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Efficiency Evaluation of Hospital IT-Services through Data Envelopment Analysis

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This thesis is about Data Envelopment Analysis, an efficiency evaluation method, and its application for hospital IT services.Through the demography changes the health care costs are emerging, especially in the hospital sector. Actually the IT costs of hospitals are also growing and already reached 5 percent. Therefore this work presents a Data Envelopment Analysis based IT services efficiency evaluation tool approach with the objective of optimizing resource allocation. This should work like new IT investments which would lead to positively influence on overall performance and cost reduction effects.
Therefore this work introduces in the Data Envelopment Analysis, its usage in hospital and information system sectors. Following up it gives proposals how to adapt this method on hospital IT services and a theoretical example case shows a possible application.

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Abbreviations

APPDEV	Non-ERP applications development.
BCC	Bankers, Charnes Cooper model.
CCR	Charnes, Cooper and Rhodes model.
CIO	Chief Information Officer.
CRM	Customer-Relationship-Management.
CRS	Constant Returns to Scale.
DATACC	Extent of customer and supplier access to operations.
DEA	Data envelopment analysis.
DMU	Decision making units.
DRG	Disease Related Groups.
EBIZ	Extent of electronic Commerce involvement with Supply Chain Members.
ERP	Enterprise-Resource-Planning.
FTE	Full-time equivalent.
HIT	Health information technology.
HITECH	Health Information Technology for Economic and Clinical Health Act.
IHDS	Integrated Health Care Delivery System.
IT	Information technology.
JCR	Journal Citation Reports.
LOS	Lenght of Stay.
OECD	Organization for Economic Cooperation.
OIBDP	Operating Income before Depreciation.
PMR	Patient Medical Report.

ROA	Return on Assets.
RTS	Returns to Scale.
SE	Scale Efficiency.
VRS	Variable Returns to Scale.

Symbols

E_j	Efficiency of DMU j.
X_{ij}	Input i of DMU j.
Y_{rj}	Output r of DMU j.
Z_j^k	Intermediate of DMU j in Stage k.
u_r	Weight of output r.
v_i	Weight of input i.
ϵ	Small non-Archimedean number.
λ_j	Proption of refering DMU j.
θ_j	Efficiency of DMU j.
s_i	Slack of Input i.
s_r	Slack of Output r.
L	Lower bound.
U	Upper bound.
M_0	Efficiency change between two periods.
j	Number of DMU.
r	Number of Outputs.
i	Number of Inputs.
k	Stage.

1 Introduction

The IT sector is getting more and more important for all industry sectors. The health-care sector is a big customer there. The average age is rising and most diseases are curable in this times due to medical evolution. This evolution is driven by new and innovative techniques. An information technology infrastructure is required as foundation for most innovations. Alike every other health care player, hospitals are affected due their usage of new diagnosis devices, databases, electronic operation tools and so on. The benefit of these technologies on care and therapy are proofed by many studies. This devices get installed and maintained by the according IT services departments. In contrast to the evaluation of new technologies, the efficiency of the serving services isn't measured yet.
Clearly there are studies about IT investments on financial performance, but non about technical efficiency of services.
The IT expenses in the health care sector are growing since years and according to Healthcare Information and Management Systems Society (2012) the average IT expenses in U.S. hospitals reached five percent of the total hospital expenses in 2011. Especially in this sector reliability, faultlessness and efficiency are essential with perilous consequences and hence extensive and costly.

Many studies proof the connection between increasing IT budgets and increasing firm performances. Exemplary the study of Beard and Elo (2007) showed that IT investments improve hospital business performance and have a cost-reducing effect.

This two studies make obvious that there should be a system to measure the efficiency of IT departments. An efficiency increase of IT services would logically equally lead to optimizations and positive effects on costs and business performance.

This must be taken in consideration especially under the aspect of increasing total health care cost and compensation attempts by insurances, governments and also on hospital level. Exemplary therefore the annual average growth rate in per capita health expenditure was 4,1 percent from 2000 until 2009. That illustrates the problem of increasing health spending (OEC (2013)). The U.S. government reacted to support the health information technology (HIT) by the HITECH act (2009) and the reference on HIT in the Affordable Care act (2010) but the problematic already reached hospitals all over the world.

The problem in this field lies in the lack of information for IT service efficiency. The IT service efficiency is strongly linked to the corresponding sector and the values they prefer. For example in manufacturing a swift system might be most important whereas for life supporting systems high reliability and robustness of a system are crucial.

Therefore this paper analyses the literature about existing systems for IT services evaluation and hospital performance measurement. It introduces into the methodology of data envelopment analysis as broad positioned evaluation tool and illustrates for an example case, how this model should work. Afterwards an approach suggests how this system should be implemented for hospitals. The conclusion illustrates the overall findings and open topics.

2 Literature Review

The literature review is ordered into a short description about the general information search and its outcome. Following it analyses efficiency evaluations for hospitals and for information technologies including theories about IT value adding. Subsequent works about efficiency measurements of information services in hospitals illustrate the former research in this topic. At last comes an example of quality inclusion into DEA and the overall literature conclusion .

The paper of Ross and Ernstberger (2006) and Wang et al. (1997) are the most related works for our application purpose, so they get an extra focus.

2.1 Literature Search

To cover the topics of this thesis for the literature search I created three search strings.

For the literature research I used the scientific database Scopus (www.scopus.com) to search in JCR 2011 accomplished journals.
The first string was about DEA application in hospitals with IT focus. To limit the output I used only the relevant category operations research.

Search 1:
(‘Data Envelopment Analysis‘ OR ‘DEA‘ OR ‘Efficiency‘ OR ‘Efficiency measure‘ OR ‘Performance‘) AND (‘Information System‘ OR ‘IT-System‘ OR ‘HIS‘ OR ‘Information Technology‘ OR ‘HIT‘) AND (‘Hospital‘ OR ‘Clinic‘)

The second search was about general efficiency evaluations for information technologies including health information systems (HIS) and technologies (HIT) in the categories operations research, medical informatics and industrial engineering.
Search 2:
(‘Data Envelopment Analysis‘ OR ‘DEA‘ OR ‘Efficiency‘ OR ‘Efficiency measure‘ OR ‘Performance‘) AND (‘Information System‘ OR ‘IT-System‘ OR ‘HIS‘ OR ‘HIT‘ OR ‘Information Technology‘)

The third search was about the data envelopment analysis and general efficiency measurements in hospitals in the categories operations research, medical informatics and industrial engineering.

Search 3:
(‘Data Envelopment Analysis‘ OR ‘DEA‘ OR ‘Efficiency‘ OR ‘Efficiency measure‘ OR ‘Performance‘) AND (‘Hospital‘ OR ‘Clinic‘)

The results are illustrated in the table 2.1.

Inputs	number of papers	hospital focus	IT focus	Hospital and IT focus	DEA application	Network DEA	multiple stages DEA	Malmquist index comparison
$search1$	96	12	8	2	53	5	10	6
$search2$	147	9	147	9	n.a.	n.a.	9	n.a.
$search3$	578	578	15	15	308	1	n.a.	47

Table 2.1: Search Strings

For all searches the number of results was good but under closer examination the IT service efficiency works are all based on other output data as for example total performance or influence on other key data, but not on the departments efficiency. Another problem was the IT services efficiency at all. No direct work about internal evaluation for a hospital or an overall applicable production function was found. Therefore this thesis literature analysis focuses on firm performances evaluations as most related alternative.

It has to be mentioned that this study is about the total efficiency of IT services in hospitals which suspends individual medical and technological topics as for example electronic health record.

2.2 Efficiency Evaluation for Hospitals

The book "Health Care Benchmarking and Performance Evaluation" of Ozcan (2008) summarizes the state of the art of data envelopment analysis in health care applications.

The first part introduces in detail in all relevant DEA basic principles on hospital examples. The second part topics DEA application in all kind of health care organizations. In the hospital section it presents fundamental works for general and special subjects. Afterwards it presents the robust DEA hospital model as in table 2.2 (Ozcan (2008) pp. 106). This model includes important inputs like labour and capital investments as well as outputs as inpatient and outpatient frequencies and costs. For interested readers it is a comprehensive framework and in connection with Liu et al. (2013) it is covering and referring into all kinds of hospital DEA usage and its developments.

