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Business Administration

Total Factor Productivity Change and Reforms of Managed Inpatient Flow at Landspitali University Hospital

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Abstract

The aim of this dissertation is to measure changes in Total Factor Productivity (TFP) and examine possible causes of such changes following reforms of managed inpatient flow at Landspítali - University Hospital (LUH) in Iceland. The change in TFP is measured as the difference in TFP that occurs within two periods of time, specifically January to March 2007 and January to March 2009. The motivation behind this study is to measure the changes in TFP, as it is a meaningful yardstick by which to measure economic changes surrounding hospital activity.

The research method used is a combination of Data Envelopment Analysis and the Malmquist Index methods (DEA-MI). These methods are used for comparing the TFP of five selected wards between two different periods, i.e., the period of January to March 2007 and the period of January to March 2009.

From an economical perspective, after the implementation of the reforms, the findings reveal that there is an average of approximately 3% decreased TFP in inpatient flow at LUH's wards under examination between the periods of January - March 2007 and January - March 2009. The cause of TFP changes measured by the variables used, Working-Load-Index and Lay Days, is not completely distinguishable, i.e., whether the cause of the decreasing TFP is caused by changes in scale efficiency or technical changes. The main conclusion drawn from this work is that TFP decreased slightly or at least was unchanged following the inpatient-managed reform when calculating the change in TFP through the DEA-MI method.

The main recommendation, from both theoretical and practical viewpoints, is to take advantage of the reliability of the DEA-MI method to measure the TFP change between wards, specializing in various medical areas, within the same hospital. In addition, Hospital managers can benefit from utilizing and elaborating on appropriate and improved methods to measure their success.

Keywords: Hospital Ward Efficiency, Total Factor Productivity, Malmquist Index, Data Envelopment Analysis.

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This dissertation is dedicated to my wife,

Erla Kristbjörg Sigurgeirsdóttir

Author's Declaration

I declare that this dissertation is original except where indicated by special reference in the text and no part of the dissertation has been submitted towards any other degree.

Any views expressed in the dissertation are those of the author and in no way represent those of the University of Iceland. The dissertation has not been presented to any other University for examination either in Iceland or overseas. References to work of other authors are included at the end of this dissertation.

SIGNED: Guðmundur Þ. Bergsson ______________________________

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List of Abbreviations

ALOS	Average Length of Stay
CRS	Constant Return to Scale
DEA	Data Envelopment Analysis
DEA-MI	Data Envelopment Analysis with Malmquist Index
DMU	Decision-Making-Unit
DRG	Diagnosis Related Group
FTE	Full-Time Equivalent Unit
IO	Input Orientation
LD	Lay Day
LUH	Landspitali – University Hospital
MI	Malmquist-Index
NLI	Nursing-Load-Index
OO	Output Orientation
RN	Registered Nurse
TFP	Total Factor Productivity
VRS	Variable Return to Scale
WLI	Work-Load-Index
$\mathbf{2007}_{\text{January - March}}$	January to March 2007
$\mathbf{2009}_{\text{January - March}}$	January to March 2007

1 Introduction

Through examination of economic statistical and analysis data for public expenditure from Statistic Iceland (Hagstofa Íslands) it is revealed that the Icelandic health care system has more than quadrupled between 1945 and 2008 when measured as a percentage of the Gross National Product. There are several fundamental reasons for this increase, predominantly the rise in costs due to medical and technological innovations over that period, in combination with increased demands from the public for "proper" health care services, meaning adequate access to required services as quickly as possible. This matter is of particular importance for the voting public of Iceland because the Icelandic state government pays major fraction of the cost of health care sector services (either directly from the state treasury or indirectly from the state treasury via Icelandic Health Insurance). However, growing demands for these services run the risk of exceeding the fixed budget set forth by the state. In other words, although this budget may increase marginally over time, that increase may not be enough to equal the increase in demands. Therefore, without examining this matter further and determining contingency measures, there is a significant risk of complications at the operational level of health care institutions that find their financial conditions inadequate and unable to meet the public's demand for services.

1.1 Background

Growing demands for health care products and services over the past six decades have placed considerable financial and organizational strain on the Icelandic health care institutions, requiring many of them to reassess their internal operations. One such institution is Landspítali - University Hospital (LUH), whose deficit spending over the past several years exemplifies the problem. Because of the hospital's increasing financial strains, over the years the management of LUH has attempted to sort out inefficiencies in its supply of services. To this end, the managers have posed critical questions about the hospital's operations and have determined several key areas requiring reforms.

