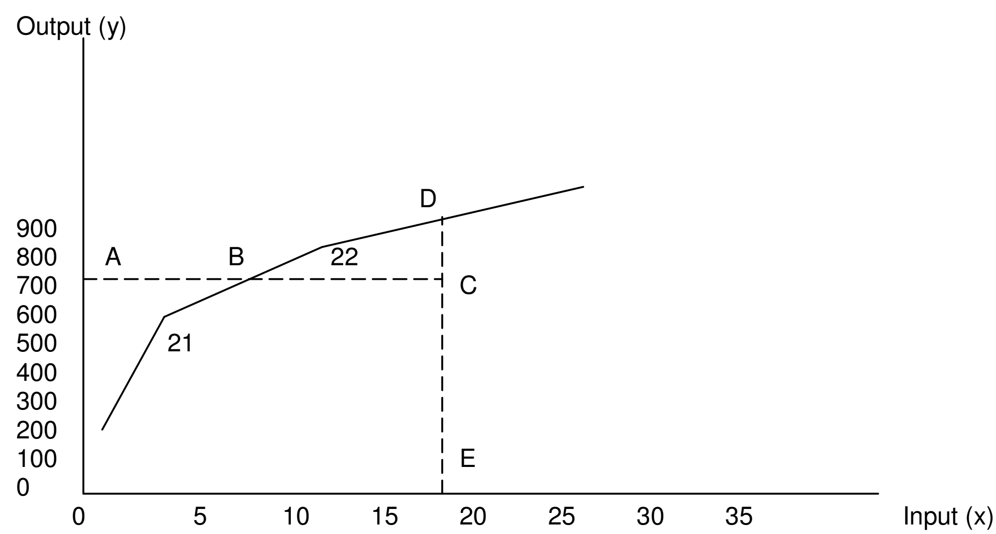


Figure A.2. 1 Measuring VRS efficiency

Technically, there are two alternative algorithms to calculate the VRS (Variable Return to Scale) efficiency using DEA. We may either use an input reducing efficiency or, alternatively, an output increasing efficiency measure.
These two alternatives are illustrated in Fig. A.2.1. for project C:
- AB/AC is the input decreasing efficiency: In this case we measure how much less input could have been used to produce the same amount of output (keeping output constant)

- EC/ED is the output increasing efficiency: now we measure how much more output could have been produced with the same amount of input (keeping input constant).

In this appendix we use the input reducing efficiency measure to illustrate the DEA method. Using project C as example, we attempt to find the minimal input required to produce the same amount of output as C produces. That is, we ask how much input it would take for a best practice DMU to produce just as much output as C. This minimal input is the input at the point B, which is a linear combination of the two frontier DMU's 21 and 22. These latter are termed reference DMU's. Thus, the idea is to move horizontally from C and toward the left until we hit the line segment at B (and find the efficiency value AB/AC).

The geometrics in Figure A.3.1 can be translated to a mathematical procedure:
Find the minimum value of the efficiency value θ where:
$\lambda_1 Y_1 + \lambda_2 Y_2 \geq Y$
$\theta.X \geq \lambda_1 X_1 + \lambda_2 X_2$
$\lambda_1 + \lambda_2 = 1$ and $\lambda_1 \geq 0$ and $\lambda_2 \geq 0$
Number 1 holds for DMU 21 and number 2 for DMU 22

This is a minimization problem, which can be solved using linear programming.
The general problem (with m inputs, k outputs and j DMU's) is stated as follows:

Minimize the objective function: $E_i = \min \theta_i$
Subject to the constraints:

for all k: $\sum_j \lambda_{ij} Y_{kj} \geq Y_{ki}$

for all m: $\theta_i X_{mi} \geq \sum_j \lambda_{ij} X_{mj}$

for all j: $\lambda_{ij} \geq 0$

while $\sum \lambda_{ij} = 1$

Explanation of symbols:
E_i is the efficiency score for observation i ($0 < E_i <= 1$)
θ_i is the efficiency score variable to be determined for observation i.
λ_i are the weights to be determined for observation i.
X_{mi} ,Y_{ki} are inputs and outputs of observation i and is the current observation.
j is all the other observations with which observation i is compared.
m is the number of inputs
k is the number of outputs

The technicalities for solving the DEA problem in a computationally efficient manner on a computer is beyond the scope of this thesis and will not be discussed here. The algorithmic issues in DEA are, however, similar to the issues to consider in linear programming.

Appendix 3: Graphical results of the regression analyses

The results of the regression analyses, as represented in Tables 5.8 and 5.10 (Housing Corporations), Tables 5.12 and 5.14 (Municipalities) and Tables 5.16 and 5.18 (Hospitals) are depicted in the next 37 Figures A.3.1 – A.3.37. The name of these figures is composed as a sequence of the following 5 abbreviations:

- Type of organization: HC (Housing Corporations), M (Municipalities) or Hosp (Hospitals).
- Measure efficacy of ICT management policies: av IF (average Infrastructure Factor) or MF (Maturity Factor).
- X axis: Measure of scale of ICT assets: WS (number of workstations), Comb (combined scale of ICT assets) or TIR (cost of Technical Information Resources = hardware/software cost excluding human resources).
- Y axis: either a or b:
  a) Measure of ICT expenditure: FTE op (Full Time Equivalents ICT Operations) or ICT cost (total ICT cost).
  b) Measure of organization performance: Turnover.
- Calculation of productivity: Abs prod (absolute productivity) or DEA prod (productivity according to Data Envelopment Analysis)

If the "low" and "high" curve are more or less the same (for example in Figure A3.3), then the curve value = 0. This implies that in Tables 5.8, 5.10, 5.12, 5.14, 5.16 and 5.18 the resulting validation value = 0, because there is not enough difference between the "low" and "high" situation.

Housing Corporations ICT productivity (related to Table 5.8)

HC ICT 1) Housing Corporations – Average Infrastructure Factor – Absolute productivity