Inputs	Outputs
Beds Service Mix FTEs Other operational Expenses	Case mix adjusted Admission Outpatient Visits (Medical Resident FTE)

Table 2.2: Robust Hospital DEA Model according to Ozcan (2008)

2.3 Efficiency Evaluation for Information Technology Services

2.3.1 Impact of IT on other sectors

One of the best suiting reference paper was Ross and Ernstberger (2006): "Benchmarking the IT productivity paradox: Recent evidence from the manufacturing sector".

This paper is interesting for our work because it analyses IT bdgets divided in categories, as this study wants to do it for service departments. Additionally it not only applies financial performance data as output, but also uses IT competences, administration and labor productivity therefor.

The paper of Ross and Ernstberger (2006) is focused on illustrating the impact of information technology investments on firm performance via Data Envelopment Analysis. Therefore it chose the manufacturing sector for a better comparison between DMUs through mainly homogeneous processes. The author mentions that the more heterogeneous service sector could be all too much diluted for a comparison. But the relevance of this statement about services is to regard critically because of the mass of papers showing dissenting opinions.

The aim of this paper is to show the relationships between inputs and outputs of IT and its business value created as: "The investments [in IT] can affect cost[s], flexibility, lead-time, efficiency, effectiveness or coordination with trading partners, and integration across the internal value chain, resulting in better customer responsiveness".

The study refers on Gurbaxani et al. (1997) und Tallon et al. (1996) saying positive IT impacts are coordinations of value adding activities and the effect is the value-adding function of the IT budget.
Figure 2.3 displays the overall model with its inputs and outputs for the input-oriented Data Envelopment Analysis.

Inputs	Outputs
IT Staff Total Staff IT Budget: -Salaries -Technology -EBusiness -CRM -Maintenance -Research a. Development	Working capital Labor Productivity Administrative Productivity Sales OIBDP ROA Discrete Variables: -APPDEV -EBIZ -Data ACC -ERP

Table 2.3: IT productivity model according to Ross and Ernstberger (2006)

Furthermore every IT budget was partitioned in eight main components as inputs. This in special is interesting for us, because most literature about IT impact on firm performance analyses only total IT expenses without further categorisation. The outputs were intermediate calculated constructs as labor productivity and administrative productivity. For the IT competences measurement they take extra IT specific characters like data-share, ERP integration and usage, EBIZ importance and own application development as direct independent IT outputs.

For the analysis the named outputs were clustered in three groups by their impacts: labour and administrative productivity, profitability, and IT competence. After a first formulation as CRS model also a VRS model was used to demonstrate scale effects and scale efficiency.
For comparison three models where generated with nearly similar inputs and model depending outputs:

> The Model 1 is the DEA baseline model including all in- and outputs. An inefficiency in scales persisted because of influences by the IT investments and IT competences. This means that there were differences in intensity of IT investments and IT competences due to scale distinctions.
>
> The Model 2 focuses on IT contribution of the value added function. This firms used the "most productive combinations of IT inputs" through the scale efficiency of 1.00, which is considered as optimal.
>
> The Model 3 illustrates IT processes and IT competences which had room for improvements by a scale efficiency of 0.96.

Despite various assets and drawbacks of the diverse models it can overall be said that "IT productivity [level] is driven by IT competencies, organizational process productivity and profitability."

With an example it is illustrated that the performance of an optimizations by direct imitation is debatable. In some cases it worked negatively, but the author speculates that this could be a short term influence clearing itself on long term evaluation.

The unexpected outcome was, that efficient firms spend less money for the IT calculated on IT employees and total workforce than inefficient. This efficient firms were in the automotive, aerospace and paper-milling sector originated through higher investments in comparison. Furthermore this differences in IT investments are statistically significant. The study can be used as a guidance how to allocate information technology resources. Therefore the operator should consider that it is equally depending on competencies and just financial expenditures won't always lead to success.
For our research topic the derivation of budgets into service divisions and the overall conclusion are presumably adaptive

The Paper of Wang et al. (1997) addresses the topic of IT investments impact on firm performance over a two stages model. For the usage of a two stages data envelopment analysis it is important to consider some additional aspects:

-are intermediate outputs rightly chosen?
-are intermediate outputs efficient generated?
-is transforming for intermediate outputs into inputs usage needed?
-are this intermediates influencing overall performance directly?

The relationship between investments in IT to changes in performance is difficult in DEA because it measures technical efficiency which means "it is not possible to produce the same amount of outputs by utilizing fewer inputs". Additionaly problematic is that there is normally no direct and apparent link from investments to the firm output.
The paper illustrates through an example that a total efficient DMU doesn't imply efficiency on all its stages.
On the example of banks they show how IT investments strategies can influence the output indirectly but measurable.
Therefore they differentiated bank operations into two subprocesses and used them as stages. The first stage was the collection of funds as deposit. For this purpose only external inputs as capital, labor and the complete IT budget were used. This unilateral distribution of IT input was caused by lack of information about the internal distribution .
In the second stage the deposits (now intermediate outputs and inputs) were used to invest in securities and as loans. External outputs were generated profits and the rate of recovered loans to integrate a risk factor. The total set of inputs and outputs is illustrated in table 2.4. For the efficiency evaluation both stages separately and the overall performance were calculated.

There were widely varying results for both stages and overall performance. But obviously no DMU that is inefficient in the IT included first stage achieves overall efficiency.

Inputs	Intermediate	Output
IT budget fixed assets number of employees	deposits	profits earned percentage of loans recovered

Table 2.4: Inputs and Outputs of Wang et al. (1997)

Furthermore they calculated for two efficient DMUs the changes in generated deposit dollars by changing IT investments by trial and error. Thereout they discovered a direct link between IT expenses and deposit generation.

Additionally they evaluated the impact per invested dollars in IT on profit generated and improved IT investments strategies that way.
Overall the paper indicates that IT costs have influence on firm profits within a specific range.

Other papers focus on more detailed influences of information technology on performance.

The article of Gurbaxani et al. (1997) is about the influence of IT budgets on firm performance as well as about the connection between IT personal and IT hardware. It proved that IT budgets and financial firm performances are linearly related, which indicates that IT departments should grow in same relation as firms. Another output was that personal and hardware are net complements and cost should increase in a similar level.

The work of Lin and Shao (2006) focuses on the influence of non traditional inputs as IT investments on productive efficiency in a two stage on parametric stochastic production and one nonparametric approach. As most other studies this also leads to better results than without IT investments.

Brynjolfsson and Hitt (1996) is one of the earlier works on information systems budget. It is focusing on changes regarding the IT paradoxon. This paper statistically proved for a large number of cases that IT spendings are accountable for substantial increases in firm output. The results were calculated over the marginal product of capital investions and illustrated that IT investments returns are comparable to other production processes.

The work of Shin (2006) considered the influence of IT and strategy on the performance of diversified firms, were it also got positive relationships between IT and the financial performance.

IT services sector was analysed from 1995-2007 over 25 countries by Chou and Shao (2014) with the aim to study its growth. Therefore it used DEA and Malmquist index for periodical comparisons and found out that it is average growing with an annual rate of 1,9 percents faster than most other service sectors. Additionally it states that the main driver of the IT sector growth is the "innovation-based technological progress".

2.3.2 Theories how IT helps increasing Efficiency

The empirical research of Tallon et al. (1996) analysed how IT works as value-adding function on business processes. It was based on the assessment that executives allocate investments into IT when they can recognize its effect on productivity. Through two equations models they found out, that IT impact can best be monitored in intermediate business processes. Thereby the IT value-adding function is measurable and they also confirmed the effect of IT is generated through coordination between processes.

The grounding literature for it was the coordination theory employed on the way information systems affect the performance. Under the assumption that every process is subdivided into activities and coordinations Malone and Crowston (1994) built their argumentation that every of this coordination has accountable costs. This effect is produced through the micro-economical theory of substitution and elasticity of demand. In the first step IT systems can be used to automate coordination processes which leads into into reducing coordination cost. This on the second stage conducts into an increasing amount of coordination processes because of demand elasticity. On the third step former expensive coordination processes get affordable, which enables this cycle to start again.