The inefficient management of inpatient flow was one of the main operational problems recognised by managers at LUH. Þorvarðardóttir et al. (2009, pp. 5, 21) informs that in November 2005, the Manager of Hospitalization at LUH reported on the need for better organisation and management of inpatient flow to the Board of

Directors. The Board responded in December 2005 by forming a task force to analyse the hospital's handling of inpatient flow and determine ways to increase its efficiency[1]. The task force detected bottlenecks in the hospital's processing of patients such as delays in discharging patients from inpatient wards and overflows of its wards. Shortages of available beds had inpatients placed in hallways and in other improper wards, which resulted in increased reports of stress amongst hospital personnel. For that reason, in October 2006, the task force proposed 21 items to improve patient flow within the hospital with the focus placed on the wards' activities and working processes. Based on these proposals, in December 2006, LUH's Board of Directors established a Project Management Committee to implement processes to improve the efficiency of inpatient flow. The committee's primary purpose was to improve the performance and the quality of the hospital's services by ensuring that inpatients have adequate access to the appropriate services within required timeframes. At that time, they recommended that hospitalization and discharge procedures should be coordinated, with the main objective being to minimise patients' wait times and maximise the overall inpatient flow.

In their report, entitled *Managed Patient Flow at LUH - Report of Project Management Committee* (2009), the committee presents its recommendations for improving inpatient flow in LUH and explains how the management of the inpatient flow changed gradually between the years 2007 and 2008. In their report, the committee also outlined the following standards for measuring the results of the managed patient flow: patients' average lengths of stay (ALOS) within each ward, the time of discharge (by date and hour), the length of patient wait times in the Emergency Room prior to hospitalization, and the number of patients waiting for services within the hospital. Additionally, they continued to monitor the amount of patient overflow in each ward and the number of patients that were required to stay in improper wards.

In their report, the committee concluded that the implementation of the managed patient flow yielded positive results. The committee's conclusion was based on the

[1] The terms Efficiency and Total Factor Productivity are used interchangeably in this chapter. Distinction between them is elaborated in the Literature Review.

measurement of ALOS in selected wards, statistical measurements, as well as inferences. Furthermore, the committee suggested that the next step would be to develop improved performance measurements for managed patient flow. The yardsticks proposed were: ALOS within wards, ratio of inpatients discharged before 1:00 pm, ALOS by Diagnostic Related Groups (DRGs), available capacity for elective surgeries, waiting lists within LUH, and the flow of patients from the hospital.

However, the shortcoming in the committee's methods is that none of their recommendations for measuring patient flow are related to scales where the evaluation of efficiency, quality, and the like, are examined. Essentially, the committee is only taking into account how expediently patients move through the health care system. However, without measuring for other important factors, such as whether proper treatment was received, patients may be returning to the hospital at higher rates which, in turn, increases financial strains. The lack of such scales is criticised in this dissertation, because there is little that can be concluded and, subsequently, gained by measuring with a single yardstick such as ALOS. Without relating this to measurements that have economic implications or, rather, some substantial meaning for decision makers or patients (e.g., some relation to a definition of efficiency, patient satisfaction, or other such benchmarks) the committee's conclusion ultimately serves limited purpose. In other words, measurement standards such as ALOS, patient's discharge time, and so on, are mere components of more complex measurements involving efficiency, patient satisfaction, job satisfaction, and/or the quality of the services.

In order to examine the committee's positive results on managed inpatient flow, on a broader and more meaningful scale, this research suggests that the efficiency change of LUH's inpatient flow be measured using certain criteria. In simple terms, efficiency is defined as the level of effectiveness a hospital displays in completing its intended purposes (e.g., treatment of the ill in a timely manner, employing competent staff, etc.). A more complex description of efficiency incorporates several other areas such as patient satisfaction and technological capabilities. By measuring efficiency change, more substantial, extensive, and, therefore, applicable results are yielded. Consequently, LUH's decision makers are given better data on which to draw conclusions regarding any improvement in inpatient flow and, subsequently, the probability of appropriate reactions increases. This suggestion is supported by Hurst and Kelley (2006, p. 13) who state that quality in health care services and efficiency are directly linked; efficiency within the health care system has been one of the most commonly used standards as a performance/quality indicator. Furthermore, Övretveit defined quality in health care as “fully meeting the needs of those who need the service most, at the lowest cost to the organisation, within limits and directives set by higher authorities” (Helminen, 2000, p. 9). Thus, according to these authors, by measuring changes in the efficiency of health care services provided, one may also obtain an indication of the change of quality over time, which is in itself a valid justification for measuring efficiency change. This implication, by itself, also provides an opportunity to draw the importance of patients’ interests into the discussion regarding improvements in LUH’s inpatient flow.

As noted above, including a measurement of efficiency change is a way to expand the assessment of the effectiveness of LUH’s reforms on the inpatient flow and the quality of services that the patient receives from the hospital. In addition, a measurement of the efficiency change, in turn, effects and is effected by the management of LUH’s employees, which must also be factored into the assessment. The reason for this is that the production and consumption of health care goods are characterised by market failures and principal-agent problems. Hospitals and their degrees of efficiency are influenced by said characteristics, which affect the overall organisational behaviour of hospitals. Professionals working within a hospital are agents for both the principals/payers of medical costs and the patients. However, a hospital’s staff interacts more closely on a daily basis with the patients than with those principals/payers who have the financial interests. This can create a conflict of interest where the patients’ demands and expectations, due to closer proximity with the working professionals, override the demands of the principals/payers. In this way, health care institutions are like political battlefields. This interpretation is supported by Breyer and Zweifel (1997, p. 285) who described hospitals as social institutions that include different groups of agents with diverged interests. The hospitals’ objective functions are described as compromises between varying interests of the agents, and the result is that quality of treatment, excess revenue, as well as slack inputs, are positively valued.