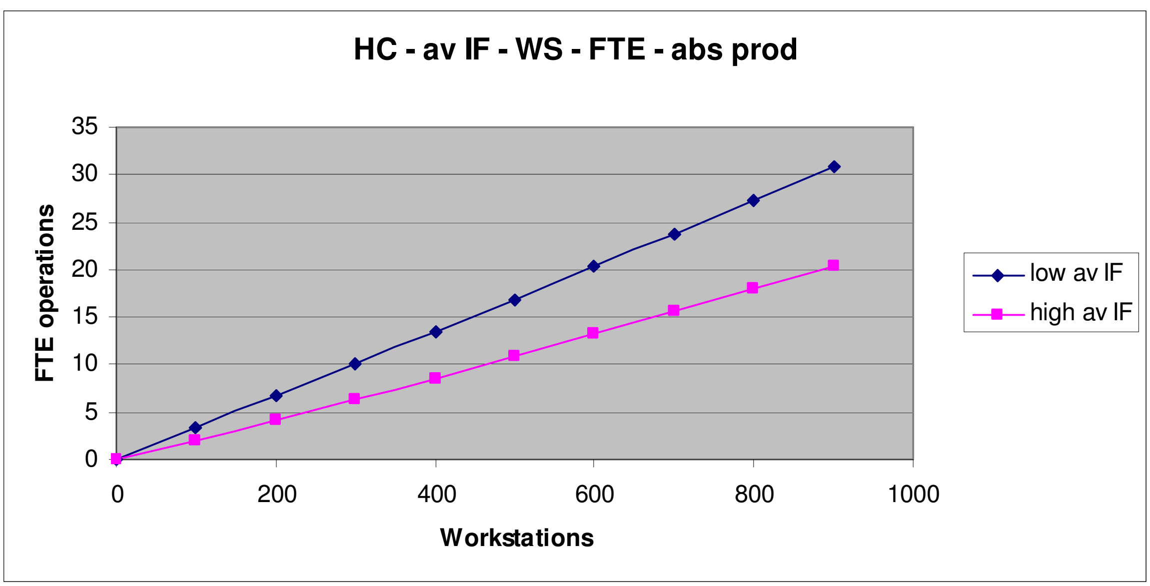


Figure A.3. 1 HC – av IF – WS – FTE op – abs prod

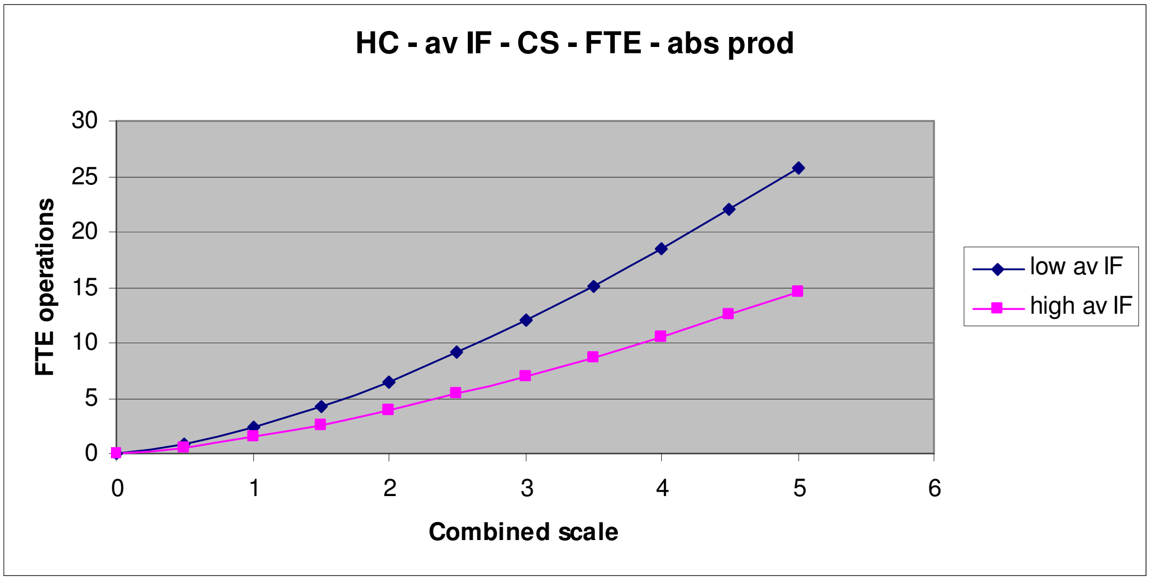


Figure A.3. 2 HC – av IF – Comb – FTE op – abs prod

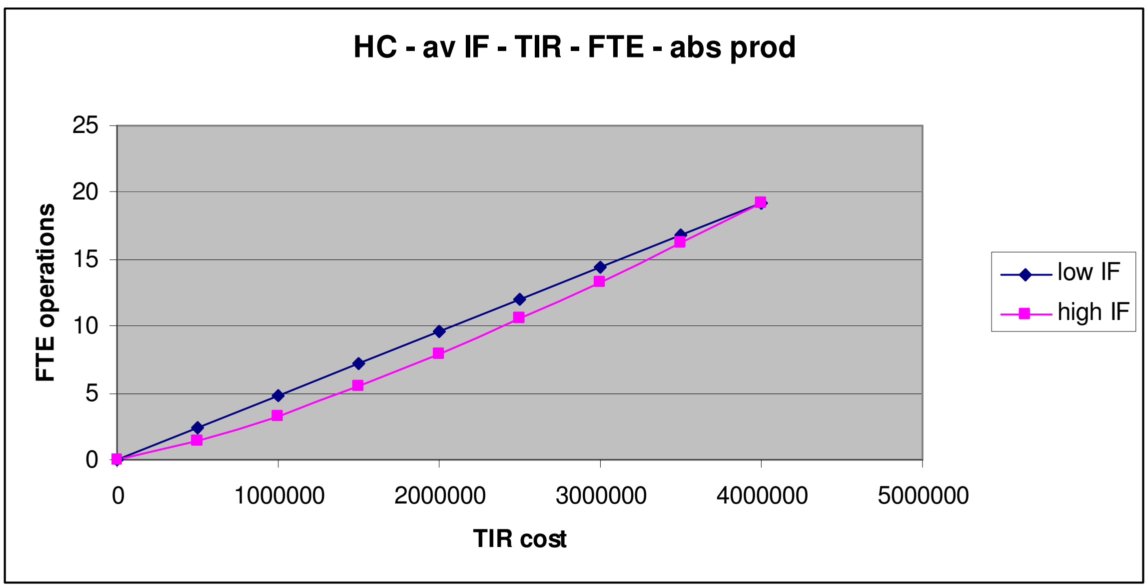


Figure A.3. 3 HC – av IF – TIR – FTE op – abs prod

➔ Curve value = 0

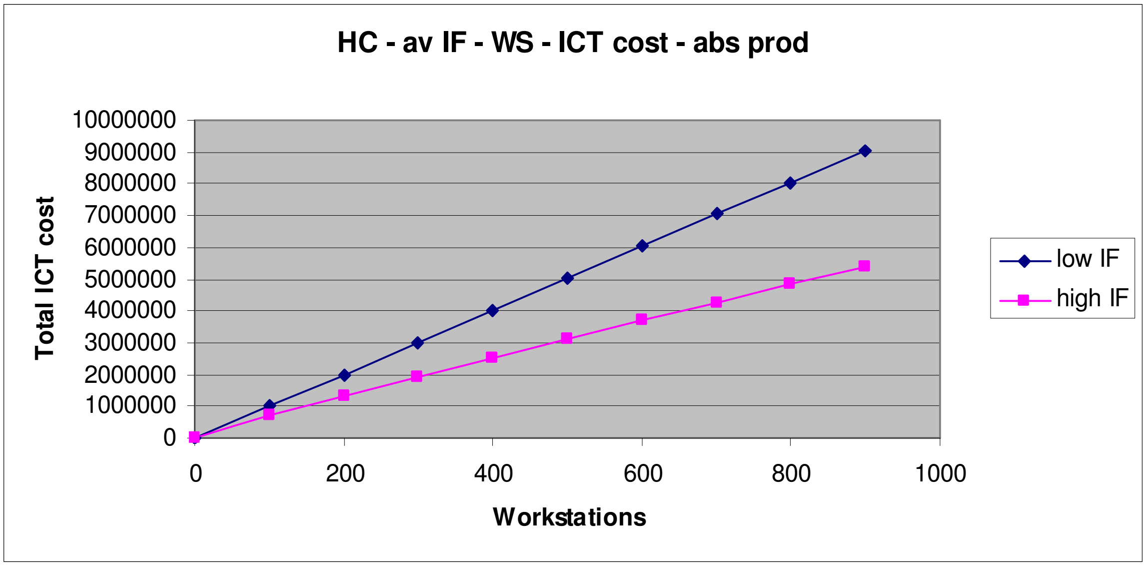


Figure A.3. 4 HC – av IF – WS – ICT cost – abs prod

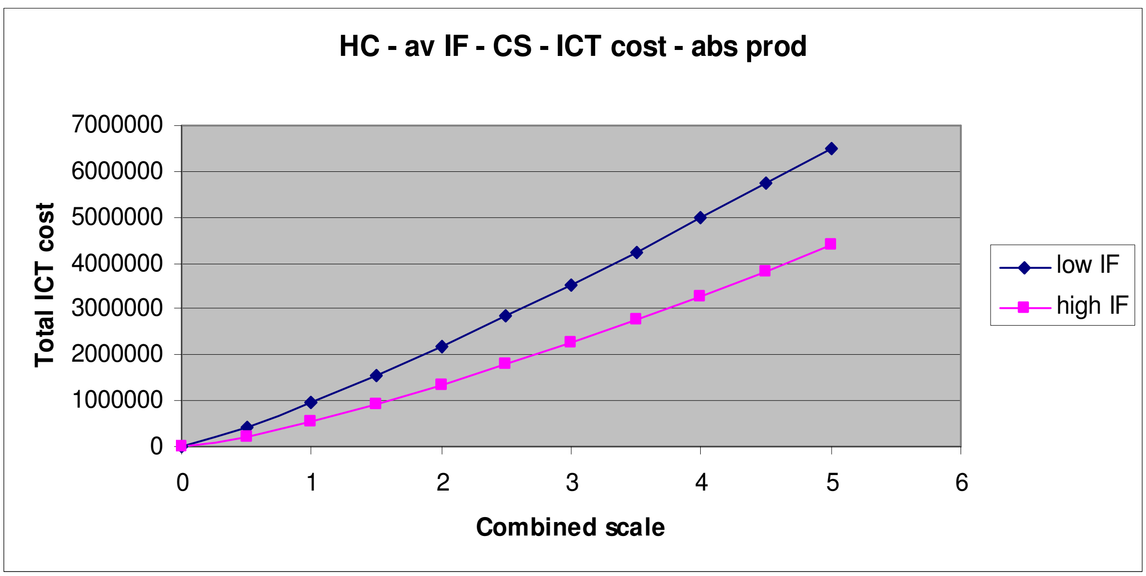


Figure A.3. 5 HC – av IF – Comb – ICT cost – abs prod

HC ICT 2) Housing Corporations – Average Infrastructure Factor – DEA productivity