Another theory about positive influence of IT on performance is from Austin (1988). The paper describes how information systems can advance production processes through "automate, informat and transform". Therefore it illustrated sevens ways how hospital can use this abilities by better information distribution, automation of standard processes, better internal communication heading to a swifter operational procedure and thus freeing of personal resources.

The concepts of Austin (1988) and Malone and Crowston (1994) are theoretically a never ending cycle of optimizations strengthening through innovations and technological progress.

2.3.3 Studies of Information Technologies in Hospitals

The paper of Buntin et al. (2011) shows generally the positive overall effect of IT in hospitals.
The HITECH act (2009) and the Affordable Care act of 2010 are signs for the increasing importance of HIT. For the invention of most new HIT developments there is an infrastructure information system framework necessary.
Based on the studies of Chaudhry (2006) and Goldzweig et al. (2009) about the "usage of health information IT" from 1995 till 2007 this study adds the time period from 2007-2010 with same methods. The study includes: "electronic health records; computerized provider order entry; clinical decision-support systems; health information exchange; e-prescribing for outpatients; patients‘ personal health records;

Inputs	Outputs
physicans	inpatients per day
nurses	outpatients per day
beds	surgical operations p. year

Table 2.5: Inputs and Outputs of Watcharasriroj and Tang (2004)

patient registries; telemedicine or remote monitoring; information retrieval; and administrative functions."

All papers were classified after their overall rating of HIT in positive, mixed positive, neutral or negative. The study found out that 62 percent where positive and 92 percent were positiv or mixed-positiv which is a quite significant statistical overhang.

Watcharasriroj and Tang (2004) analyses the effects of size and information technology in 92 public nonprofit hospitals in Thailand. Therefore it first measured hospital efficiencies via data envelopment analysis. Afterwards it combined this measurements with sizing data through the Mann-Whitney-Test and at least used the Tobit regression analysis to determine the influence of IT investments.

The chosen inputs for the study were number of physicians, nurses and beds. The chosen outputs were average outpatient per day, average inpatients per day and number of surgical operations, but it is mentioned that a weighting grounded on case-mix indexes or diagnosis-related groups (DRGs) would fit better to measure the impact of a patient on resource consumption. Unfortunately no complete data set was available. The used model (Table 2.5) is similar to Al-Shammari (1999).

For the IT correlation analysis it used investments in patient medical record (PMR) systems as IT characters.

The study revealed that IT investments positively support process efficiency and therefore hospital efficiency. Agreeing with the studies of Lee and Menon (2000) and Solovy (2001), it determined that this influence is higher in larger hospitals. Overall IT seems to increase hospital productivity and it is also strengthened by hospital size.

Parente and Dunbar (2001) detected that hospitals with integrated IT systems have higher total and operating margins than hospitals without. Problem within this study was, that the effect of IT on performance could not be stated by its regression analysis because no statical definitely changing effect on HIT could be stated. This revealed the question, if just wealthier hospitals invest more in IT or IT is in charge for financial performance. Nonetheless it summarized proved: hospitals with integrated HIT have higher total profits margins than without.

The article by Solovy (2001) about the "most-wired" hospitals, a group of hospitals with above average HIT application and self-claiming pioneer, proved that they have higher productivity through lower expenses and better credit rankings than average U.S. hospitals. Unfortunately there is no analysis if this is affected by their higher information technology usage and investments.

Thouin et al. (2008) analysed the impact of information technology investments on overall performance in health care. In specially it tested the influence of IT budget, IT outsourcing and IT personal on financial output with special attention on the IT productivity paradoxon. For the calculation of this three hypotheses it used the regression analysis on IHDS data which includes next to hospitals nearly all health care facilities. The overall implication is that increasing IT spending and IT outsourcing significantly increases financial performance whereas IT personal contrasty doesn't lead to changes.

The study of Lee and Menon (2000) is analysing the influence of IT investments on firm output and process efficiency. The examined U.S. hospitals were more technical efficient when their IT investments were higher and that the non-IT capital still has more impact on productivity than IT capital.

2.4 Data Envelopment Analysis

In the DEA section only topics which aren't statistically proved and accepted are shown as indices how they could be used. All other Methodology is in chapter 3.

2.4.1 Quality Measurements

The paper of Nayar and Ozcan (2008) shows how quality measurements can be included into data envelopment analysis additionally to the standard technical efficiency measurements. This was the first systematic study of data envelopment analysis with quality inclusion considering the health care sector.

As the standard hospital evaluation formulation (see table 2.2) has no quality measurement included they had to select suiting characters. Due to a lack of overall hospital quality key data, they decided to use the available data about therapy quality. Therefrom they chose the measurements for pneumonia treatment as the one with best available data.

Inputs	Outputs	Quality
hospital size supply Total f-time and p-time staff total assets	adjusted discharges total outpatient visits Training f-time equivalents	initial antibiotic timing oxygenation assessment pneumococcal vaccination

Table 2.6: Inputs and Outputs of Nayar and Ozcan (2008)

For the analysis of quality and efficiency without trade offs two models were tested. Model 1 is the comparative measurement without quality measurements whereas Model 2 integrates them directly into the DEA formulation as independent outputs.

In Model 1 16 out of 53 DMUs were efficient. The 37 inefficienct hospitals had an average efficiency of 0.72 percent while the average efficiency over all DMUs was 0.81 percent. Another calculation with more hospitals through variables reduction shows, that out of 11 (from 117 hospitals) efficient hospital only 4 could be included into the final sample.

In Model 2 with included quality measures 21 out of 53 hospitals were efficient which is an increase of five. This five former inefficient ones that were already in Model 1 nearly efficient. This could mean that this hospitals optimization aim was on quality, but through correlation the technical efficiency grew with it. The average DMU efficiency for inefficiency ones was now 0.78 percent and for all 0.86 percent. The correlations coefficient of Spearman, which indicates the benevolence of the relationship between two functions, was 0.77.

Inputs	number of DMUs	number of efficient DMUs	average efficiency all	a. efficiency inefficient DMUs
Model 1	53	16	81	72
Model 2	53	21	86	78

Table 2.7: Results of Nayar and Ozcan (2008)

The interesting results of this comparison are, that technical efficient hospitals were also the qualitative efficient ones and nearly technical efficient hospitals were combined with quality measurements the newly efficient. In this study no quality-efficiency trade-offs were found. Moreover it seems that quality and quantity efficiency works together. This is also verified by the Spearman-correlation-coefficient of over 0.75 which means a high accordance.
This example demonstrates that optimizations of performance in quality and quantity are simultaneously possible.

The book of Sherman and Zhu (2006) already used quality inclusion in the bank sector. In contrast their cases with inclusion of quality as additional input and also the independent analysis brought negative results. Quality and efficiency traded themselves of in both examples without differences.

This papers underline the problematic of other studies about measurement quality with DEA and can't confute the well known claim, that quality improvements and technical efficiency improvements contradict each other. It indicates that both are possible results therefore analysing this problematic could help finding a overall relationship about this trade-offs.

2.5 Literature Conclusion

This literature review proved through many application examples that data envelopment analysis is a suitable and well-known tool for efficiency measuring in hospital and IT sector. But the search couldn't help with an overall information technology efficiency evaluation function. Neither the just IT based literature, nor the hospital IT research were even touching this subject. Most hospital IT services analysis focus on their impact on firm performance. This I chose as the most related and built the comparing review thereon. Next to it there were papers which prove the influence of IT on every kind of hospital key data as number of days supplied, reduction of LOS and FTEs per bed (Parente and Van Horn, R Lawrence (2006)) or between the influence of staffed beds and services on IT adoption(Wang et al. (2005)). Whereas the first section gives some little insights into the efficiencies a IT services assist the second gives no hints.
Summarized there is a lack in research for measuring internal efficiency for IT services, especially in the hospital sector.

3 Methodology

Data Envelopment Analysis is based on the initial work "Measuring the efficiency of decision making units" by Charnes, Cooper and Rhodes from 1978. The method is a non-parametrical evaluation tool for evaluation of relative efficiency of multiple inputs and outputs. It can be used for efficiency measuring, ranking, resource allocations and as multi-attribute decision tool.
It is widely used with over 60 000 results at Scopus and has an enormous methodical development ongoing. DEA is mostly used in banking, health care, agriculture and farm, transportation and education (Liu et al. (2013)). It so covers multiple sectors in their complete complexity over network structures, scale effects and characteristic attributes.