Furthermore, the risk ‘appetite’ of the agents matters significantly. Douma and Schreuder (1998, p. 122) explained that, only if the agent is risk-averse, the agent’s reward structure (salary combination) should be based on measured performance. However, if the agent is risk-neutral then the principal should allow the agent to accept all of the risk of his performance based upon contract (then the agent is a contractor). It is challenging to support the claim that the employees of LUH's wards are risk-neutral. All of the employees in the wards of LUH are paid by salary combination (i.e., wage earners), therefore, it follows that the principals should examine dimensions of labour performance, in order to monitor the performance of the employees.

1.2 Research Focus and Research Objectives

As discussed previously, there are several reasons to include changes in efficiency in an assessment of the results the committee obtained for managed patient flow, a significant one being to obtain a more extensive and more meaningful scale with which to measure the actual positive results of LUH's reforms in inpatient flow. In order to accomplish this task, the first step is to define the scope for the proposed measurement of the efficiency change. In order to do this, the hospital systems and processes must first be examined. The Figure 1 below illustrates the processing of inpatients through the hospital from entry to discharge:

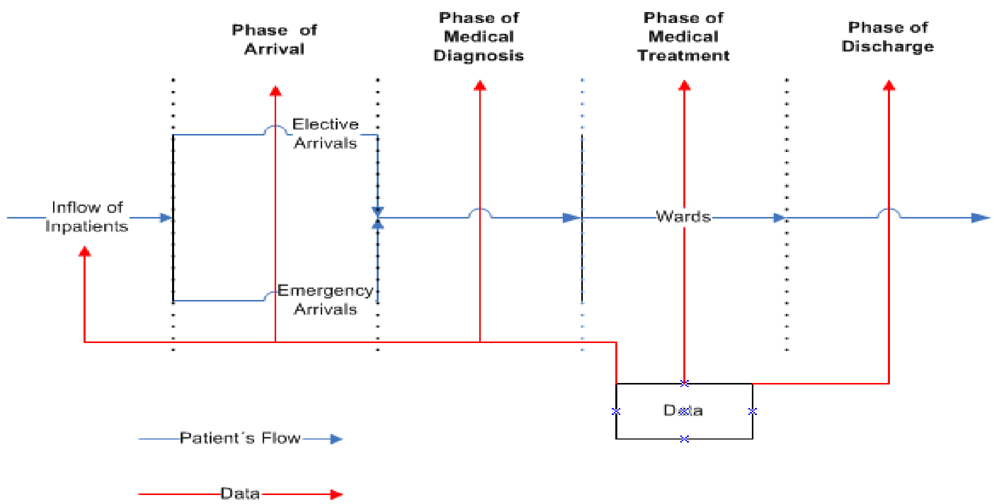

Figure 1: Process of Inpatient's Flow

The above process is divided into four phases namely arrival, medical diagnosis, medical treatment, and discharge; furthermore, the data regarding activity and finance is expected to be collected in each phase.

To determine at what point in the process it is best to measure efficiency changes, the recommended actions for improvement of inpatient flow, contained within the report of the Project Management Committee, are further reviewed. These actions are roughly divided into three categories. The first category describes actions during the patient's hospitalization, such as to hospitalize a patient within one hour after the decision about hospitalization is confirmed. Additionally, within 24 hours of hospitalization, the time of the patient's discharge has to be estimated, the patient is to be informed of this time, and the discharge schedule is to be recorded in the patient's medical file. The second category describes actions recommended during a patient's stay within the hospital ward, for example, beginning standard patient checks on the ward no later than 9:00 am and ending no later than 10:00 am. The committee also recommended that medical professionals use wireless networks and laptops to record data, to arrange medical testing, and to order medications as well as to order any required information from patients' prior medical records. The third category describes recommended actions related to the patient's discharge from the hospital. The recommendation was that discharge should occur before 12:00 am and the bed should be ready for a new patient within one hour after the prior patient's discharge (a possible reason for the proposed discharge time was to have beds ready for the remainder of a day). Additionally, the roles of discharge teams, emergency room doctors and nurses, ward doctors, and nurse supervisors in both the emergency rooms and wards were defined.

Based on review of the recommended actions, I conclude that a measurement of efficiency change, specifically as it relates to improvements in managed patient flow, would be most accurate by measuring changes in the medical treatment phase. The rationale for this conclusion lies in the fact that the vast majority of the actions recommended and implemented focus on the phase where the patients receive medical treatment while staying in the hospital's inpatient wards. As such, if there is a positive result in inpatient flow, then one expects to see improved efficiency within the phase where the patient receives the greatest amount of medical services and/or the phase wherein the patient spends the longest duration of time while at the hospital.