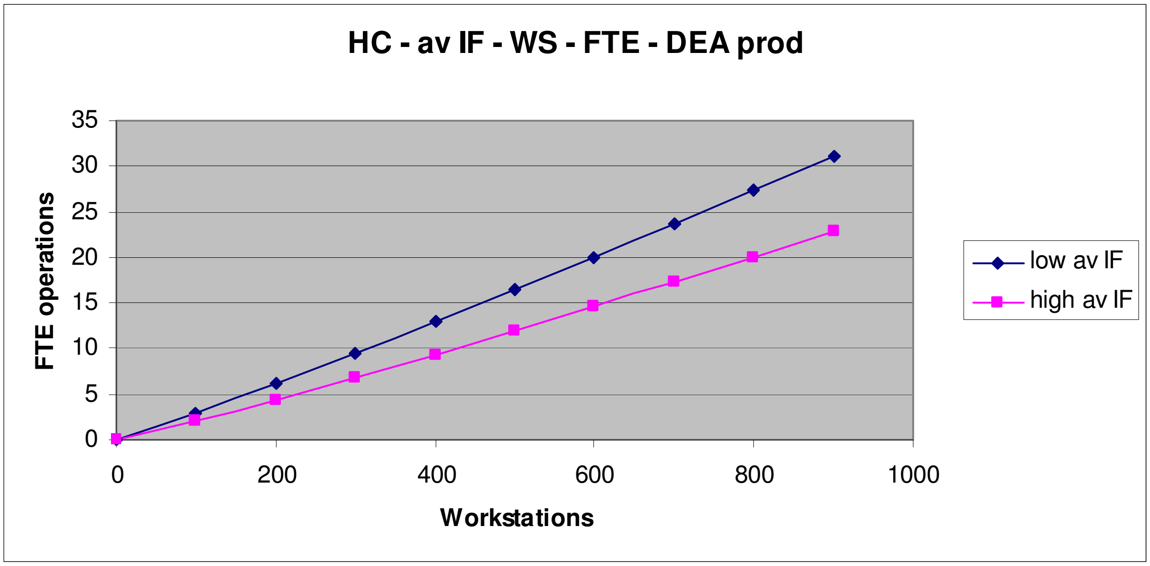


Figure A.3. 6 HC – av IF – WS – FTE op – DEA prod

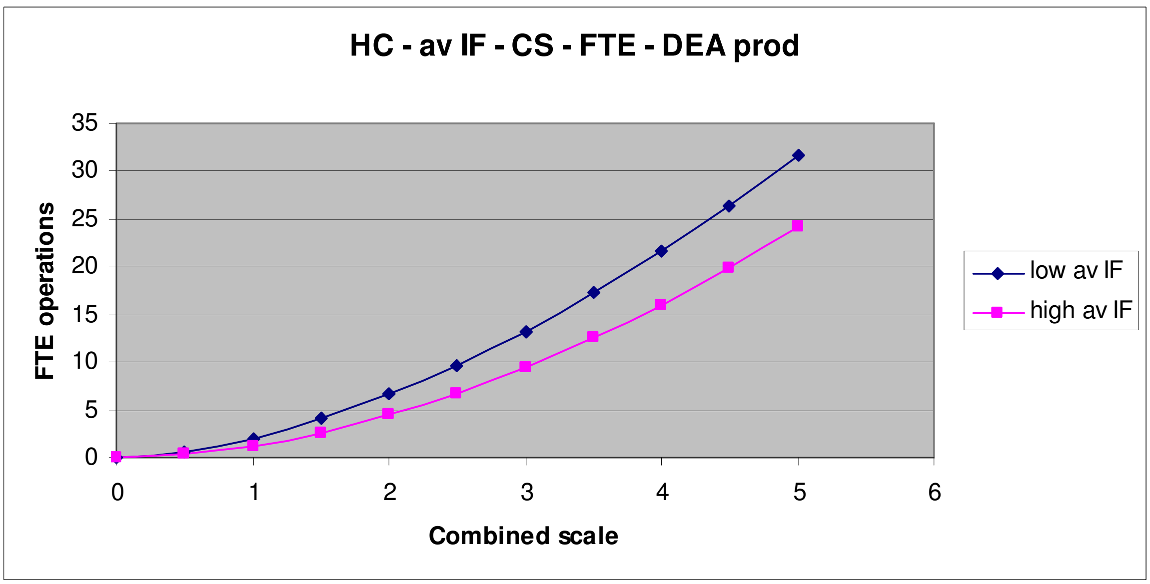


Figure A.3. 7 HC – av IF – Comb – FTE op – DEA prod

No results for HC – Average IF – DEA productivity – TIR cost – FTE operations

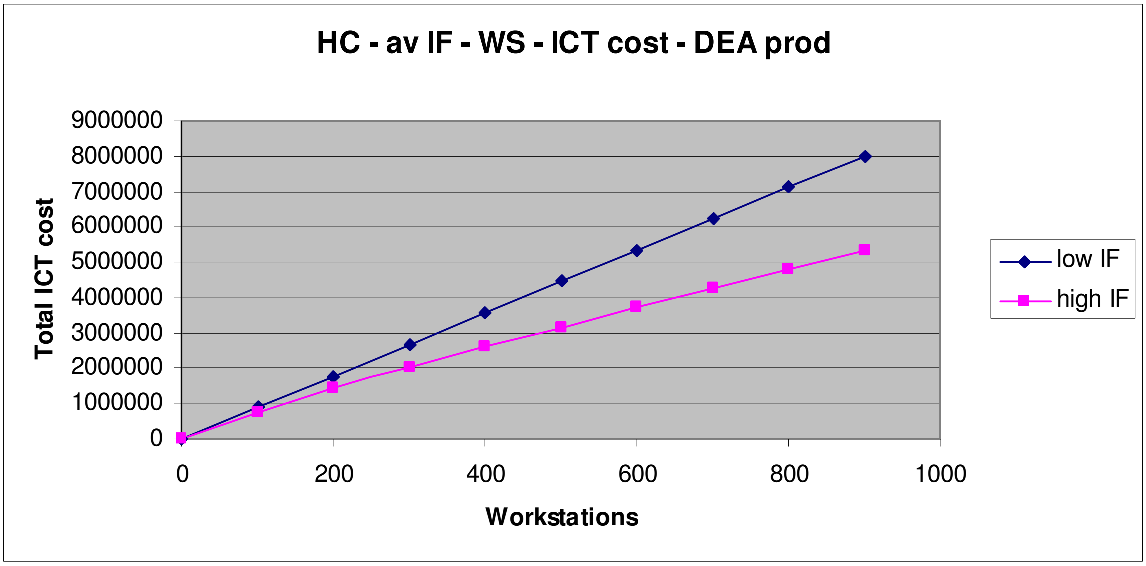


Figure A.3. 8 HC – av IF – WS – ICT cost – DEA prod

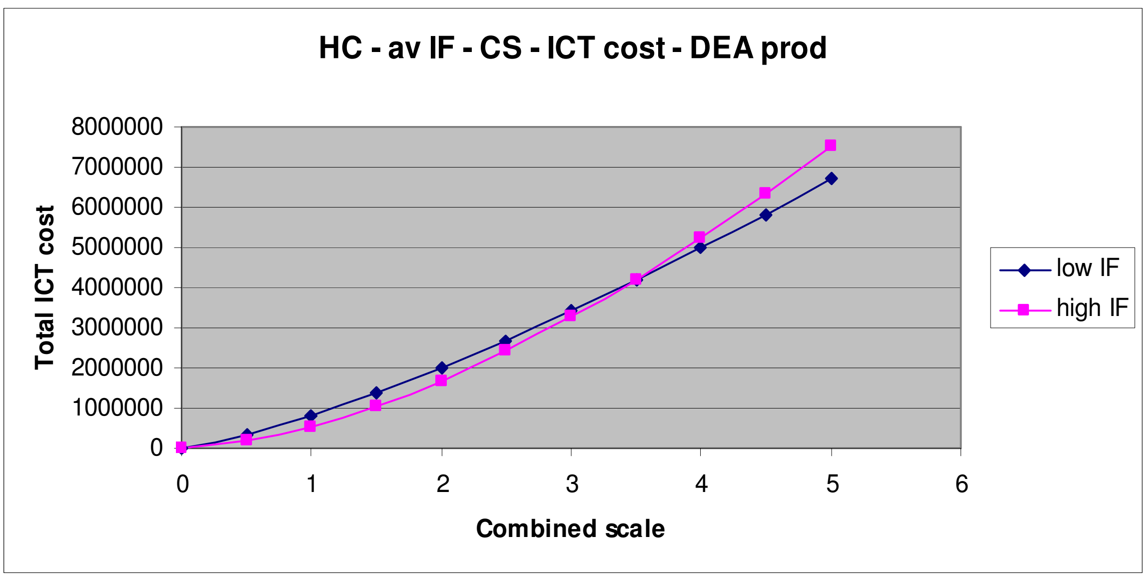


Figure A.3. 9 HC – av IF – Comb – ICT cost – DEA prod

➔ Curve value = 0

HC ICT 3) Housing Corporations – Maturity Factor – Absolute productivity

No results for HC – MF – Absolute productivity – Workstations – FTE operations

No results for HC – MF – Absolute productivity – Combined scale – FTE operations

No results for HC – MF – Absolute productivity – TIR cost – FTE operations

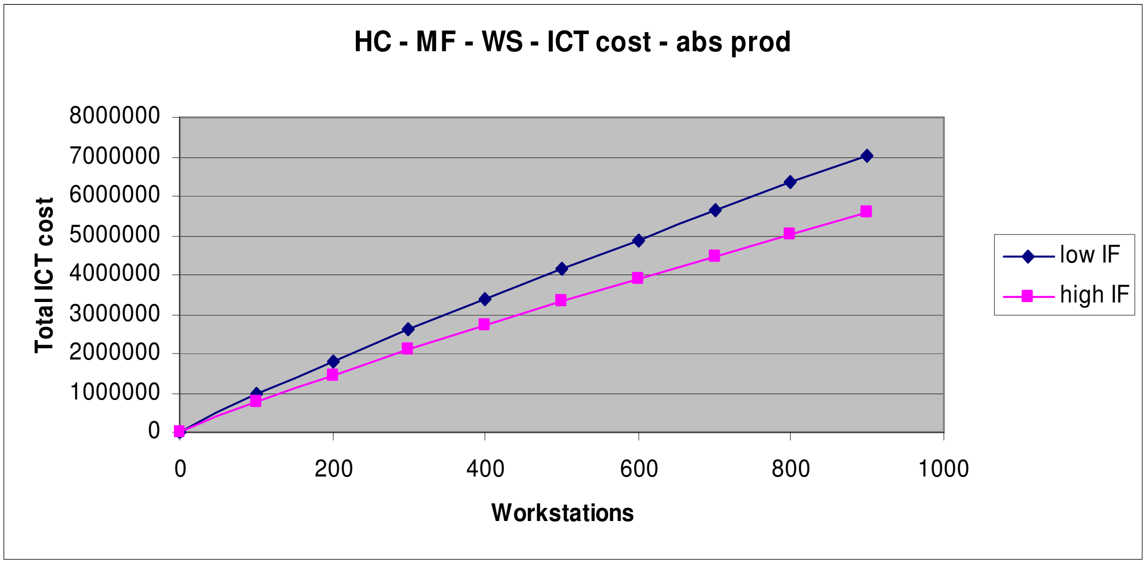


Figure A.3. 10 HC – MF – WS – ICT cost – abs prod

No results for HC – MF – Absolute productivity – Combined scale – Total ICT cost

HC ICT 4) Housing Corporations – Maturity Factor – DEA productivity

No results for HC – MF – DEA productivity – Workstations – FTE operations (as b(low)<1 and b(high)>1).

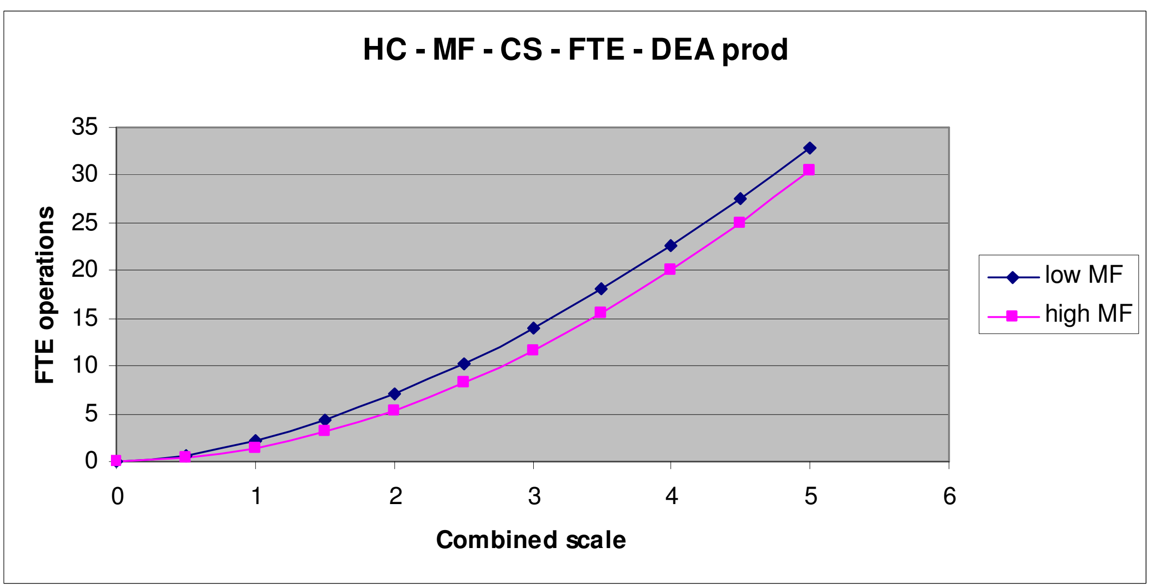


Figure A.3. 11 HC – MF – Comb – FTE op – DEA prod

➔ Curve value = 0

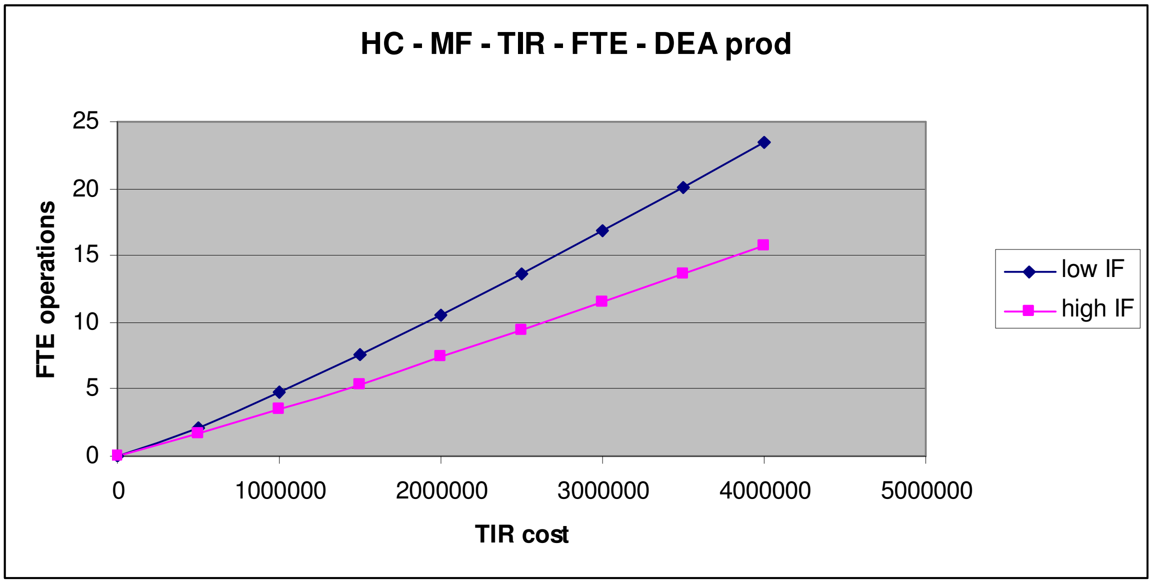


Figure A.3. 12 HC – MF – TIR – FTE op – DEA prod

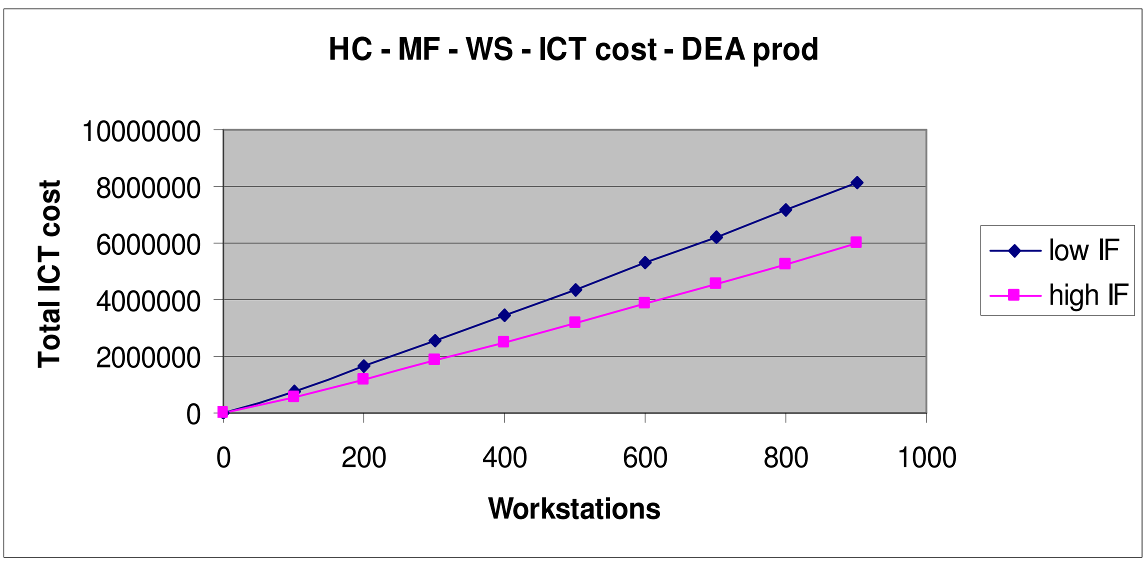


Figure A.3. 13 HC – MF – WS – ICT cost – DEA prod

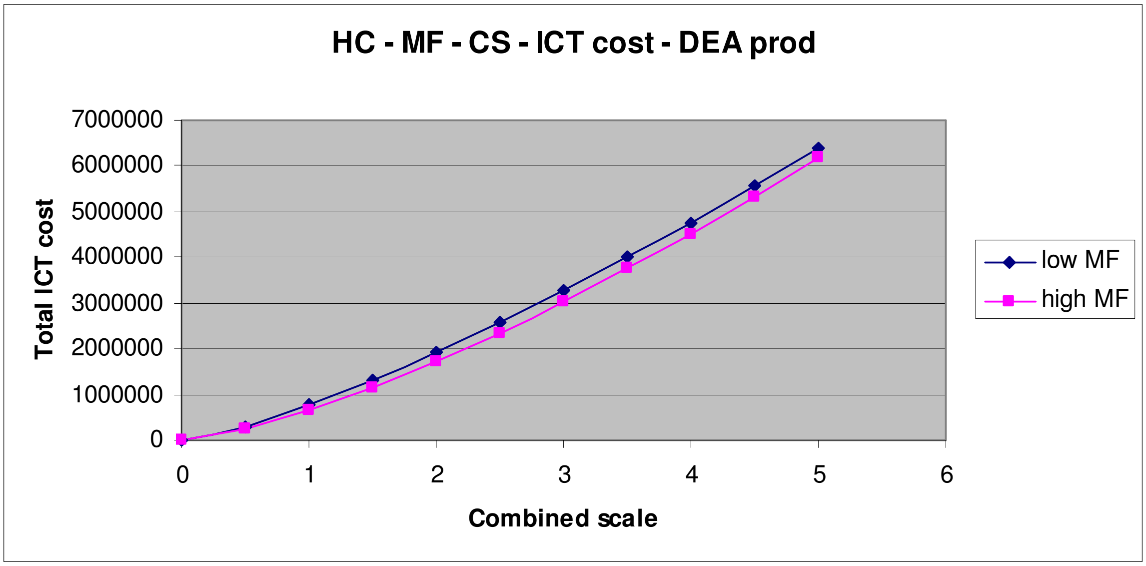


Figure A.3. 14 HC – MF – Comb – ICT cost – DEA prod

➔ Curve value = 0

Housing Corporations Business productivity (related to Table 5.10)

HC OP 1) Housing Corporations – Average Infrastructure Factor – Absolute productivity