3.1 General

DEA is based on mathematical programming especially linear programming. The aim of DEA is to measure the efficiency of so called decision making units (DMUs) like a department, firm or university. Every of this DMUs has multiple ordinal scaled inputs and outputs regardless of their type. As Charnes, Cooper and Rhodes developed it for non-profit-organisations, the data did not have to be measurable in monetary or other ways. It only has to be comparable to each other, which is given by their ordinal measurement. The adoption of DEA to other disciplines is quite simply because of the opportunity to use the production function as basis.

A positive distinction to most other comparison efficiency evaluation techniques is that the value targets are the high performer instead of average. For that reason DEA not just ranks DMUs, it is also illustrating the path to become a high performer. According to Ozcan (2008) it is actual not "a standard tool for benchmarking and decision making" in health care but, its usage and benefit is proved by a great number of studies.
Different from most optimization techniques DEA does not try to calculate a optimal solution, it moreover constructs an efficiency frontier by building a multidimensional correlated frontier of either inputs or outputs. The generated frontier consists of the best performing DMUs, whereas inefficient DMUs get the distances and directions for improvements to match the frontier. A disadvantage is that DEA has no optimization guidance for efficient DMUs caused by its orientation on best performers. The normally used kind of efficiency is the technical efficiency which

measures how much of the maximal achievable efficiency a DMU achieves. The data set must consist of ordinal scaled characters independent whether panel or raw kind. In contrast to other techniques no previous normalization of the data set is regarded.
The number of minimum DMUs is around twice or ternary the combined number of in- and outputs to calculate significant results (see Kao (2014), Golany and Roll (1989), Conference on New Uses of DEA in Management (1989)).

3.1.1 Orientation

For the choice of the suiting model it is important to know which data types can be used. Therefore there are three kinds of orientation in DEA: input-, output- or non-orientation. An input-oriented model has full influence on inputs and nearly no influence on outputs whereas output-oriented works vice versa.
The non oriented method has influence on both, inputs and outputs. To increase the efficiency a slack calculation is necessary.

3.2 Theoretical Model

The problem within this thesis is that it was planed as work about the usage of DEA as an efficiency measurement tool on a hospital IT case. Unfortunately this data wasn't available from our partners, so we changed the topic into a literature research about DEA, efficiency measurement for hospital IT services, an example case on self generated material and a guidance for later studies. Therefore we chose a simple model with DMUs, two in- and outputs.
In the following chapters we included this formulations. The Table 3.1 illustrates the assignment of data for the hospital IT service efficiency case.

Classical DEA Model	Hospital IT-Efficiency model
$DMUs$	IT-Departments
$Inputs$	Budget and Labour hours
$Outputs$	Revenue and quality

Table 3.1: Classical DEA model and its application in a Hospital IT-Efficiency Model

3.3 Constant Returns to Scale

The standard data envelopment analysis model is a constant return to scales model named after their inventors Charnes, Cooper and Rhodes as CCR model, but nowadays better known under CRS model.

The basic principle is efficiency as the ratio of weighted outputs to weighted inputs:

$$E_o = max\frac{\sum_{r=1}^{s} u_r Y_{ro}}{\sum_{i=1}^{m} v_i X_{io}} \tag{3.1}$$

subject to:

$$\tag{3.2}$$

$$\frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1 \qquad j = 1, ..., n, \tag{3.3}$$

$$\tag{3.4}$$

$$v_r, u_i \geq \epsilon; \qquad r = 1, ..., s, \quad i = 1, ..., m. \tag{3.5}$$

With Y_{rj}, X_{ij} as outputs and inputs for the jth DMU normally acquired through observation and with $u_r, v_i \geq \epsilon$ as the variable weights. Whereas 'o' is the actually calculated DMU. $\epsilon > 0$ "is a "small non-Archimedean" quantity" with a positive factor as restriction to provide that every character has impact (Banker et al. (1984)). For more information about weights see chapter 3.5

The next step is to linearize the non linear decision model to make it simpler calculable for computer.

Therefore we now obtain that the Efficiency is between 0 and 1 ($0 \leq E_o \leq 1$).
For every DEA model an Envelopment form and a Multiplier form is available and the transformation is simply said through converting the linear model into a dual model. But first the fractional program must be linearized:

obj(1):

$$\sum_{i=1}^{m} X_{oi} v_i = 1 \tag{3.6}$$

ct (2)

$$\frac{\sum_{r=1}^{s} Y_{jr} u_r}{\sum_{i=1}^{m} X_{ri} v_i} \leq 1 \qquad j = 1, .., n \tag{3.7}$$

$$\Rightarrow \sum_{r=1}^{s} Y_{jr} u_r \leq \sum_{i=1}^{m} X_{ji} v_i \qquad j = 1, .., n \tag{3.8}$$

$$\Rightarrow \sum_{r=1}^{s} Y_{jr} u_r - \sum_{i=1}^{m} X_{ji} v_i \leq 0 \qquad j = 1, .., n \tag{3.9}$$

Thus results the input oriented linear constant returns to scale decision model:

$$E_o = max \sum_{r=1}^{s} Y_{or} u_r \tag{3.10}$$

subject to:

$$ \tag{3.11} $$

$$\sum_{r=1}^{s} Y_{jr}u_r - \sum_{i=1}^{m} X_{ji}v_i \leq 0 \qquad j = 1, ..., n, \tag{3.12}$$

$$\sum_{i=1}^{m} X_{oi}v_i = 1 \tag{3.13}$$

$$ \tag{3.14} $$

$$v_r, u_i \geq \epsilon \qquad r = 1, ..., s, \qquad i = 1, ..., m. \tag{3.15}$$

The relative Efficiency of a DMU is the maximal ratio of optimal Input and achieved Input. The formula for measuring the relative efficiency of a specific DMU (see 3.12) is:

$$E_o = \max_{i=1}^{m}\{\frac{\tilde{X_{oi}}}{X_{oi}}\} = \gamma \tag{3.16}$$

To compare DMUs this calculation must be made for all DMUs. Efficient reference DMUs be judged:
Is the difference of calculation 3.12 zero, the DMU is efficient and the efficiency target are the inputs/outputs. Is there a difference in 3.12 then a shadow price for a input/output exists and the optimization proportions λ and reference DMUs have to be compute.

After this calculations the efficiency frontier is generated and inefficient DMUs can calculate their optimal solution trough composite reference DMUs (Benchmark-DMUs)

$$D\tilde{M}U = \sum_{j=1}^{n} \lambda_j DMU_j \tag{3.17}$$

This is used for output oriented models to calculate the reference DMUs. Used with an input oriented model its outputs are the former targets. For outputs it is due to output analysis :

$$u_r > \epsilon \Rightarrow \quad \tilde{Y_{or}} = \sum_{j=1}^{n} \lambda_j Y_{jr} = Y_{or} \quad r = 1, ..., s \tag{3.18}$$

$$u_r = \epsilon \Rightarrow \quad \tilde{Y_{or}} = \sum_{j=1}^{n} \lambda_j Y_{jr} > Y_{or} \quad r = 1, ..., s \tag{3.19}$$

Input analysis

$$v_i > \epsilon \Rightarrow \quad \tilde{X_{oi}} = \sum_{j=1}^{n} \lambda_j X_{ij} = \gamma X_{oi} \quad i = 1, ..., m \tag{3.20}$$

$$v_i = \epsilon \Rightarrow \quad \tilde{X_{oi}} = \sum_{j=1}^{n} \lambda_j X_{ij} < \gamma X_{oi} \quad i = 1, ..., m \tag{3.21}$$

According to Ozcan (2008) the RTS (returns to scale) factor of a DMU is the sum off all λ. If $\sum \lambda < 1.0$ the rates to return are increasing for this DMU whereas if $\sum \lambda > 1.0$ it is decreasing. "The efficient DMUs are considered as having constant returns to scale and so they have $\sum \lambda = 1.0$"(Ozcan (2008) p.47).

For the calculation of the output oriented CRS model, calculation of weights and slacks I reference to Ozcan (2008) page 38 pp.