Based on the above premises, it is clear that one of the greatest opportunities to improve efficiency in inpatient flow is to improve the efficiency of the inpatient ward service, as the inpatient ward service is evidently one of the main factors in determining how long patients stay at the hospital. Because of implemented reforms in managing inpatient flow the following question is examined to determine the effects of implemented reforms in managing inpatient flow at LUH. **Did the Total Factor Productivity of the selected inpatient wards change between the first three months of 2007 and the first three months of 2009?** To examine this subject further: **If the productivity levels of selected wards did change, what were the causes of those changes?**

Therefore, the overall aim of this thesis is to evaluate the results of the implemented managed inpatient flow by efficiency measurement, and to determine the origin of the possible changes in efficiency. The number of available wards examined in order to answer the research question is approximately six for the given period. This is because, as discussed above, the committee's conclusion about the positive result of reforms in inpatient flow was based on the measurement of ALOS in selected wards, i.e., the implementation of the reforms was not completed in all wards of the hospital in the first months of 2009. For the purposes of answering the research questions, the objectives of this study will be to explore various data, models, and methods to estimate the results/outcomes of managed patient flow at LUH and to outline conclusions based on these results.

1.3 Reflexivity

Indeed, the reader should be aware of the author's background and how it has influenced the choice of subject for this dissertation, as well as the approach and methods used to answer the research questions including interpretations of the results and conclusions. I hold a BSc. degree in economics and have complete courses in a MSc. program with emphasis on operational research, management, and health economics. Furthermore, I was an assistant director within the division of Finance at LUH between 2000 and 2006. Part of that position included participation in LUH's Board of Directors' task force that formed in December 2005. Moreover, it is a personal belief that methods in operational research, economics, and business administration should be more widely used within the Icelandic health care sector.

Because of my background (education, work experience, and views), there is a chance of certain biases. For example, the subject of this thesis pertains to the activity of LUH, however, I am not educated as a health care professional, nor do I have extensive experience as an inpatient, which creates a possibility that important factors may be excluded from this approach, the discussions, and/or the conclusions. That stated, the same circumstances creating that possible bias might also, in turn, reduce "existent bias" as I am an outsider presenting a different viewpoint. This more diverse point of view is implemented to tackle the dissertation subject.

The reader should also be notified that this dissertation is a second version. The first version qualified in October 2010 but I used the right to withdraw that version to make appropriate changes, mainly on the structure

2 Literature Review

In this chapter, I review the methods used for measuring productivity changes and their origins. Furthermore, the methods described in the researched literature are further discussed and inferences are drawn regarding more suitable methods for answering the research questions such as whether or not the efficiency has changed following the reforms in LUH's inpatient flow and identifying the causes of any such changes detected.

2.1 Measuring Productivity Changes over a Period of Time

From this point in the dissertation, the terms efficiency and productivity and therefore Total Factor Productivity (TFP) will have distinct meaning. According to Jacobs, Smith, and Street (2006, p. 4), the terms are unfortunate used interchangeably. And furthermore they define productivity as "the ratio of some (or all) valued outputs that an organisation produces to some (or all) inputs used in the production process". In its simplest expression, a measurement of productivity can be completed by dividing units of outputs by units of inputs, or by dividing units of inputs by units of outputs e.g., in an environment with one type of input and one type of output. The result of such a calculation shows how many units of output one gets for one unit of input, or vice versa. The term efficiency is on the other hand based on comparison between two or more units e.g. amounts produced per time unit, and so on. Alike with TFP, either efficiency can be measured that one tries to minimise the use of inputs to a given output or one tries to maximise the produced outputs to a given input to produce a positive effect on efficiency.

In reality, there are typically multiple inputs used to produce one output; furthermore, multiple inputs can yield multiple outputs. The case of multiple inputs and multiple outputs is a common occurrence in the health care sector where, for example, one ward commands the use of labour, medicine, and beds as inputs in order to 'produce' health in its various forms for both inpatients and outpatients. This occurrence of multiple inputs and multiple outputs in the health care sector result in the requirement of multidimensional methods to calculate changes in productivity over a period.

Researchers have developed varying methods for efficiency measurements, such as Jacobs et al. (2006, pp. 11-12) who divide them mainly into parametric and non-parametric methods. Parametric methods are based on the assumption that data follows some probability distribution; therefore, a definite functional form is needed for the calculations in order to use this method. Consequently, with a parametric method, a relatively large number of elements are required to draw conclusions about the efficiency levels. On the contrary, when using non-parametric methods, one does not need to have a large number of elements. One also does not need a definite functional form nor is one required to find appropriate probability distributions in order to calculate efficiency. Furthermore, a non-parametric method such as Data Envelopment Analysis (DEA) can be used to calculate efficiency using multiple inputs and outputs. The above notions can be described as “principles” for choosing the proper method (e.g., DEA) for efficiency measurements, which also apply to measuring units produced between two periods. According to Jacobs et al. (2006, pp. 12, 129), the Malmquist Index (MI) is the most common method used in calculating changes in TFP over time. Furthermore, the advantage of this index (over other known methods that utilize indices to measure relative changes) is that no information about prices of inputs and outputs or technological and behavioural assumptions is necessary. The distinguishing of efficiency changes and finally can the MI values be calculated by combination of non-parametric methods, such as DEA and the method of MI.