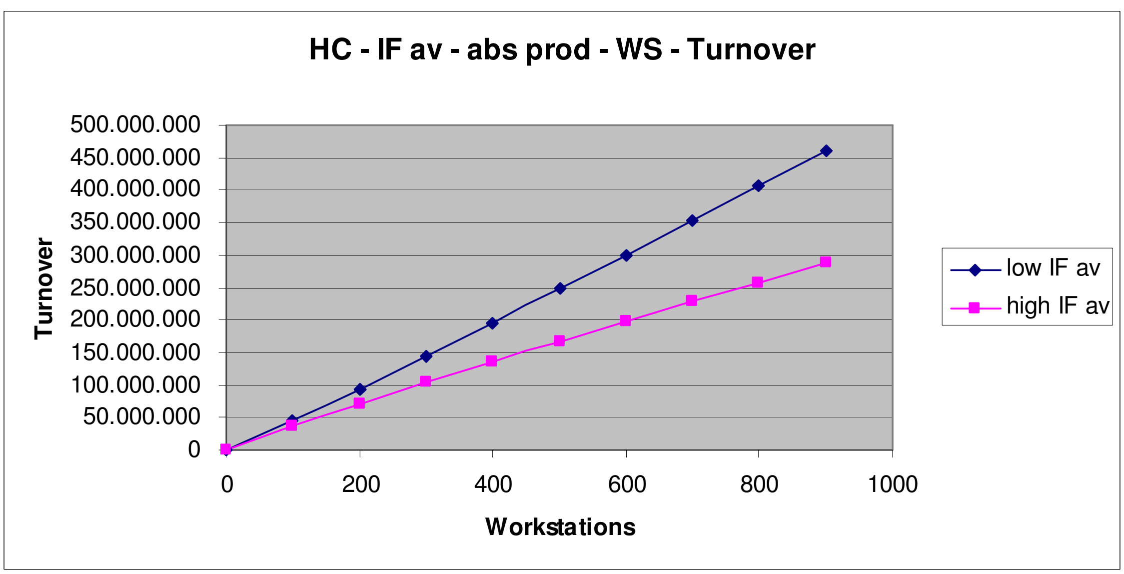


Figure A.3. 15 HC – av IF – WS – Turnover – abs prod

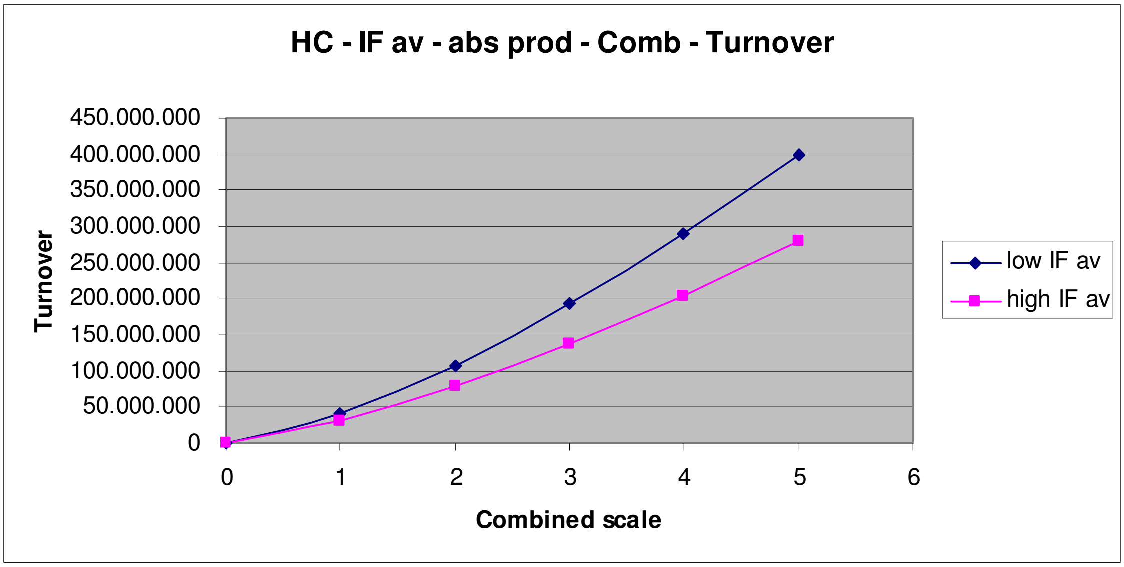


Figure A.3. 16 HC – av IF – Comb – Turnover – abs prod

HC OP 2) Housing Corporations – Average Infrastructure Factor – DEA productivity

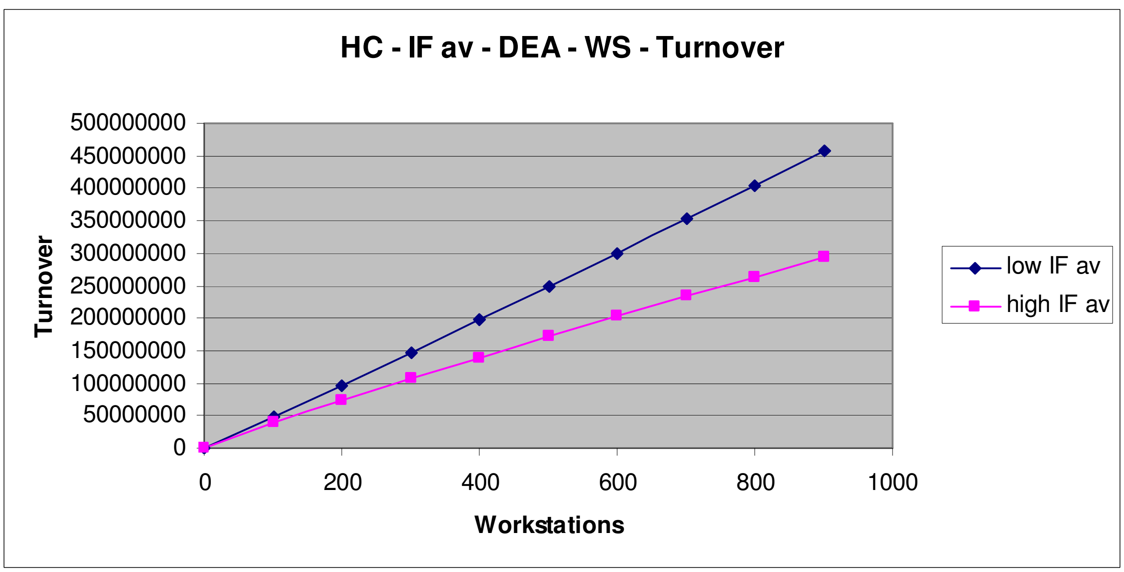


Figure A.3. 17 HC – av IF – WS – Turnover – DEA prod

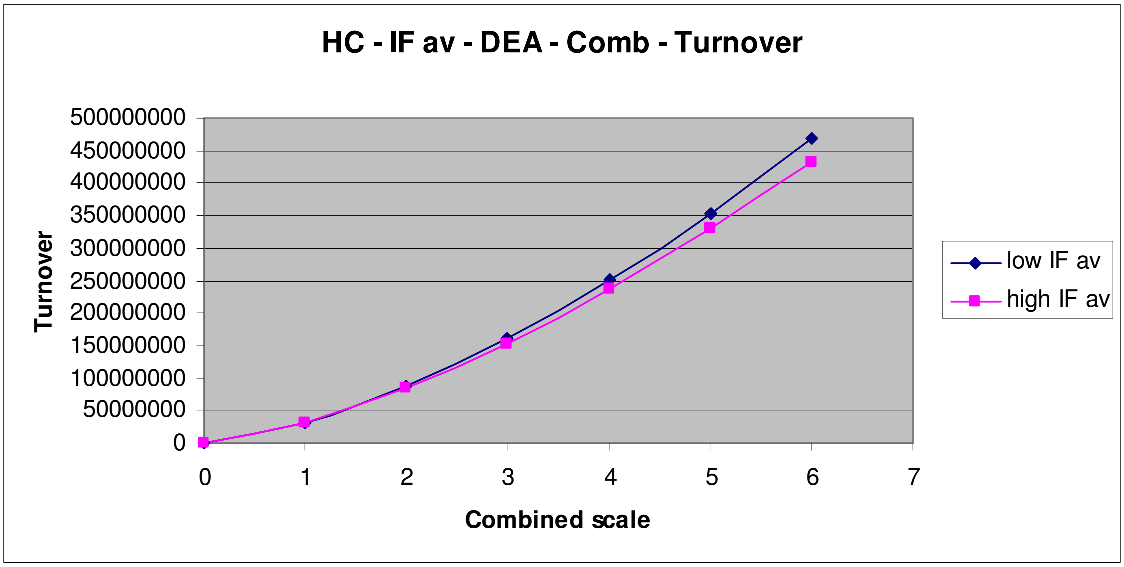


Figure A.3. 18 HC – av IF – Comb – Turnover – DEA prod

➔ Curve value = 0

Municipalities ICT productivity (related to Table 5.12)

M ICT 1) Municipalities – Average Infrastructure Factor – Absolute productivity

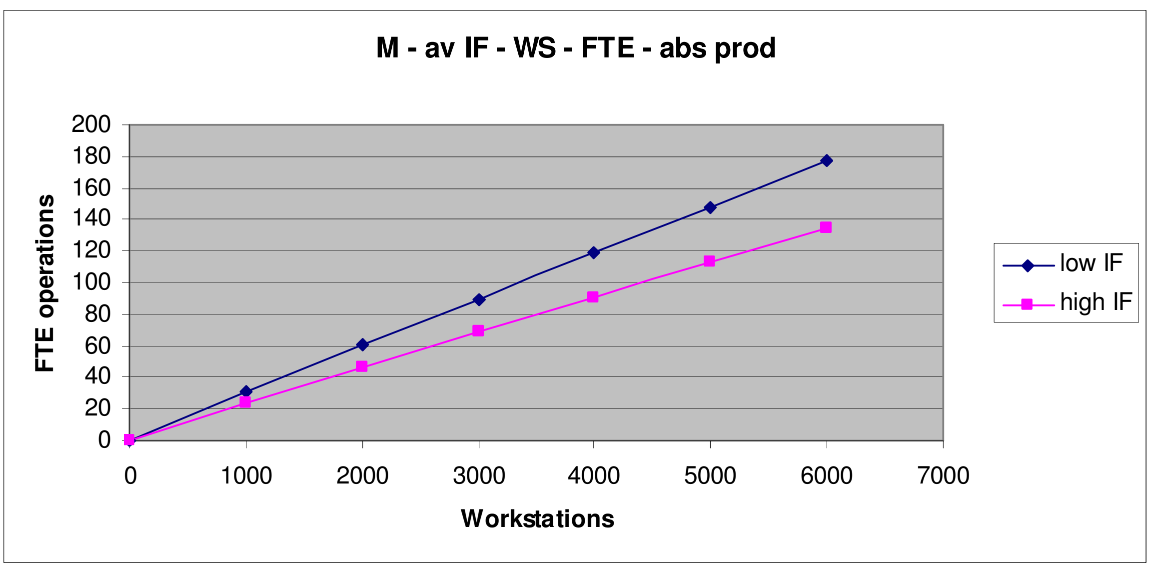


Figure A.3. 19 M – av IF – WS – FTE op – abs prod

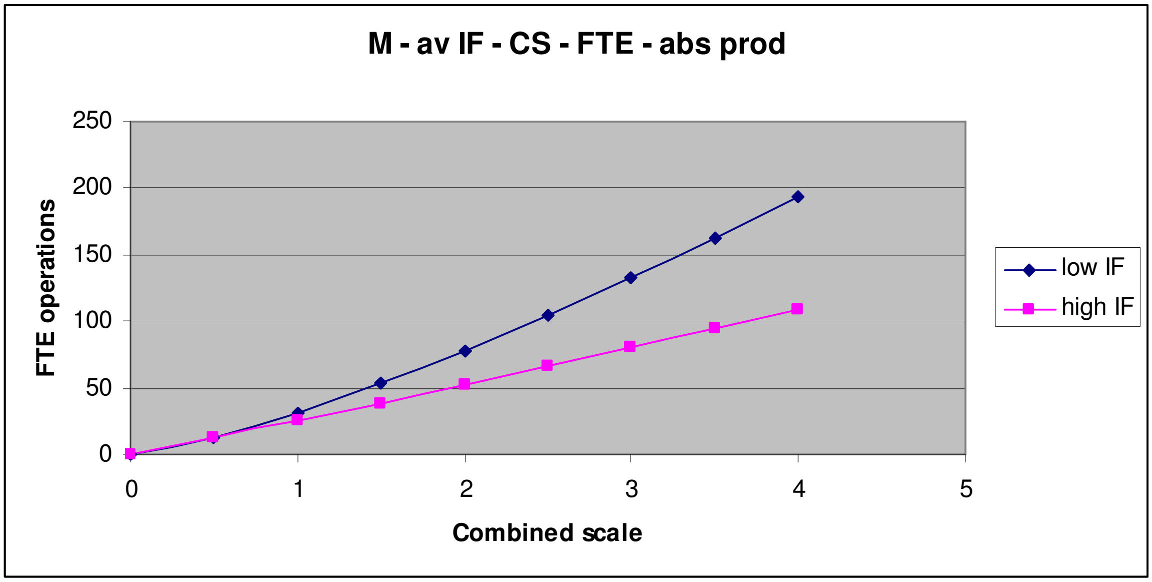


Figure A.3. 20 M – av IF – Comb – FTE op – abs prod

No results for M – Average IF – Absolute productivity – TIR cost – FTE operations (as b(low)<1 and b(high)>1).