3.3.1 CRS Modulation

For the creation of our example case we used the organigram of a university hospitals IT departments. The budget and return types should represent monetary values, labour hours the work summarized working hours of all IT employees and satisfaction is factor for external satisfaction with IT services. The numbers are loose without any connection to reality.

Kind	Input	Input	Output	Output
Divisions	Budget	Labour hours	Return	Satis-faction
IT-Service Center	500	40	700	300
Infrastructure Server and Networks	500	50	300	600
Cross-Sectional Services	400	50	200	700
Application: Research and Development	500	50	400	600
Application: Hospital Maintenance	400	40	500	400
Medical Documentation	500	50	500	500
Application: Administration	600	40	800	500
Other	400	30	300	200

Table 3.2: CRS Example Model

Out of the example table 3.2 in accordance to the CRS model formulation the formula for DMU 1 with all subjects was created in table 3.3. This calculation must be done for every DMU.

3.4 Variable Returns to Scale

The VRS model is based on Banker et al. (1984) where they extended the constant returns to scale model into the variable returns to scale model.
This modification was required by different sizes of DMUs in a set and consequential differentiating economies of scale which lead to incompatibilities. This happens when an in-/decrease in inputs isn't correlated with the same change in outputs.
This model integrates the scale differences into the CRS model through subtracting an unrestricted variable u_o in the objected function and constraint set (Kao (2014)).

Figure 3.1 illustrates the difference of a CRS (left) and a VRS (right) efficient frontier on a simple one input one output case. The Formula for the VRS input oriented

max	700 w1 +	300 w2					(obj: EFF(k))
$s.t.$							
	700 w1 +	300 w2	-500 v1	-40 v2		$\leq$0	(ct: EFF DMU 1)
	300 w1 +	600 w2	-500 v1	-50 v2		$\leq$0	(ct: EFF DMU 2)
	200 w1 +	700 w2	-400 v1	-50 v2		$\leq$0	(ct: EFF DMU 3)
	400 w1 +	600 w2	-500 v1	-50 v2		$\leq$0	(ct: EFF DMU 4)
	500 w1 +	400 w2	-400 v1	-40 v2		$\leq$0	(ct: EFF DMU 5)
	500 w1 +	500 w2	-500 v1	-50 v2		$\leq$0	(ct: EFF DMU 6)
	800 w1 +	500 w2	-600 v1	-40 v2		$\leq$0	(ct: EFF DMU 7)
	300 w1 +	200 w2	-400 v1	-30 v2		$\leq$0	(ct: EFF DMU 8)
			500 v1	40 v2		=1	(Norm inputs)
				w1		$\geq$ 0.0001	(non-negative w1)
				w2		$\geq$ 0.0001	(non-negative w2)
				v1		$\geq$ 0.0001	(non-negative v1)
				v2		$\geq$ 0.0001	(non-negative v2)

Table 3.3: CRS Formulation for DMU 1

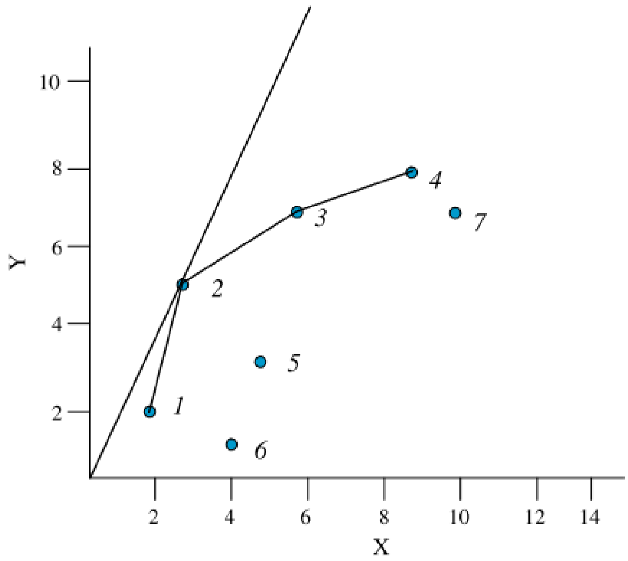

Figure 3.1: Comparision of a CRS Frontier and a VRS Frontier according to Cook and Seiford (2009)

model is in envelopment format

$$min \quad \theta - \epsilon(\sum_{i=1}^{m} s_i^+ + \sum_{r=1}^{s} s_r^+) \tag{3.22}$$

$$\sum_{j=1}^{n} \lambda_i X_{ij} + s_i^- = \theta X_{io} \qquad i = 1, ..., m \tag{3.23}$$

$$\sum_{j=1}^{n} \lambda_i Y_{rj} + s_r^+ = Y_{ro} \qquad r = 1, ..., s \tag{3.24}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \qquad j = 1, ..., n \tag{3.25}$$

$$\lambda_j \geq 0 \qquad j = 1, ..., n \tag{3.26}$$

The Efficient Targets for this VRS model are calculated for Inputs as follows:

$$\hat{Y_{ro}} = Y_{ro} + s_i^{+*} \qquad r = 1, ..., s \tag{3.27}$$

and for Outputs:

$$\hat{X_{io}} = \theta * X_{io} - s_i^{-*} \qquad i = 1, ..., m \tag{3.28}$$

An additional benefit by calculation of CRS and VRS model for a case is the simple computation of scale efficiency. Scale efficiency is the ratio of optimal CRS efficiency and optimal VRS efficiency.

$$\text{Scale Efficiency(SE)} = \frac{\theta^*_{CRS}}{\theta^*_{VRS}} \tag{3.29}$$

For the calculation of the output oriented VRS model, calculcation of weights and slacks I reference to Ozcan (2008) page 55 p.

3.5 Multiplier Models

According to Ozcan (2008) (pp.57) a multiplier model is the formulation of the envelopment model in linear form. Multiplier models have the advantage that every input and output can be weighted separately. The already known input- and output-weights v_i and u_r are optimal ones calculated by relative evaluation of all DMUs. That means this weights are the ones which maximize the efficiency of the focal DMU. This weightings can also be used for calculation of slacks of a DMU in types.

In the envelopment DEA models there was no differentiation weighting of inputs and outputs, but in reality an input as budget might be more important as training of employees. Therefore the multiplier model introduces a new form of rating characters. The task of assessing weights is important and should be done sensibly and with broad knowledge of the matter. It must be considered that no DMU can outweight itself to efficiency. Statistical data as quartiles or median can assist as an informative basis before setting this boundaries.

Another benefit is, that trough setting upper $U_{i,k}$ or lower $L_{i,k}$ bounds a minimum/-maximum usage of inputs/outputs can be defined. Likewise also data sets can be filtered this way by stating cone-ratios for input to output proportions called styles defined by upper and lower bounds:

For inputs:

$$L_{ik} \leq \frac{v_i}{v_k} \leq U_{ik} \qquad i = 1, ..., m \tag{3.30}$$

For outputs:

$$L_{rz} \leq \frac{u_i}{u_z} \leq U_{rz} \qquad r = 1, ..., s \tag{3.31}$$

3.6 Non-oriented Model

The non-oriented DEA model is as the name implies neither input nor output oriented. It is used for applications where both factors can be influenced at once. The efficient targets are for this purpose calculated by the slacks.

$$max \quad \sum_{i=1}^{m} w_i^- s_i^- + \sum_{r=1}^{s} w_r^+ s_r^+ \tag{3.32}$$

$$\sum_{j=1}^{n} \lambda_j X_{ij} + s_i^- = X_{io} \qquad i = 1, ..., m \tag{3.33}$$

$$\sum_{j=1}^{n} \lambda_j Y_{rj} + s_r^+ = Y_{ro} \qquad r = 1, ..., s \tag{3.34}$$

$$\lambda_j, s_i^-, s_r^+ \geq 0 \qquad j = 1, ..., n \tag{3.35}$$

For the usage of variable returns to scale this equation must be added:

$$\sum_{j=1}^{n} \lambda_j = 1 \qquad j = 1, ..., n \tag{3.36}$$

3.7 Network DEA

Kao (2014) means it is necessary to understand the production process of a DMU and internal correlations to evaluate a performances measurement. Therefore it arguments trough the two-stages banking example from Wang et al. (1997) (see 3.7) were the convectional black box view has clouded the direct link between IT investments and total performance. Constructive of this problem settings the general network DEA was developed by Färe and Grosskopf (2000).