Referring back to the case of LUH and their reforms in the inpatient flow, the number of selected inpatient wards is relatively low for a measurement of the change in TFP following the reforms in the inpatient flow, which makes it impossible to use parametric methods to explore the change in TFP over the period under examination. Furthermore, the price of the wards’ production does not exist. For these reasons, particularly in lieu of the period examined, the proposed analytical technique that is most accurate for measuring the TFP change in LUH’s inpatient flow following the reforms is the DEA combined with the MI method, which is hereafter abbreviated as DEA-MI.

Another group, Färe et al. (1994), originally demonstrated how a measurement of TFP change could be executed by calculating a geometric mean of two Malmquist Indexes. By using the information presented by Färe et al. (1994, pp. 68-83), and a similar explanation from Jacobs et al. (2006, pp. 92, 101-102), a measurement of TFP change between two points/periods of time can be calculated by using panel data. This is chiefly a measurement of distances in an output-input spectrum. The measurement of distances depends on which technology is used: Constant Return to Scale (CRS) technology, where it is assumed that no scale inefficiency exists, or Variable Return to Scale (VRS) technology, where it is assumed that scale inefficiency does exist.

Based on the illustration by Jacobs et al. (2006, pp. 131-133), the CRS and VRS frontiers are graphically displayed as follows in Figure 2, where the y-axis represents one type of production[2] y and the x-axis represents one type of input x:

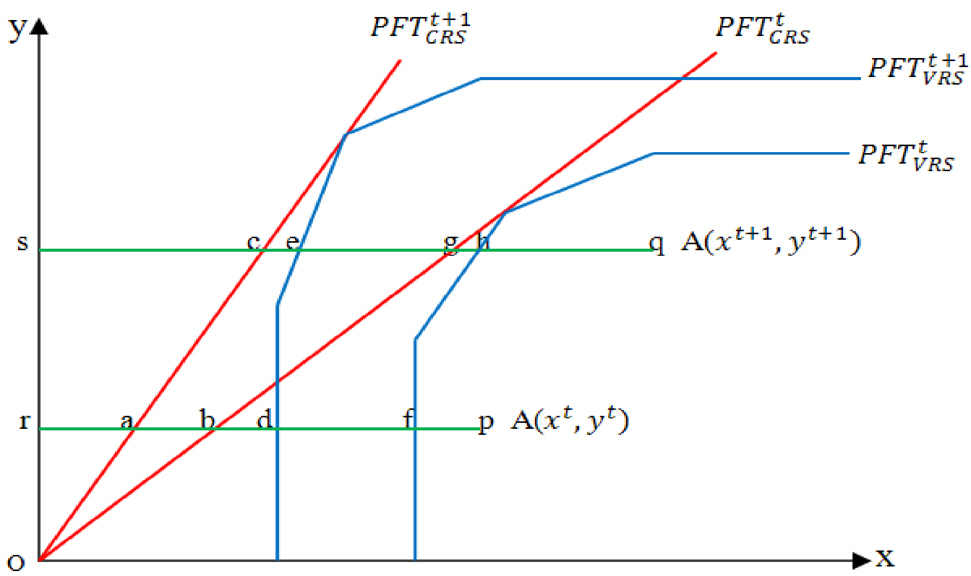

Figure 2: Graphical Illustration of the Measured Spectrum in the DEA-MI Method

In the above figure[3], there are four frontiers shown: two CRS frontiers (one CRS frontier in time t and one CRS frontier in time t+1) and two VRS frontiers (one VRS frontier in time t and one VRS frontier in time t+1). Furthermore, the mix of input and output for unit A in time t and time t+1 is revealed. The purpose of the DEA-MI method is to calculate relevant frontiers and measure the relative change in distances of each unit between the two periods[4] (see the mathematical expression in the Research Methods chapter). Furthermore, Jacobs et al. (2006, pp. 133-132) observe

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[2] The terms output and production will be used interchangeably hereafter.

[3] Please note the figure describes a case of one dimension for both input and output.

[4] Inherently the MI can be calculated relatively to either CRS technology or VRS technology.

that, when analysing panel data, changes in TFP can be represented as the total change in factor productivity between the two times, denoted as MI. This MI can further be decomposed into technical change, denoted as T and technical efficiency change, denoted as E. The technical change (T) indicates the changes in productivity levels due to technical progress for the wards. Technical efficiency change (E) in addition, can be split into separate variables as follows. Pure efficiency change (P), indicates the ward's distance from the current technically efficient frontier (under the VRS method) from one period to the next, and scale efficiency change (S) captures the change in deviation between the VRS and CRS methods. An illustrative expression of the MI with references to Figure 2 is illustrated as follows:

$$\text{MI} = \text{E x T} = (\text{P x S}) \text{ x T} = \frac{(\frac{se}{sq})}{(\frac{rd}{rp})} \text{ x } \left[\frac{(\frac{sc}{sq})}{(\frac{se}{sq})} / \frac{(\frac{rb}{rp})}{(\frac{rf}{rp})}\right] \text{ x } \sqrt{\left[\frac{(\frac{sg}{sq})}{(\frac{sc}{sq})} \; x \; \frac{(\frac{rb}{rp})}{(\frac{ra}{rp})}\right]}$$