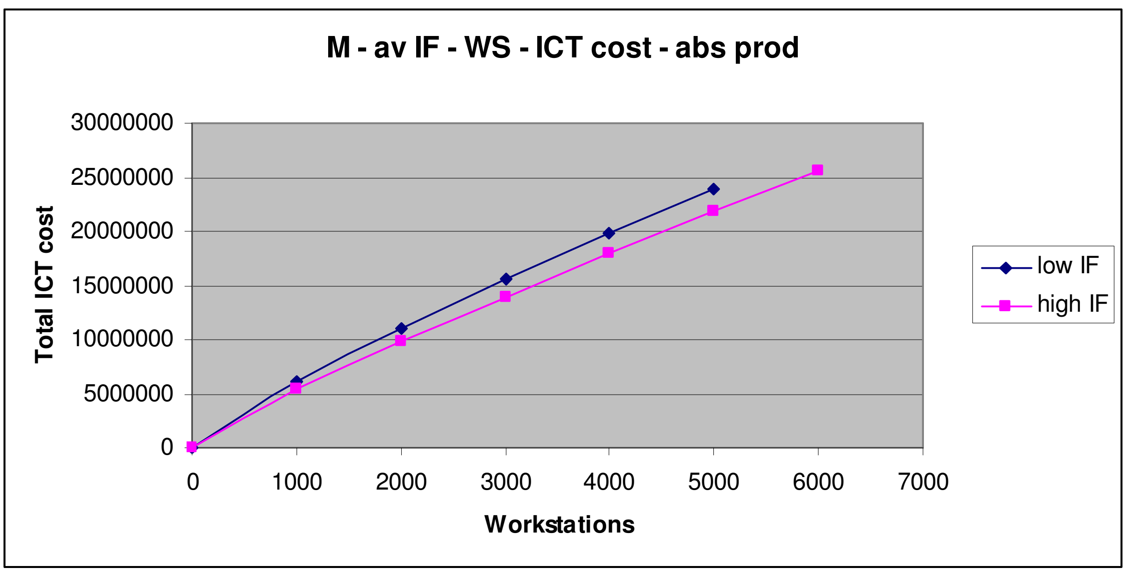


Figure A.3. 21 M – av IF – WS – ICT cost – abs prod

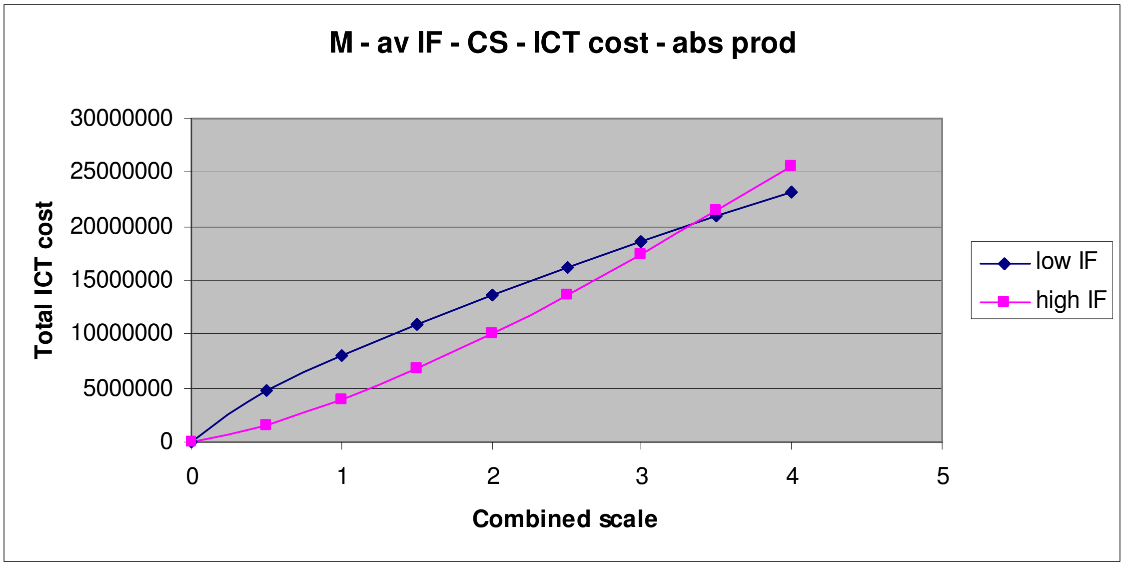


Figure A.3. 22 M – av IF – Comb – ICT cost – abs prod

➔ Curve value = 0

M ICT 2) Municipalities – Average Infrastructure Factor – DEA productivity

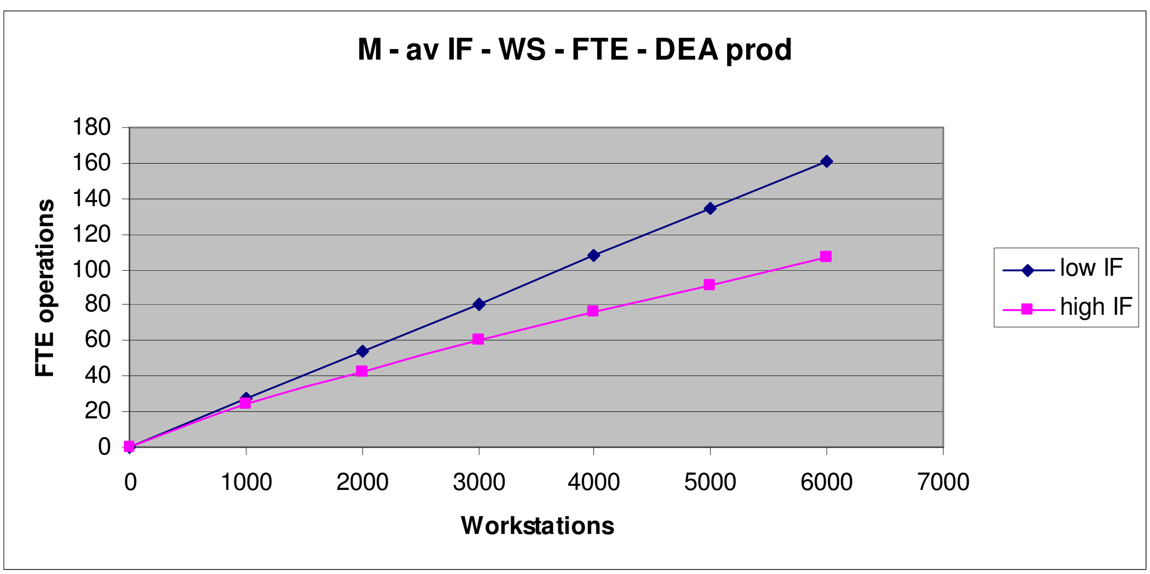


Figure A.3. 23 M - av IF – WS – FTE op – DEA prod

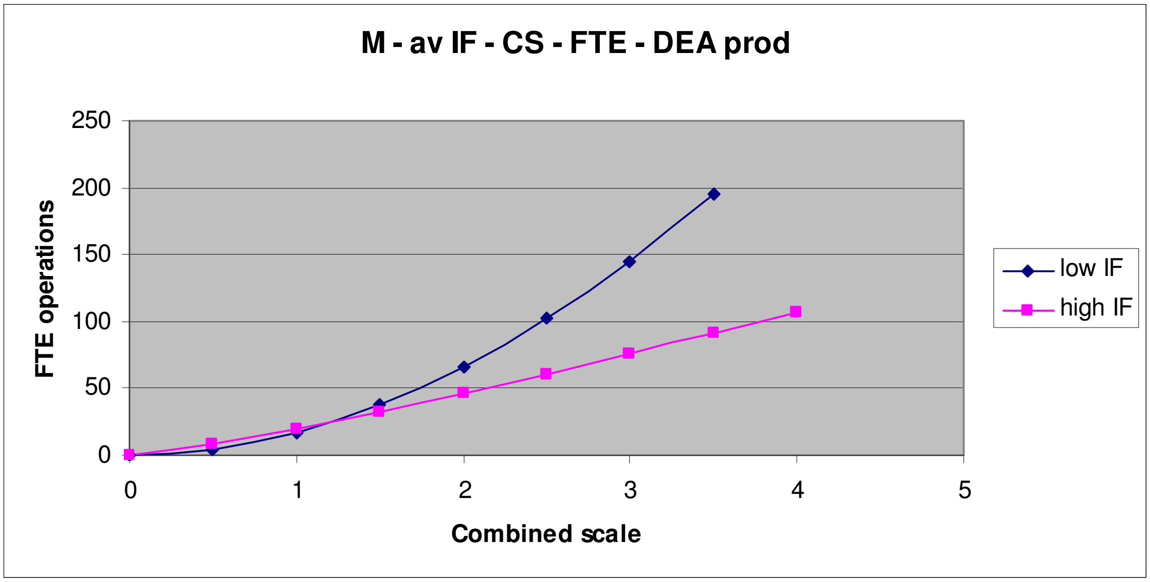


Figure A.3. 24 M – av IF – Comb – FTE op – DEA prod

No results for M – Average IF – DEA productivity – TIR cost – FTE operations (as b(low)<1 and b(high)>1).