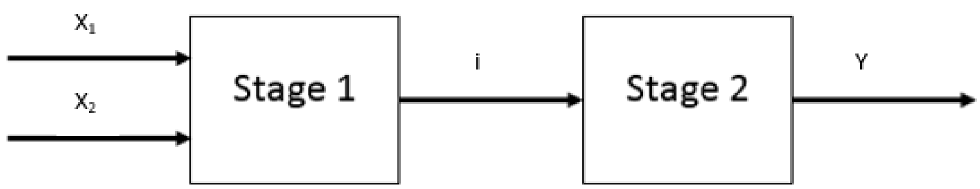

Figure 3.2: Two-stage production process according to Wang et al. (1997)

The model is based on the general CRS model of Charnes et al. (1978). In a network DEA analysis, with its white box view, every DMU is divided into many subprocesses which cooperate. Every input can be used by all processes and every output can be either input of a intermediate process or a final output.
Additionally to the known input X and output Y a new variable Z is created as subprocess. The inputs and outputs get splitted on several inputs $X^{(k)}$ and $Y^{(k)}$ for

different stages. An example is in Figure 3.2 where the two external inputs X_1, X_2 in stage 1 get transformed into the intermediate output i, which is also intermediate input for stage 2 where it gets transformed in external output Y.

An overall system can be efficient even when all subprocesses are inefficient. Also in two stages process a DMU 1 with stage 1 efficiency lower than DMU 2 and both with efficiency stage 2 can be overall more efficient (Kao and Hwang (2010)). Due to their different advantages, disadvantages and application both models for network data envelopment analysis as envelopment and multiplier model are mentioned (for more details see Kao (2014)).
Envelopment model:

$$\min \theta \tag{3.37}$$

$$s.t. \tag{3.38}$$

$$\sum_{j=1}^{n} \lambda_j^{(k)} X_{ij}^{(k)} + s_i^{-(k)} = \theta X_{io}^{(k)}, \qquad i \in I^{(k)}, \qquad k = 1, ..., p \tag{3.39}$$

$$\sum_{j=1}^{n} \lambda_j^{(k)} Y_{rj}^{(k)} - s_i^{+((k))} = Y_{ro}^{(k)}, \qquad r \in O^{(k)}, \qquad k = 1, ..., p \tag{3.40}$$

$$\sum_{j=1}^{n} \lambda_j^{(k)} Z_{fj}^{(k)} + s_f^{o((k))} = Z_{fo}^{(k)}, \qquad f \in M^{(k)}, \qquad k = 1, ..., p \tag{3.41}$$

$$\sum_{j=1}^{n} \lambda_j^{(k)} Z_{gj}^{(k)} - s_g^{o(k)} = Z_{go}^{(k)}, \qquad g \in N^{(k)}, \qquad k = 1, ..., p \tag{3.42}$$

$$s_i^{-(k)}, s_r^{+(k)}, s_f^{o(k)}, s_g^{o(k)}, \lambda_j^{(k)} \geq 0, \tag{3.43}$$

$$i \in I^{(k)}, r \in O^{(k)}, f \in M^{(k)}, g \in N^{(k)}, \quad j = 1, ..., n, \qquad k = 1, ..., p; \tag{3.44}$$

Please note that the non archimedean number ϵ is left out for simplicity. Additional to the envelopment formulation also the formulation of the multiplier form is suiting. This is simplified the same as the envelopment model linearized.

Multiplier Model:

$$E_o^s = \qquad \max \frac{\sum_{r=1}^{s} u_r Y_{ro}}{\sum_{i=1}^{m} v_i X_{io}} \tag{3.45}$$

$$s.t. \sum_{r \in O^k 1}^{s} u_r^{(k)} Y_{rj}^{(k)} + \sum_{g \in N^{(k)}} \hat{w_g^{(k)}} Z_{gj}^{(k)} - \sum_{i \in I^{(k)}} v_i^{(k)} X_{ij}^{(k)} \tag{3.46}$$

$$- \sum_{f \in M^{(k)}} w_f^{(k)} Z_{fj}^{(k)} \leq 0 \qquad j = 1, ..., n, k = 1, ..., p \tag{3.47}$$

$$u_r^{(k)}, v_i^{(k)}, w_f^{(k)}, \hat{w_g^{(k)}} \geq 0, \tag{3.48}$$

$$r \in O^{(k)}, i \in I^{(k)}, f \in M^{(k)}, g \in N^{(k)}, k = 1, ..., p \tag{3.49}$$

For calculating the efficiency of one network DEA DMU the formula is:

$$E_O^{(k)} = (\sum_{r \in O^{(k)}} u_r^{(k)} Y_{rO}^{(k)} + \sum_{g \in N^{(k)}} \hat{w_g^{(k)}} Z_{gO}^{(k)}) / (\sum_{i \in I^{(k)}} v_i^{(k)} X_{iO}^{(k)} + \sum_{f \in M^{(k)}} w_f^{(k)} Z_{fO}^{(k)}) \quad (3.50)$$

The here mentioned formulae are the basis for advanced network structures as parallel, series or mixed structure and have to be adapted on the specific structure.

3.8 Malmquist Index

The malmquist index is a tool to compare DMUs over several time periods. It is based on the principal work of Malmquist (1953) and adapted by Fare et al. (1994) on data envelopment analysis. The "malmquist efficiency is defined as geometric mean of efficiency scores" (Ozcan (2008)):

$$M_0 = [\frac{\theta_0^t(X_0^t Y_0^t)}{\theta_0^t(X_0^{t+1} Y_0^{t+1})} \frac{\theta_0^{t+1}(X_0^t Y_0^t)}{\theta_0^{t+1}(X_0^{t+1} Y_0^{t+1})}]^{\frac{1}{2}} \quad (3.51)$$

With M_0 as efficiency change between the actual(t) and the next period(t+1). Furthermore the efficiency change can be separated into the technical efficiency and technology changes. Therefore M_0 gets mathematically divided into:

$$M_0 = \underbrace{\frac{\theta_0^t(X_0^t Y_0^t)}{\theta_0^{t+1}(X_0^{t+1} Y_0^{t+1})}}_{\text{technical efficiency}} * \underbrace{[\frac{\theta_0^{t+1}(X_0^{t+1} Y_0^{t+1})}{\theta_0^t(X_0^{t+1} Y_0^{t+1})} * \frac{\theta_0^{t+1}(X_0^t Y_0^t)}{\theta_0^t(X_0^t Y_0^t)}]^{\frac{1}{2}}}_{\text{technology change}} \quad (3.52)$$

A problem is that always only two periods can be compared a time. The benefit of longitudinal evaluation of DMUs is the illustration of overall changes of a DMU as well as technology and technical efficiency.

3.9 Problematics

3.9.1 System Status

For the integration of the actual system status regarding hardware and software actuality and expandability no appropriate key data character was found. For theoretical inclusion concepts see chapter 4.2.

3.9.2 Quality Measurements

The assessment of quality as an output score in DEA applications is feasible. Therefore quality outputs can be used as additional outputs and as independent outputs. For more information and for possible problematics see chapter 2.4.1.

3.9.3 Advanced Data Analysis

For further data analysis there are two main ways. On the one hand it is the ranking of DMUs, on the other hand it is the data correlation and grouping of DMUs.

The topic of advanced evaluation of DEA internal rankings is given through the fact that there is no determination between efficient DMUs. For this problematic the paper of Friedman and Sinuany-Stern (1998) provides a combined ranking method based on the standard methods of canonical correlation analysis, discriminant analysis of ratios and cross efficiency matrix. Another insight in the ranking of DMUs is in the review of Adler et al. (2002) where several other methods are detailed illustrated.

Another advanced data analysis is the correlations analysis. This technique is used internal for grouping of DMUs dependent on similar inputs and outputs for better application of optimization guidance as described in Golany (1996). The other usage is the correlation analysis for DEA results to not included data as in for example in Watcharasriroj and Tang (2004) for the correlation of size and IT investments. For both tests the non-parametrical Mann-Whitney ranks statics or regression models as e.g. Tobit regression can be used.