As noted in the beginning of this subchapter, one tries to minimise the use of inputs to a given output or one tries to maximise the produced outputs to a given input. When the former is the objective of the DEA calculation, to determine distance functions to produce the MI, it is hereafter defined as Input Oriented (IO) variation (the prerequisite is that output is constant; this method can then be used to explore the possible proportional reduction in input quantities). When the latter is the objective of the DEA calculation, to determine distance functions to produce the MI, it is hereafter defined as Output Oriented (OO) variation (the prerequisite is that input is constant; this method can then be used to explore the possible proportional expansion in output quantities). Whether an IO variation or OO variation is implemented depends on whether the decision-maker can control the use of inputs or control the output produced. When the decision-maker can control the use of inputs but not the quantities of the output produced, then IO is implemented. However, if the decision-maker can control quantities of outputs produced, but not inputs used, then OO is implemented.

In review of the concept of TFP measurement, Hollingsworth et al. (1999, pp. 164-165) point out that until 1998 over 60% of the studies used DEA whilst 5% of the studies applied the MI method. Hollingsworth later (2003, pp. 210-213) provides a systematic review of 135 non-parametric studies within the health care sector. Of these studies, 22 measured productivity changes using the DEA-MI. Among these 22 studies, 10 studies were within the hospital sector, however, none of these 10 studies measure productivity changes between wards exclusively in the same hospital. This is concluded on the basis that the number of units in the mentioned studies are relatively high (the range of units is from 17 up to 1545) because the individual hospitals have considerably less wards each.

For the purposes of this dissertation, six out of these 10 studies were selected at random and reviewed. Reichmann (2000), Maniadakis and Thanassoulis (2000), Maniadakis, Hollingsworth and Emmanuel (1999) and Tambour (1997) studied the impact of external changes (such as changes in hospitals' payment systems) on hospital efficiency with the DEA-MI method, while Prior (2006) as well as Sola` and Prior (2001) split the DEA-MI model and expressed the dimensions of quality changes. As such, it appears that no DEA-MI studies in the literature address the subject of TFP change solely within one hospital. Furthermore, no DEA-MI studies seem to explore the effects of individual hospital manager's reforms. Nevertheless, it should be noted that the DEA-MI method seems to be commonly used when studying the impacts that interventions have on hospitals.

All of the six randomly chosen studies express results regarding the causes of the TFP changes measured, however, for the purpose of this dissertation; only four out of the six are useful. The two that are not of use include the change in the quality of hospitals' services as one of the causes for the measured change (in addition to change in technical change, and technical efficiency change). Reichmann (2000, p. 318) presented results regarding TFP changes in 22 Austrian hospitals, which were calculated on a yearly basis between 1994/1995 to 1997/1998. She used the MI to calculate the change as well as the origins of the change. Maniadakis and Thanassoulis (2000, p. 1582) revealed a measured improvement in TFP in 75 Scottish hospitals from 1991/1992 to 1995/1996. The change reported was 13.3% in total and the areas where change occurred appear to be in allocative efficiency (change of 8.9%), in pure technical efficiency (change of 4.2%), and, lastly, by scale efficiency (change of 0.7%). Maniadakis, Hollingsworth and Thanassoulis (1999, p. 80) calculated changes based on the MI as well as the origins of the changes in 75 Scottish hospitals from 1991/1992 to 1995/1996. They found that the productivity improved by 7.2 %, technical change by 2.5%, pure technical change by 4.2%, scale efficiency change by 0.7%, and therefore the technical efficiency change was 4.8%. Tambour (1997, p. 64) found out that the TFP of 20 ophthalmology departments in Sweden, between the years of 1998 to 1993, changed on average by 43.5%, where the efficiency change was 5.1%, the scale efficiency change was -8.7% and technical change was 47.1%.

2.2 The "Appropriate Method" in DEA-MI Calculation

According to Jacobs et al. (2006, p. 101), it is appropriate to apply the VRS method[5] when scale inefficiency exists inside the production units. They advise that the firms in the health care sector (therefore, the health production units such as wards) do not operate at an optimal scale due to imperfect competition, regulations, constraints on finance, etc., within this sector. However, Jacobs et al. (2006, p. 138) take into consideration that the VRS method for the calculation of the MI may not correctly measure the changes in TFP. They further claim that most authors recommend the use of the CRS implementation of DEA-MI to measure change in TFP correctly.