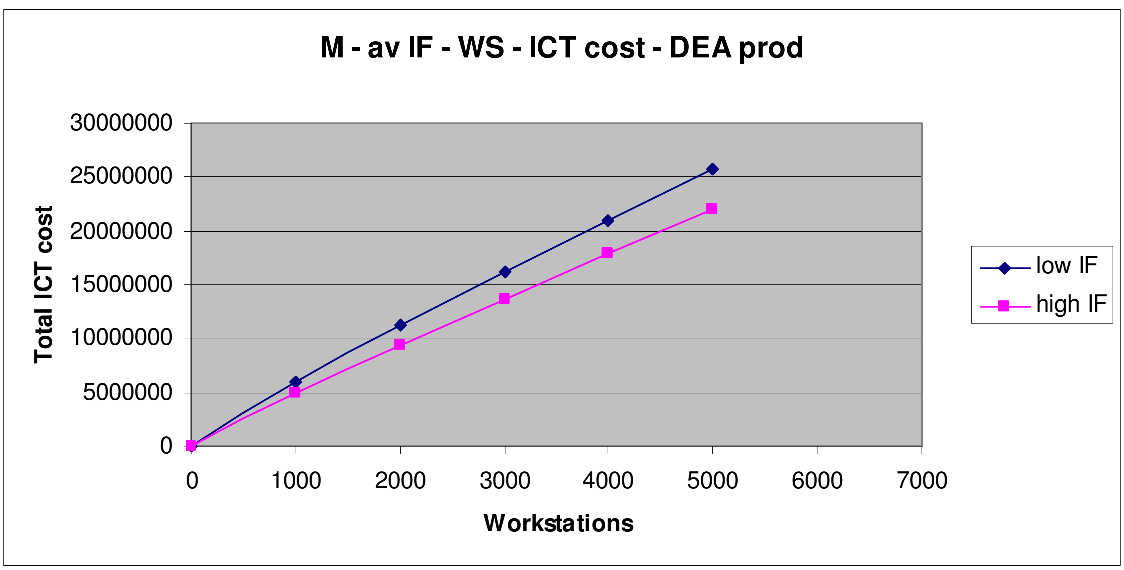


Figure A.3. 25 M – av IF – WS – ICT cost – DEA prod

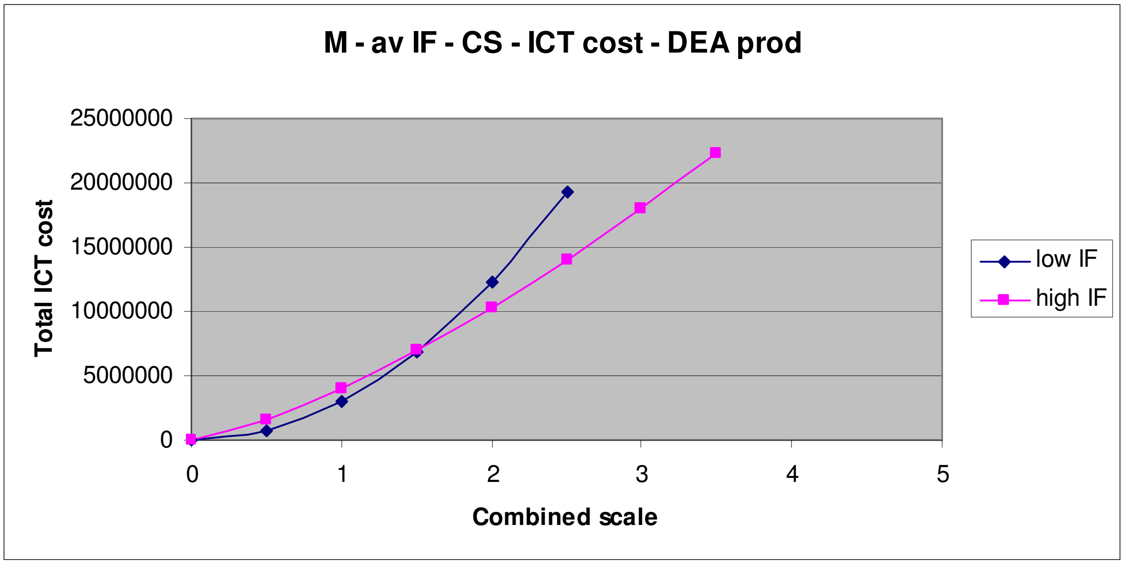


Figure A.3. 26 M – av IF – Comb – ICT cost – DEA prod

➔ Curve value = 0

M ICT 3) Municipalities – Maturity Factor – Absolute productivity

No results

M ICT 4) Municipalities – Maturity Factor – DEA productivity

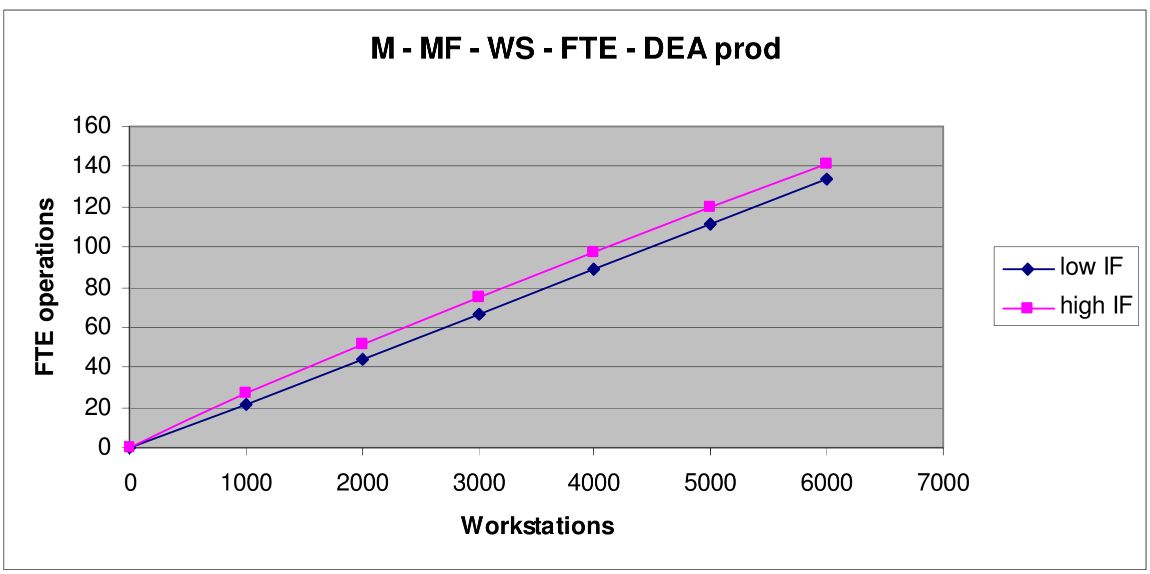


Figure A.3. 27 M – MF – WS – FTE op – DEA prod

➔ Curve value = 0

No results for M – MF – DEA productivity – Combined scale – FTE operations

No results for M – MF – DEA productivity – TIR cost – FTE operations

No results for M – MF – DEA productivity – Workstations – Total ICT cost

No results for M – MF – DEA productivity – Combined scale – Total ICT cost

Municipalities Business productivity (related to Table 5.14)

M OP 1) Municipalities – Average Infrastructure Factor – Absolute productivity

No results

M OP 2) Municipalities – Average Infrastructure Factor – DEA productivity

No results

Hospitals ICT productivity (related to Table 5.16)