4 Results

The results chapter is divided into a calculation analysis section where the example model gets interpreted for the input oriented CRS and VRS model as well as for the non-oriented CRS model. The second part is dedicated for the approaches for establishing the data envelopment analysis in hospital IT services.

4.1 Calculation Analysis

Our former introduced example model (chapter 3.3.1) was calculated using DEAFrontier for Excel from Professor Joe Zhu.

4.1.1 CRS Example Model

In this chapter we analyse the CRS example model 3.2 .
Therefore the linear model was calculated for every focal DMU as in table 3.3 illustrated for DMU1.
The result analysis are:

DMU No.	DMU Name	Input-Oriented CRS Efficiency	Σλ	RTS	Benchmarks		
1	DMU 1	1,00000	1,000	Constant	1,000 DMU 1		
2	DMU 2	0,87391	0,913	Increasing	0,717 DMU 3	0,196 DMU 7	
3	DMU 3	1,00000	1,000	Constant	1,000 DMU 3		
4	DMU 4	0,90213	0,979	Increasing	0,596 DMU 3	0,085 DMU 5	0,298 DMU 7
5	DMU 5	1,00000	1,000	Constant	1,000 DMU 5		
6	DMU 6	0,89362	1,064	Decreasing	0,213 DMU 3	0,745 DMU 5	0,106 DMU 7
7	DMU 7	1,00000	1,000	Constant	1,000 DMU 7		
8	DMU 8	0,57143	0,429	Increasing	0,143 DMU 5	0,286 DMU 7	

Figure 4.1: Efficiency of the CRS Example Model

The DMUs 1, 3, 5 and 7 are efficient, due an efficiency score of 1, whereas DMUs 2, 4, 6 and 8 are inefficient.
The efficient targets were calculated by formula 3.17. This optimal lambda represents the factor the focal should move into the direction of the mentioned DMU. For example DMU 2 should head to DMU 3 with Factor 0.717 and with 0.196 to DMU 7.
The column RTS, for returns to scale, describes the differences in economies for inputs and outputs. This means for a constant RTS ($\lambda = 0$) as in DMU 1 when all

inputs increase a level, all outputs will increase in the same level. For in/decreasing DMUs ($\lambda \neq 0$) the changes in inputs and outputs are proportional with the factor sum of lambda, for example 0.913 for DMU 2.

DMU No.	DMU Name	Efficient Input Target Labour hours	Budget	Efficient Output Target Value returned	Satisfactionfactor
1	DMU 1	40,00000	500,00000	700,00000	300,00000
2	DMU 2	43,69565	404,34783	300,00000	600,00000
3	DMU 3	50,00000	400,00000	200,00000	700,00000
4	DMU 4	45,10638	451,06383	400,00000	600,00000
5	DMU 5	40,00000	400,00000	500,00000	400,00000
6	DMU 6	44,68085	446,80851	500,00000	500,00000
7	DMU 7	40,00000	600,00000	800,00000	500,00000
8	DMU 8	17,14286	228,57143	300,00000	200,00000

Figure 4.2: Targets of the CRS Example Model

The targets for inputs and outputs are calculated over the formulae 3.20-3.23 for the multiplier model or for the envelopment form in 3.29 and 3.30. For efficient DMUs the targets stay similar while inefficient reduce their inputs.

The multiplier model output additionally presents the calculated multiplier for each DMU. Please consider, that this examples was without a "small non-archimedean" quantity, so that some inputs were ignored. The review of slacks is leaved here because of their minor importance in input oriented models.

DMU No.	DMU Name	Input-Oriented CRS Efficiency	Optimal Multipliers Labour hours	Budget	Value returned	Satisfactionfactor
1	DMU 1	1,00000	0,00000	0,00200	0,00143	0,00000
2	DMU 2	0,87391	0,02000	0,00000	0,00013	0,00139
3	DMU 3	1,00000	0,00000	0,00250	0,00000	0,00143
4	DMU 4	0,90213	0,00255	0,00174	0,00085	0,00094
5	DMU 5	1,00000	0,00000	0,00250	0,00143	0,00071
6	DMU 6	0,89362	0,00255	0,00174	0,00085	0,00094
7	DMU 7	1,00000	0,00000	0,00167	0,00106	0,00030
8	DMU 8	0,57143	0,00000	0,00250	0,00143	0,00071

Figure 4.3: Multiplier of the CRS Example Model

4.1.2 VRS Example model

The calculation of efficiency is based on the model done as in 3.20-3.23 for the multiplier model or for the envelopment form in 3.29 and 3.30. Based on the inclusion of scale economies the VRS example model has a change in efficient DMUs. The former efficient always stay equal and additionally an inefficient can change as DMU 8 did in this case.

The inclusion of that DMU changes the efficiency frontier. Imagine CRS as a strict linear function with fixed incline for the hole Cartesian coordinates system whereas in VRS the incline is changing for stages with similar scale economics. For a graphical presentation see figure 3.1. Certainly this is just a simplification for illustrating the topic. In a multi-attributes DEA the frontier is a multidimensional frontier.

Through this scale efficiency the frontier approaches heading the DMUs. Therefore the input targets are higher and inefficiency in attributes decreases.

DMU No.	DMU Name	Input-Oriented VRS Efficiency	Benchmarks							
1	DMU 1	1,00000	1,000	DMU 1						
2	DMU 2	0,90909	0,636	DMU 3	0,273	DMU 7	0,091	DMU 8		
3	DMU 3	1,00000	1,000	DMU 3						
4	DMU 4	0,91250	0,594	DMU 3	0,094	DMU 5	0,281	DMU 7	0,031	DMU 8
5	DMU 5	1,00000	1,000	DMU 5						
6	DMU 6	0,90000	0,250	DMU 3	0,500	DMU 5	0,250	DMU 7		
7	DMU 7	1,00000	1,000	DMU 7						
8	DMU 8	1,00000	1,000	DMU 8						

Figure 4.4: Efficiency of the VRS Example Model

Comparing the numbers of the efficient input targets of the CRS and the VRS model a significant influence in scales is proved for this example case.

		Efficient Input Target		Efficient Output Target	
DMU No.	DMU Name	Labour hours	Budget	Value returned	Satisfactionfactor
1	DMU 1	40,00000	500,00000	700,00000	300,00000
2	DMU 2	45,45455	454,54545	372,72727	600,00000
3	DMU 3	50,00000	400,00000	200,00000	700,00000
4	DMU 4	45,62500	456,25000	400,00000	600,00000
5	DMU 5	40,00000	400,00000	500,00000	400,00000
6	DMU 6	42,50000	450,00000	500,00000	500,00000
7	DMU 7	40,00000	600,00000	800,00000	500,00000
8	DMU 8	30,00000	400,00000	300,00000	200,00000

Figure 4.5: Targets of the VRS Example Model

DMU No.	DMU Name	Input-Oriented VRS Efficiency	Optimal Multipliers Labour hours	Budget	Value returned	Satisfactionfactor	Free Variable	Returns to Scale
1	DMU 1	1,00000	0,00000	0,00200	0,00143	0,00000	0,00000	Constant
2	DMU 2	0,90909	0,01818	0,00018	0,00000	0,00073	0,47273	Increasing
3	DMU 3	1,00000	0,00000	0,00250	0,00000	0,00143	0,00000	Constant
4	DMU 4	0,91250	0,01500	0,00050	0,00013	0,00063	0,48750	Increasing
5	DMU 5	1,00000	0,00000	0,00250	0,00143	0,00071	0,00000	Constant
6	DMU 6	0,90000	0,00000	0,00200	0,00100	0,00100	-0,10000	Decreasing
7	DMU 7	1,00000	0,00000	0,00167	0,00106	0,00030	0,00000	Constant
8	DMU 8	1,00000	0,00000	0,00250	0,00000	0,00000	1,00000	Increasing

Figure 4.6: Multiplier of the VRS Example Model

4.1.3 Non-oriented CRS Example Model

The non-oriented CRS example is a special case because the targets can‘t be calculated as before through summarizing $\lambda * DMU$ as in oriented models. Therefore the calculation of slacks is essential for non-oriented models. The efficient targets have to be calculated by adding the slacks to the inputs.