Furthermore, the VRS method can yield a result with no feasible solution within the equations' constraints. I explain and reveal the origin of the problem based on Zhu's benchmark models (2003, pp. 131-137) whereas benchmarking models are used to compare a "new" production unit to a given frontier, such as to the VRS frontier. Zhu (2003, p. 134) expresses equations for DEA calculation (VRS –IO and VRS-OO) as follows:

$$\frac{1}{D(x_n^{new},\ y_m^{new})} = min_{\phi\lambda}\phi \qquad \textbf{(VRS-IO)}$$

Subject to:

$$\phi x_n^{new} - \sum_{i=1}^{I} X_{i,n}\lambda_i \geq 0 \qquad (n = 1,\ldots,N)$$

$$-y_m^{new} + \sum_{i=1}^{I} Y_{i,m}\lambda_i \geq 0 \qquad (m = 1,\ldots,M)$$

$$\sum_{i=1}^{I} \lambda_i = 1 \qquad (i = 1,\ldots,I)$$

$$\lambda_i \geq 0$$

[5] As discussed prior, the MI can be calculated relative to either CRS technology or VRS technology. The terms used are hereafter the "CRS method" and the "VRS method" instead of CRS technology and VRS technology. Furthermore, the VRS-IO terms the method-variation discussed.

$$\frac{1}{D(x_n^{new},\ y_m^{new})} = max_{\rho\lambda}\rho \qquad \textbf{(VRS-OO)}$$

Subject to:

$$x_n^{new} - \sum_{i=1}^{I} X_{i,n}\lambda_i \ \geq 0 \qquad (n = 1,\ldots,N)$$

$$-\rho y_m^{new} + \sum_{i=1}^{I} Y_{i,m}\lambda_i \geq 0 \qquad (m = 1,\ldots,M)$$

$$\sum_{i=1}^{I} \lambda_i = 1 \qquad (i = 1,\ldots,I)$$

$$\lambda_i \ \geq 0$$

Where:

i is an index for production unit(s).

n is an index for type of input(s).

m is an index for type of output(s).

ϕ is a scale that measures the efficiency of the new production unit's use of input(s), comparing to the benchmark frontier.

ρ is a scale that measures the efficiency of the new production unit's output level(s), comparing to the benchmark frontier.

λ_i is a vector of efficiency elements (weights).

$X_{i,n}$ is the benchmark's input matrix.

$Y_{i,m}$ is the benchmark's output matrix.

x_n^{new} is the input vector for the new production unit.

y_m^{new} is the output vector for the new production unit.

By calculating VRS models for IO variation and OO variation, Zhu (2003, p. 135) asserts that interpretations are determined by the models' results, as well as by the necessary and sufficient conditions for infeasiblity and super-efficiency. When both of the models, VRS-IO method-variation and VRS-OO method-variation, are infeasible, this indicates that the "new" production unit has the smallest input level and the largest production level compared to the composed frontier (noted as CASE I in Figure 3). When VRS-IO method-variation gives an infeasible solution and VRS-OO method-variation gives a feasible solution, the cause is that the "new" production unit has the largest production level compared to the composed frontier (noted as CASE II in Figure 3). Therefore, VRS-OO method-variation is used to elaborate the production surpluses. When VRS-IO method-variation is feasible and VRS-OO method-variation is infeasible, it is caused by the fact that the new production unit has the smallest input level compared to the composed frontier (noted as CASE III in Figure 3). Therefore, VRS-IO method-variation is used to elaborate the input savings. When VRS-IO method-variation is feasible and VRS-OO method-variation is feasible, both models can be used to determine whether input savings and production surpluses exist (noted as CASE IV in Figure 3).

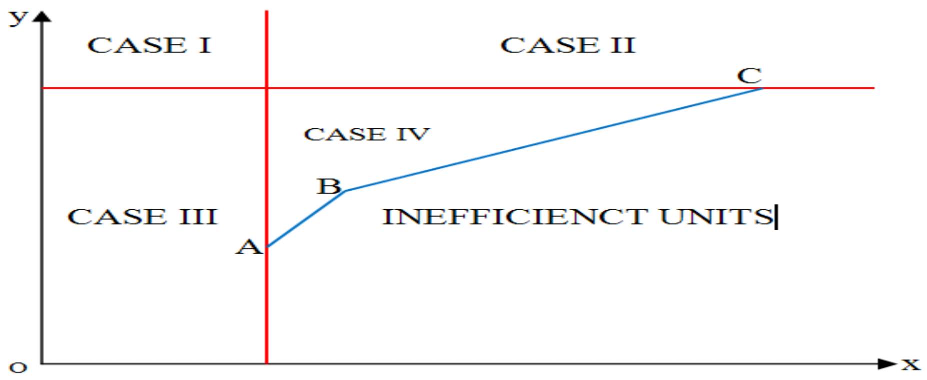

Figure 3: The Areas of Feasible and Non-Feasible Solutions by the VRS Variable-Benchmark Model

As noted, there exist non-feasible solutions when the VRS method is used. To complete the explanation regarding why the VRS method can yield a result with no feasible solution within the equations' constraints, the following VRS equations are based on Zhu (2003, pp. 278-279), Jacobs et al. (2006, pp. 136-137) and Solà's and Prior's (2001, p. 242)[6]:

$$\frac{1}{D_i^t(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = min_{\phi\lambda}\phi_j \qquad \textbf{(A.DEAMI-VRS III)}$$