Hosp ICT 1) Hospitals – Average Infrastructure Factor – Absolute productivity

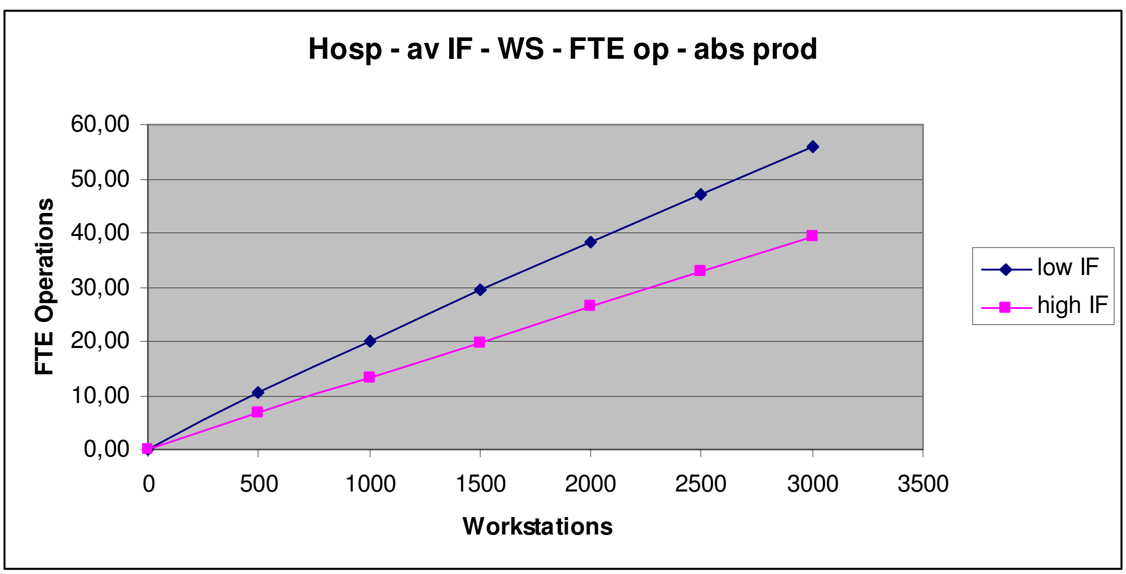


Figure A.3. 28 Hosp – av IF – WS – FTE op – abs prod

No results for Hosp – av IF – abs productivity – Combined scale – FTE operations

No results for Hosp – av IF – abs productivity – TIR cost – FTE operations

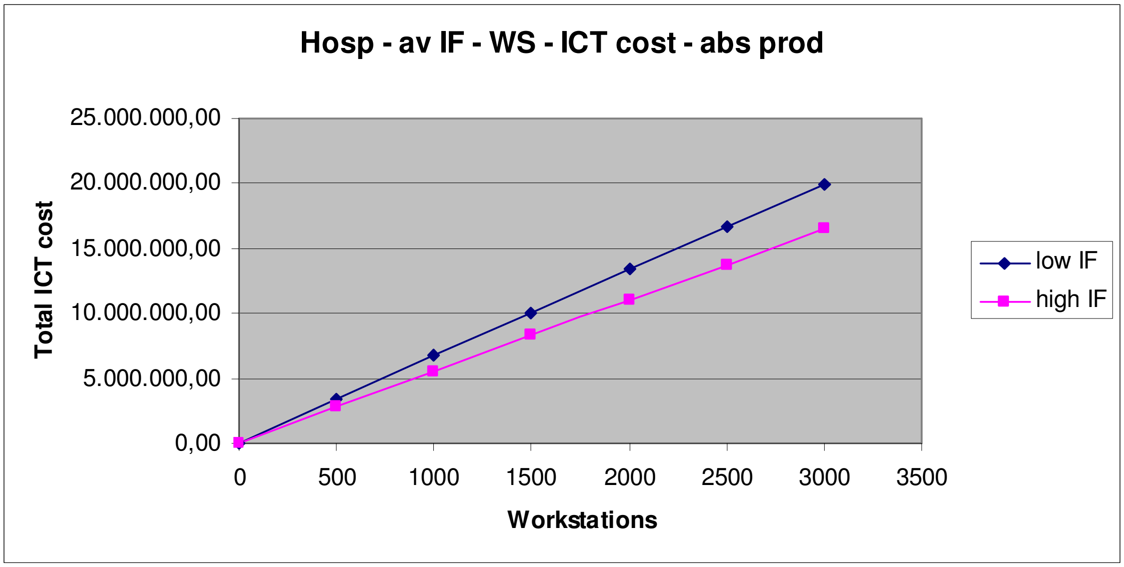


Figure A.3. 29 Hosp – av IF – WS – ICT cost – abs productivity

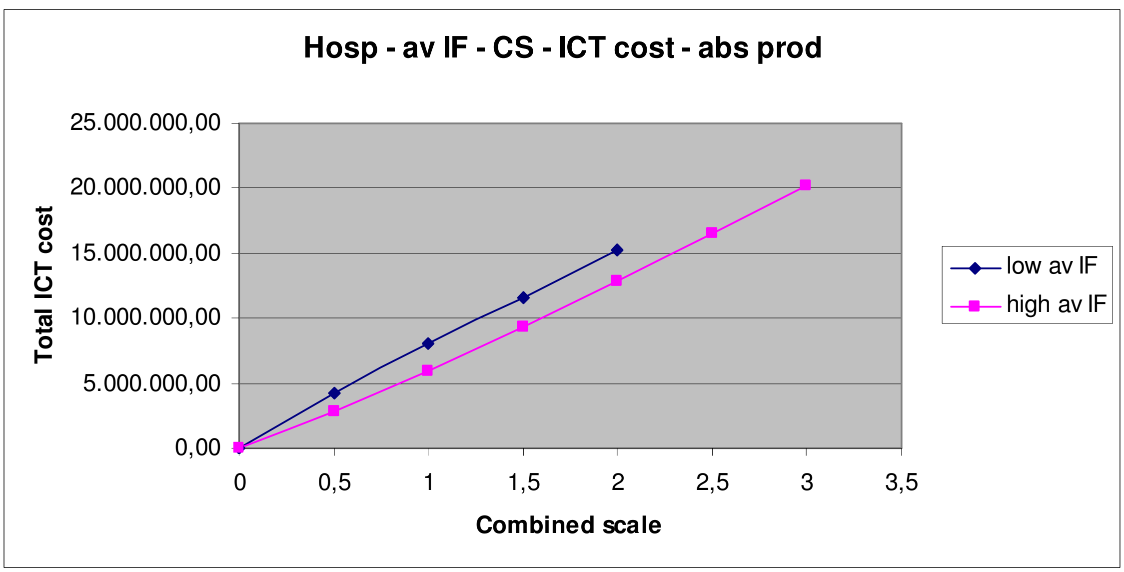


Figure A.3. 30 Hosp – av IF – Comb – ICT cost – abs productivity

Hosp ICT 2) Hospitals – Average Infrastructure Factor – DEA productivity

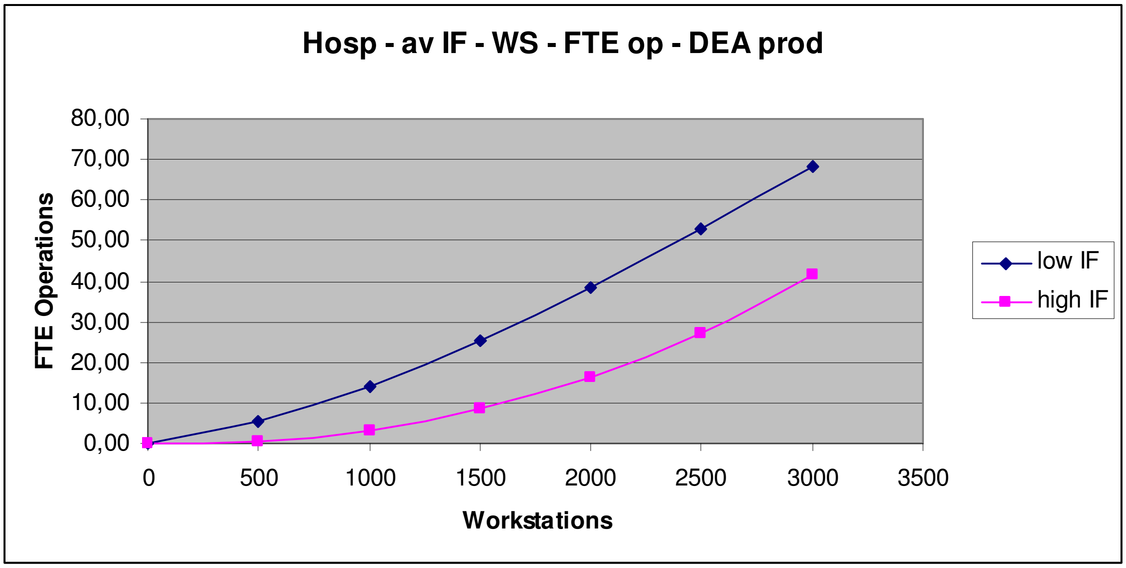


Figure A.3. 31 Hosp – av IF – WS – FTE op – DEA productivity

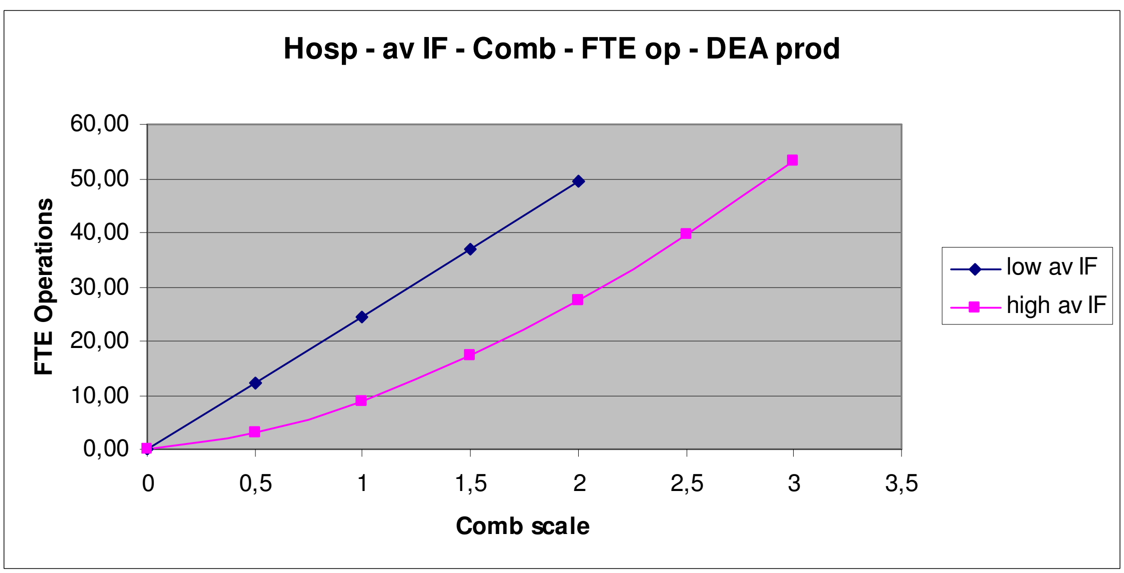


Figure A.3. 32 Hosp – av IF – Comb – FTE op – DEA productivity

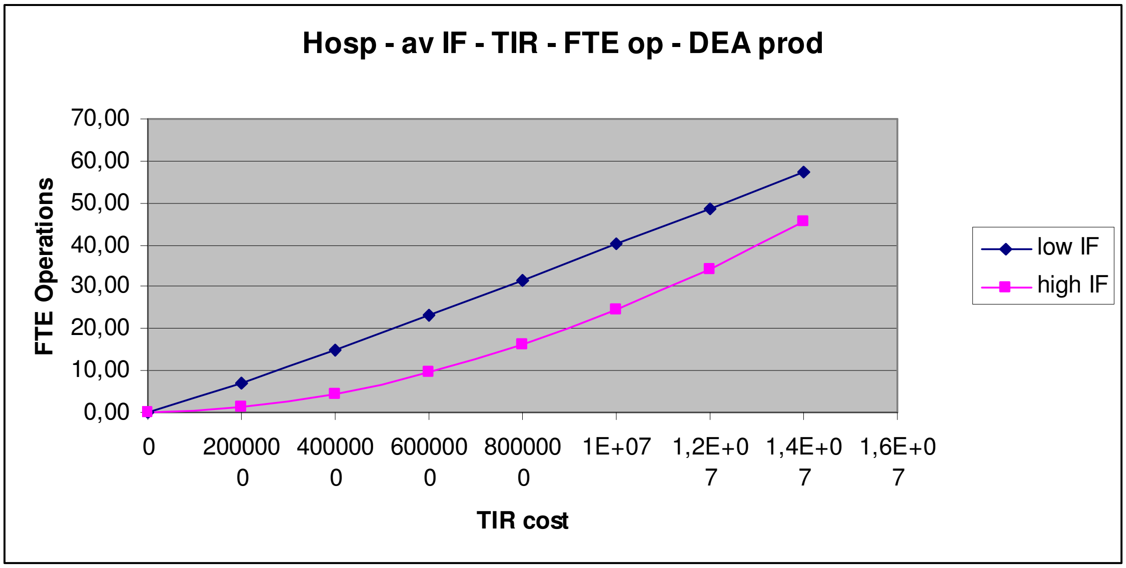


Figure A.3. 33 Hosp – av IF – TIR – FTE op – DEA productivity

No results for Hosp – av IF – DEA productivity – Workstations – Total ICT cost (as b(low)<1 and b(high)>1).

No results for Hosp – av IF – DEA productivity – Combined scale – Total ICT cost

Hosp ICT 3) Hospitals – Maturity Factor – Absolute productivity

No results for Hosp – MF – abs productivity – Workstations – FTE operations

No results for Hosp – MF – abs productivity – Combined scale – FTE operations

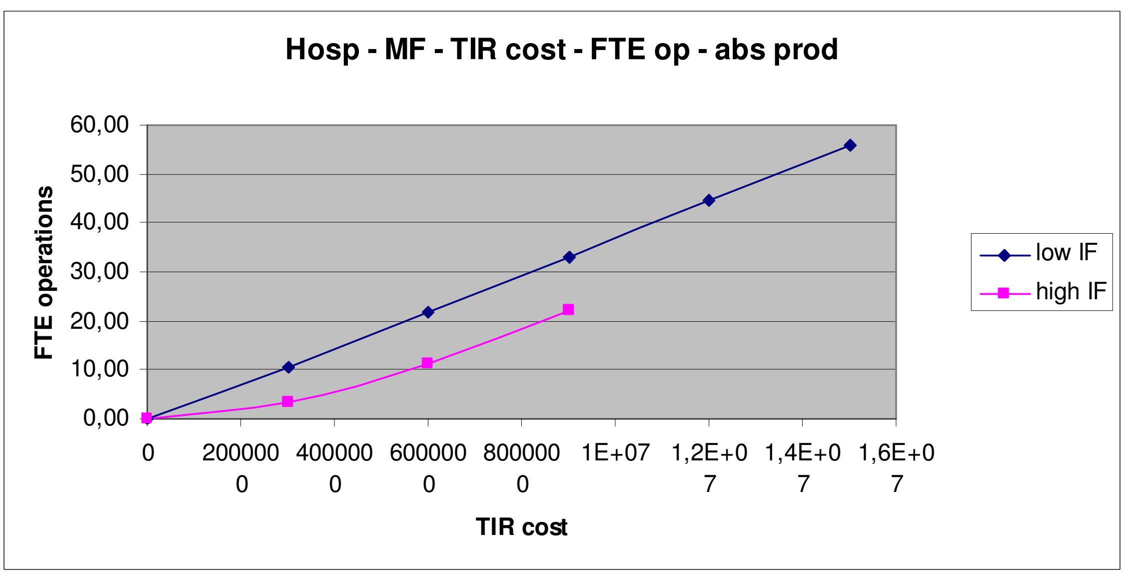


Figure A.3. 34 Hosp – MF – TIR – FTE op – abs productivity

No results for Hosp – MF – abs productivity – Workstations – Total ICT cost

No results for Hosp – MF – abs productivity – Combined scale – Total ICT cost

Hosp ICT 4) Hospitals – Maturity Factor – DEA productivity

No results for Hosp – MF – DEA productivity – Workstations – FTE operations

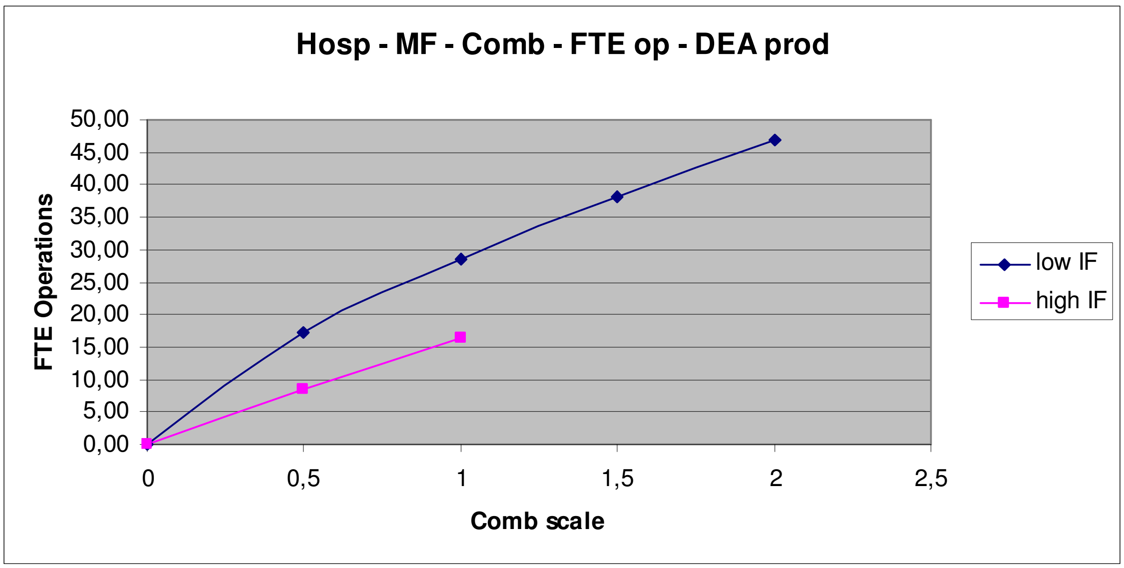


Figure A.3. 35 Hosp – MF – Comb – FTE op – DEA productivity

No results for Hosp – MF – DEA productivity – TIR cost – FTE operations

No results for Hosp – MF – DEA productivity – Workstations – Total ICT cost

No results for Hosp – MF – DEA productivity – Combined scale – Total ICT cost

Hospitals Business productivity (related to Table 5.18)

Hosp OP 1) Hospitals – Average Infrastructure Factor – Absolute productivity

No results

Hosp OP 2) Hospitals – Average Infrastructure Factor – DEA productivity

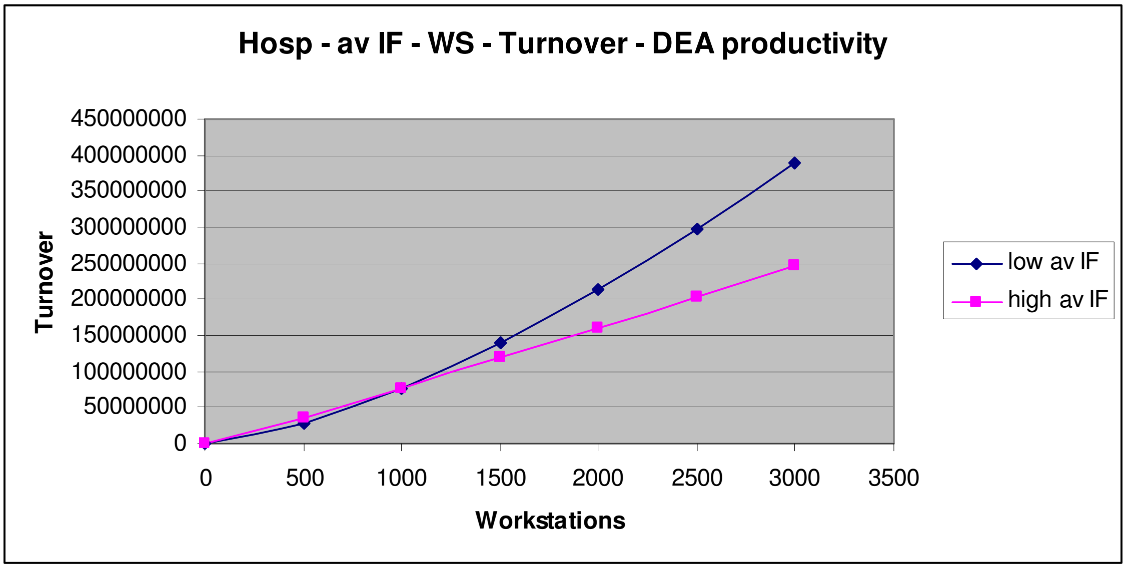


Figure A.3. 36 Hosp – av IF – WS – Turnover – DEA productivity

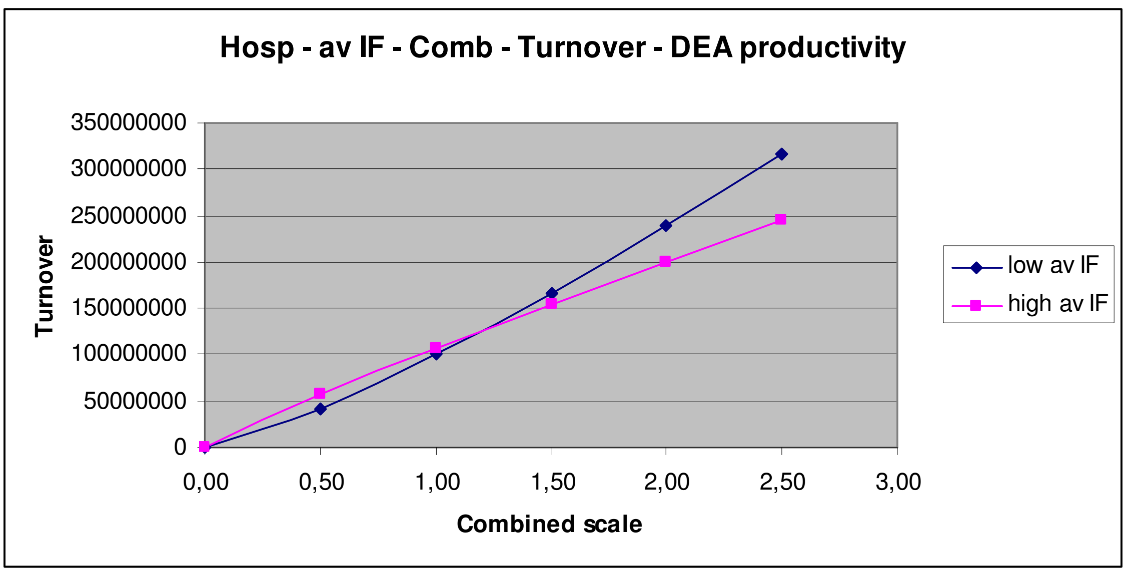


Figure A.3. 37 Hosp – av IF – Comb – Turnover – DEA productivity

➔ Curve value = 0

Appendix 4. Cybernetic view ICT management policies

Organizations of the same type are divided in section 2.7.3 in 4 groups: rigid (R: low IF and low MF), planned (P: high IF and low MF), flexible (F: high IF and high MF) and chaotic (C: low IF and high MF). This is visualized in Figure 2.17. The organizations investigated in this research have a relatively low level of ICT spending and ICT maturity. So these organizations can be positioned in the "Planned (P)" or "Rigidity (R)" quadrant of Figure 2.17. In Table A4.1 the average IF, average ICT cost / workstation and average number of workstations / FTE operations are represented.