		Efficient Input Target		Efficient Output Target	
DMU No.	DMU Name	Labour hours	Budget	Value returned	Satisfactionfactor
1	DMU 1	40,00000	500,00000	700,00000	300,00000
2	DMU 2	50,00000	500,00000	515,00000	600,00000
3	DMU 3	50,00000	400,00000	200,00000	700,00000
4	DMU 4	50,00000	500,00000	515,00000	600,00000
5	DMU 5	40,00000	400,00000	500,00000	400,00000
6	DMU 6	50,00000	500,00000	625,00000	500,00000
7	DMU 7	40,00000	600,00000	800,00000	500,00000
8	DMU 8	30,00000	400,00000	525,00000	350,00000

Figure 4.7: Efficiency of the Non-oriented Model

4.2 Further Approaches

To adopt data envelopment analysis to a real Hospital IT services case some uncertainties must be established. This approach expresses the results I got by my literature research and the example model.

4.2.1 Model Determination

Due to the mass of different DEA models, we only slightly broached in the former section, it is difficult so select a specific model, therefore I will give approaches.

The orientation of a data envelopment analysis is depending on the influence of the DMU.

Normally a CIO or IT manager is responsible for the efficiency evaluation. I assume the outputs of IT services are fixed because in hospitals the level of functionality and reliability must be secured due to higher (life-)risk applications. For computers in operations rooms or life sustaining support systems e.g. a reduction in services like maintenance is irresponsible.

Therefore I suggest a input-oriented DEA model would suit best. Of course in some hospitals, with higher influence of the IT responsible manager, a non-oriented model could also work, but the influence on guaranteed IT services has to be monitored strictly.

The kind of DEA model is depending on the desired outcome of the evaluation. A conventional DEA model would fit for just calculating the overall efficiency of an

CRS Results		Input Slacks		Output Slacks		Sum of	RTS	Optimal Lambdas					
DMU No.	DMU Name	Labour hours	Budget	Value returned	Satisfactionfactor	lambdas		with Benchmarks					
1	DMU 1	0,00000	0,00000	0,00000	0,00000	1,00000	Constant	1,000	DMU 1				
2	DMU 2	0,00000	0,00000	215,00000	0,00000	1,15000	Decreasing	0,400	DMU 3	0,550	DMU 5	0,200	DMU 7
3	DMU 3	0,00000	0,00000	0,00000	0,00000	1,00000	Constant	1,000	DMU 3				
4	DMU 4	0,00000	0,00000	115,00000	0,00000	1,15000	Decreasing	0,400	DMU 3	0,550	DMU 5	0,200	DMU 7
5	DMU 5	0,00000	0,00000	0,00000	0,00000	1,00000	Constant	1,000	DMU 5				
6	DMU 6	0,00000	0,00000	125,00000	0,00000	1,25000	Decreasing	1,250	DMU 5				
7	DMU 7	0,00000	0,00000	0,00000	0,00000	1,00000	Constant	1,000	DMU 7				
8	DMU 8	0,00000	0,00000	225,00000	150,00000	0,75000	Increasing	0,250	DMU 5	0,500	DMU 7		

Figure 4.8: Slacks of the Non-oriented Model

IT department, but the results would only inadequately pattern optimization ways and especially internal processes with their efficiencies would be ignored.
Therefore I would suggest to establish a network DEA model for the systems adoption. Based on the commonalities of both data sets also a first introduction of a convectional and the future expansion is possible through similar external inputs and outputs.
The inputs are easily determined and multiple studies give guidance (e.g. Ross and Ernstberger (2006)). Concluding with most studies financial budget and working hours are essential.
As approximate value for the system status we need a calculated value with assessment of IT hardware, IT software, their interaction and their dimension based on actuality, extensibility, efficiency and functionality. In my research I could not find a suiting performance figure. As long as there is no such value I suggest orientation on the model of Beard and Elo (2007) of rating IT investment. Alternatively and more simply would be a directly concentration on IT write offs. For both scale efficiencies will most likely arise and have to be observed.
The biggest problematic of evaluation of IT services are the required output factors. An important question there is what is the benefit of IT and how to measure it. Former they simply analysed the time savings with information systems and weighted them monetary. This method isn't applicable nowadays and even if used, no more realistic.

In addition how could measurements as usability, efficiency and reliability be included? Furthermore we can just calculate with accounting data and slightly subjective quality factors. Therefore the used internal accounting system should allocate data. Alternative optimal would be a system like case-mix points or DRGs including the IT utilization in the complete case alike Ozcan (2008) as an percentage share.

Additionally one ore two factors of quality respective performance and overall satisfaction would suit to involve non-functional objectives.
The kind of used data as raw or panel is thanks to DEA relatively regardless.

For longitudinal comparisons the malmquist index comparison and for internal grouping a Mann-Whitney-Test would match.

5 Conclusion

The main problem of this thesis was the lack of data. All approaches are made therefore on literature and the example case. The portability to a real case seems realistic but is not guaranteed.

Using a motivating example, I demonstrated that DEA can be employed to measure efficiency of IT divisions in hospitals. Through application of a input oriented network DEA model not only total efficiency could be measured, but also efficiency and economies of subprocesses could be evaluated. This deep going evaluation could affect the IT efficiency on operational level through usage as practical optimization guidance. It must be debated if measurements on this level are useful or to detailed.

The overall problem which is creating the data input problematic is the lack in IT services efficiency measurements. A lot of studies focus on the firm/hospital performance improvements through IT, but no one on the departments own efficiency. Therefore this output framework was completely new generated.

Another problem is the selection of proper data characters. The input factors are easy to establish logically and on proof trough many applications. The problematic factors are the outputs. For a significant, global and comparable evaluation aspects as the actuality of a system, the real benefit and nonfunctional/quality conditions should be taken into account. Therefore no suiting measurements were found. Additionally the approaches of results section could not been tested yet.

The aspect of quality and technical efficiency analysis via DEA is always linked to the threats of trade-offs. For the hospital sector quite positive examples where found but are this results also generalizable to the IT sector? Can a quality measurement directly and independently be integrated in the outputs? And is there a positive correlation between technical and qualitative efficiency? Are this aspects positively influencing overall efficiency?

Another critical question is whether this data is available in similar or related kind in medical controlling?

This problematics should be addressed before or at least while implementing this data envelopment analysis model into hospital IT services as efficiency measurement and optimization tool.

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Appendix

DMU No.	DMU Name	Input Slacks Labour hours	 Budget	Output Slacks Value returned	 Satisfactionfactor
1	DMU 1	0,00000	0,00000	0,00000	0,00000
2	DMU 2	0,00000	32,60870	0,00000	0,00000
3	DMU 3	0,00000	0,00000	0,00000	0,00000
4	DMU 4	0,00000	0,00000	0,00000	0,00000
5	DMU 5	0,00000	0,00000	0,00000	0,00000
6	DMU 6	0,00000	0,00000	0,00000	0,00000
7	DMU 7	0,00000	0,00000	0,00000	0,00000
8	DMU 8	0,00000	0,00000	0,00000	0,00000

Figure 5.1: Slacks of the CRS Example Model

DMU No.	DMU Name	Input Slacks Labour hours	 Budget	Output Slacks Value returned	 Satisfactionfactor
1	DMU 1	0,00000	0,00000	0,00000	0,00000
2	DMU 2	0,00000	0,00000	72,72727	0,00000
3	DMU 3	0,00000	0,00000	0,00000	0,00000
4	DMU 4	0,00000	0,00000	0,00000	0,00000
5	DMU 5	0,00000	0,00000	0,00000	0,00000
6	DMU 6	2,50000	0,00000	0,00000	0,00000
7	DMU 7	0,00000	0,00000	0,00000	0,00000
8	DMU 8	0,00000	0,00000	0,00000	0,00000

Figure 5.2: Slacks of the VRS Example Model

Ehrenwörtliche Erklärung

Ich erkläre hiermit ehrenwörtlich, dass ich die vorliegende Arbeit selbständig angefertigt habe. Die aus fremden Quellen direkt und indirekt übernommenen Gedanken sind als solche kenntlich gemacht.

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Ort, Datum

Unterschrift