Table A4 1 Proxy P3 and cybernetic view on ICT management policies

	Housing Corporations	Municipalities	Hospitals
	Planned	Planned	Planned
Average IF	0,55	0,62	0,62
ICT cost / workstation	7700	5300	6200
Workstations / FTE operations	47	43	57
	Rigid	Rigid	Rigid
Average IF	0,37	0,47	0,49
ICT cost / workstation	8800	5400	5700
Workstations / FTE operations	42	47	51

We can see that Housing Corporations behave according to proxy P3.
Total ICT cost / workstation (P) < Total ICT cost / workstation (R)
Number of WS / FTE operations (P) > Number of WS / FTE operations (R)

Municipalities behave only partly according to proxy P3:
Total ICT cost / workstation (P) < Total ICT cost / workstation (R)
But Number of WS / FTE operations (P) < Number of WS / FTE operations (R)

Hospitals behave only partly according to proxy P3:
Number of WS / FTE operations (P) > Number of WS / FTE operations (R)
But Total ICT cost / workstation (P) > Total ICT cost / workstation (R)

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SAMENVATTING

Informatie en communicatie technologie (ICT) speelt tegenwoordig een steeds belangrijker rol in organisaties. Dit vereist een toenemende beschikbaarheid van een complex systeem van hardware, software en een ICT organisatie met medewerkers, die over de juiste kennis beschikken. De complexiteit van het hardware/software systeem is het resultaat van de wijze waarop standaard componenten worden samengevoegd in een organisatiespecifiek ICT systeem. Hoe complexer het hardware/software systeem, des te hoger de ICT uitgaven zijn, niet alleen voor hardware/software, maar ook voor de ICT medewerkers. In deze thesis wordt onderzocht hoe de complexiteit van hardware/software en de complexiteit van de ICT organisatie kan worden beperkt door enerzijds standaardisatie in hardware/software en anderszijds door standaardisatie van organisatorische processen. Dit is, voor zover ik weet, het eerste onderzoek waarin de relatie tussen schaalgrootte en complexiteit in ICT expliciet wordt gedefinieerd en gemeten.

De technologische ontwikkeling in de ICT levert een continu aanbod van nieuwe producten, die moeten worden geïntegreerd in het hardware/software systeem van een organisatie. Dankzij de wet van Moore is de technische en economische levensduur van bestaande producten relatief kort, waardoor de ICT organisatie permanent geconfronteerd wordt met het dilemma van integratie versus vervanging. Dikwijls hebben nieuwe applicaties overlappende functionaliteit met bestaande applicaties en zij gebruiken een ander infrastructuur platform, hetgeen dit dilemma nog moeilijker maakt. Er is vaak onenigheid tussen ICT medewerkers en de gebruikers over de wenselijkheid van applicaties: gebruikers benadrukken het belang voor de business en ICT medewerkers onderstrepen de complexiteit en de kosten. De gebruikers denken in termen van business opbrengsten/kosten, terwijl ICT medewerkers vaak denken in termen van ICT opbrengsten/kosten. Gebruikers willen applicaties optimaliseren en ICT medewerkers willen infrastructuur optimaliseren. Dit laatste leidt tot minder ICT complexiteit. In organisaties met lage ICT budgetten bestaat altijd een spanning tussen de uitgaven aan applicaties en de uitgaven aan infrastructuur. Als er te weinig geld wordt besteed aan de vernieuwing van de infrastructuur, dan is een onnodig grote ICT complexiteit het gevolg daarvan. Dit leidt vervolgens tot additionele uitgaven voor ICT menskracht. Aan de andere kant leiden te lage uitgaven aan applicaties tot onvoldoende business ondersteuning door applicaties. Daarom is de balans tussen infrastructuur en applicaties belangrijk voor schaalgroottevoordelen in ICT én business.

Standaardisatie van bedrijfsprocessen en standaardisatie van gegevens is een meer fundamentele manier om de ICT complexiteit te reduceren. Als bedrijfsprocessen worden herontworpen conform de mogelijkheden van standaard applicaties (zoals SAP), dan kan het aantal applicaties worden gereduceerd. Als interfaces tussen applicaties kunnen worden gestandaardiseerd (bijvoorbeeld volgens de regels van een internationale standaardisatie organisatie), dan kan het aantal interfaces tussen applicaties worden gereduceerd. Een voorbeeld hiervan is het initiatief van de IHE (2010), dat beoogt om de complexiteit te reduceren van de integratie van de “healthcare enterprise”. Deze benadering om complexiteit te reduceren valt echter buiten de scope van dit onderzoek.

Deze studie levert nieuwe inzichten op in de besparingen op basis van schaalgrootte van ICT afdelingen. Er is aangetoond dat infrastructuur gerelateerde investeringen een efficiënter

gebruik van ICT middelen mogelijk maken. In dit onderzoek worden de relaties tussen *ICT beleid, ICT middelen en ICT uitgaven* geanalyseerd. Op basis van gegevens van woningcorporaties, gemeenten en ziekenhuizen wordt aangetoond dat - in deze relatief weinig aan ICT bestedende organisaties - de uitgaven voor ICT infrastructuur het belangrijkste ICT beleidscriterium blijken te zijn. Het blijkt dat organisaties die weinig besteden aan infrastructuur gemiddeld 20% meer uitgeven aan operationele ICT menskracht en totale ICT kosten, dan organisaties die veel besteden aan infrastructuur (zie Figure 4.2 pagina 81 voor definitie infrastructuurkosten als de som van hardware, software en menskracht). De mate van ICT volwassenheid (volgens COBIT 4.0) was het tweede onderzochte ICT beleidscriterium. Er kon echter nauwelijks een positieve relatie worden gevonden tussen ICT uitgaven en de mate van volwassenheid.

In dit onderzoek is ook de relatie tussen *ICT beleid, ICT middelen en de performance van de organisatie* onderzocht. Op basis hiervan is geconcludeerd dat woningcorporaties een zeker minimum van hun ICT uitgaven aan applicaties moeten besteden, om schaalgrootte besparingen te kunnen realiseren in hun bedrijfsprocessen. In de praktijk wordt aanbevolen dat woningcorporaties minimaal 42% van hun ICT uitgaven besteden aan infrastructuur. Daarnaast dient minimaal 47% te worden besteed aan applicaties. Voor ziekenhuizen geldt een vergelijkbaar advies om minimaal 54% aan infrastructuur en minimaal 42% aan applicaties te besteden. In dit onderzoek konden geen percentages voor gemeenten worden bepaald in verband met de beperkingen van de beschikbare data.

De theoretische bijdrage van dit onderzoek is gelegen in de formulering van de definitie van de effectiviteit van het ICT beleid en de meting van dit construct. De analyse van de productiviteit van de ICT en van de bedrijfsprocessen is gebaseerd op theorieën betreffende systemen, cybernetica en complexiteit. Er wordt een nieuwe manier geïntroduceerd om de relatie te meten tussen de effectiviteit van ICT beleid en kostenbesparingen in ICT door schaalgrootte voordelen. Bovendien wordt de relatie bepaald tussen de effectiviteit van ICT beleid en kostenbesparingen in bedrijfsprocessen door schaalgrootte voordelen.

In hoofdstuk 1 worden de volgende constructen plus hun relaties gedefinieerd: (1) effectiviteit van ICT beleid, (2) ICT uitgaven, (3) schaalgrootte van ICT middelen en (4) organisatie performance. Vervolgens worden het onderzoeksdoel en de onderzoeksvragen gedefinieerd, waarna de theoretische en praktische onderzoeksbijdragen worden beschreven. Tenslotte wordt de onderzoeksaanpak expliciet gemaakt.

In hoofdstuk 2 wordt de theoretische fundering van de constructen beschreven. Deze fundering bestaat uit drie pijlers. Ten eerste: de wetenschap van cybernetica en complexiteit, die uitvoerig wordt beschreven, omdat deze wordt gebruikt in verschillende delen van dit onderzoek. Het besturingsconcept wordt gebruikt in de definitie van de basis hypothese H1; het complexiteit concept wordt gebruikt om schaalgroottevoordelen en -nadelen uit te leggen in de conversie van ICT uitgaven naar ICT middelen ("assets"). Ten tweede: de "Resource Based View" als fundament voor de definitie van ICT middelen en ICT beleid. Ten derde: de economische theorieën over schaalgroottevoordelen. Op deze drie pijlers zijn de theorieën gebouwd die specifiek zijn voor de constructen. In hoofdstuk 2 wordt ook de theoretische fundering van ICT beleid behandeld. Dit betreft ICT infrastructuur en ICT organisatie conform COBIT/ITIL. Tenslotte wordt een cybernetische visie ontwikkeld op ICT beleid, om uit te leggen waarom er een delicate balans is tussen infrastructuur en applicaties in organisaties met een laag niveau van ICT uitgaven.

In hoofdstuk 3 worden de constructen meer gedetailleerd gedefinieerd. Vervolgens wordt de basishypothese H1 geformuleerd betreffende de relaties tussen de constructen (1) effectiviteit van ICT beleid, (2) ICT uitgaven en (3) schaalgrootte van ICT middelen. Voor elk construct wordt een benadering ("proxy") geformuleerd, om de theoretische constructen passend te maken met de dataset van M&I/Partners. De hoeveelheid ICT uitgaven wordt benaderd vanuit de "Total cost of ownership" (TCO) visie. De complexiteit van de ICT middelen is gedefinieerd als een theoretisch construct, om de schaalgrootte van ICT middelen te vertalen naar ICT uitgaven (in de zin van inspanning van ICT personeel). De effectiviteit van ICT beleid wordt vanuit twee gezichtspunten benaderd: gebaseerd op de volwassenheid van de ICT organisatie en gebaseerd op het infrastructuur beleid. Tenslotte wordt hypothese H2 geformuleerd, betreffende de relatie tussen (4) organisatie performance, (3) schaalgrootte van ICT middelen en (1) effectiviteit van het ICT beleid. Het onderzoeksmodel wordt uitgelegd in Figuur 3.10.

In hoofdstuk 4 worden eerst de empirische data verzamelingen gepresenteerd. Daarnaast wordt de onderzoeksmethodologie uitgelegd en worden de constructen meetbaar gemaakt. De data verzamelingen bestaan uit data van woning corporaties, gemeenten en ziekenhuizen over de periode 2002-2008. In de methodologie wordt onderscheid gemaakt tussen een globale en een gedetailleerde analyse (Figuur 4.4). De *globale* analyse bestaat uit "Partial Least Square" (PLS) regressie en lineaire regressie, om een globale visie te krijgen op de validiteit van de hypothesen. De gedetailleerde methodologie gebruikt "power" regressie en is gebaseerd op twee manieren om de productiviteit te bepalen: de *absolute* en de *relatieve* productiviteit. Voor de bepaling van de relatieve productiviteit wordt "Data Envelopment Analysis" (DEA) gebruikt, een techniek die geschikt is om vergelijkbare organisaties te benchmarken. De constructen worden geoperationaliseerd en er wordt een additionele proxy gedefinieerd, betreffende de meting van de schaalgrootte van de ICT middelen.

In hoofdstuk 5 worden de data van de woning corporaties, gemeenten en ziekenhuizen geanalyseerd, in overeenstemming met de methodologie. De basis hypothese H1 wordt in de detailanalyse op 20 verschillende manieren getest. Dit was noodzakelijk omdat er verschillende metingen zijn gebruikt voor de drie constructen en twee manieren om de productiviteit te bepalen. De resultaten van de berekeningen worden grafisch weergegeven in Appendix 3. De hypothese H2 betreffende de organisatie performance wordt in de detailanalyse op 4 verschillende manieren getest. Daarna worden H1 en H2 opnieuw geanalyseerd, maar nu simultaan, conform de methodologie (zie Figuur 4.4). Tenslotte wordt er een overzicht gegeven van de validiteit van de hypothesen.

In hoofdstuk 6 worden de onderzoeksresultaten bediscussieerd. Vervolgens worden de beperkingen van dit onderzoek geanalyseerd in termen van verschillende validiteitaspecten. Tenslotte worden de implicaties van de onderzoeksresultaten besproken in de conclusie.

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