Subject to: (t = prior time)

(t+1 = posterior time)

$$\phi_j x_{j,n}^{t+1} - \sum_{i=1}^{I} X_{i,n}^t \lambda_i \geq 0 \qquad (n = 1,\ldots,N)$$

$$-y_{j,m}^{t+1} + \sum_{i=1}^{I} Y_{i,m}^t \lambda_i \geq 0 \qquad (m = 1,\ldots,M)$$

$$\sum_{i=1}^{I} \lambda_i = 1 \qquad (i = 1,\ldots,I)$$

$$\lambda_i \geq 0 \qquad (j = I+1,\ldots,2I)$$

[6] The models are general expression of the VRS models in Appendix A.

$$\frac{1}{D_j^{t+1}(x_{i,n}^{t}, y_{i,m}^{t})} = min_{\phi\lambda}\phi_i \qquad \textbf{(A.DEAMI-VRS IV)}$$

Subject to: (t = prior time)

(t+1 = posterior time)

$$\phi_i x_{i,n}^t - \sum_{j=I+1}^{2I} X_{j,n}^{t+1}\lambda_j \geq 0 \qquad (n = 1,\ldots,N)$$

$$-y_{i,m}^t + \sum_{j=I+1}^{2I} Y_{j,m}^{t+1}\lambda_j \geq 0 \qquad (m = 1,\ldots,M)$$

$$\sum_{j=I+1}^{2I} \lambda_j = 1 \qquad (i = 1,\ldots,I)$$

$$\lambda_j \geq 0 \qquad (j = I+1,\ldots,2I)$$

Where:

i is an index for the production units at time t whereas I is the total number of the production units.

j is an index for the same production units but at time t+1.

n is an index for the type of inputs whereas N is the total number of input types.

m is an index for the type of outputs whereas M is the total number of output types.

ϕ_i and ϕ_j are vectors that measures the efficiency of the production unit's use of input(s) at time t and t+1 respectively, comparing to the frontiers at time t+1 and t.

λ_i and λ_j are vectors of efficiency elements (weights) at time t and t+1 respectively.

$X_{i,n}^t$ and $X_{j,n}^{t+1}$ are input matrices at time t (or t+1) for all the production unit(s).

$Y_{i,m}^t$and $Y_{j,m}^{t+1}$ are output matrices at time t (or t+1) for all the production unit(s).

$x_{i,n}^t$ and $x_{j,n}^{t+1}$ are input vectors at time t (or t+1) for the individual production unit under comparison.

$y_{i,n}^t$ and $y_{j,n}^{t+1}$ are output vectors at time t (or t+1) for the individual production unit under comparison.

Further elaboration of these constraints reveals why there can be no feasible solution within the equations' constraints. For example, from the equation DEAMI-VRS III, where the constraint is $\phi_j x_{j,n}^{t+1} - \sum_{i=1}^{I} X_{i,n}^t\lambda_i \geq 0$, the possible combinations of each ward's inputs and weights at time t ($\sum_{i=1}^{I} X_{i,n}^t\lambda_i$) can be larger than the measured input element and the scale for the ward under examination at time t+1 $\phi_j x_{j,n}^{t+1}$. This conclusion is valid for other the constraints (i.e. $-y_{j,m}^{t+1} + \sum_{i=1}^{I} Y_{i,m}^t\lambda_i \geq 0$, $\phi_i x_{i,n}^t - \sum_{j=I+1}^{2I} X_{j,n}^{t+1}\lambda_j \geq 0$, $-y_{i,m}^t + \sum_{j=I+1}^{2I} Y_{j,m}^{t+1}\lambda_j \geq 0$) in the equations

DEAMI-VRS III and DEAMI-VRS IV. This result is based on the same criteria of necessary and sufficient conditions for infeasiblity and super-efficiency as in Zhu's benchmark models, for example, instead of comparing a new production unit to a given production frontier, the VRS method compares a production unit in a prior time to the production frontier in the posterior time, or vice versa.

The attributes of the data can also influence whether the MI is calculated relative to either the CRS method or VRS method. If the production units in the sample are relatively different in size, the likelihood of non-feasible solutions increases. Furthermore, if there are only a few production units in the sample the constraint $\sum \lambda_i = 1$ (or $\sum \lambda_j = 1$) in the VRS method is more inflictive than the constraint $\sum \lambda_i \geq 1$ (or $\sum \lambda_j \geq 1$) in the CRS method. In such a situation, e.g., when there are only a few production units that are different in size, there is a greater risk of not yielding a result at all.

In accordance with the discussion above and the result of the DEA-MI calculations by the VRS method in Appendix A (which were performed through the first version of this dissertation as described in the Introduction section), I conclude that the CRS method is the appropriate one for calculating the change in TFP among the wards at LUH. Moreover, in the literature, the CRS method seems to be more often used to calculate changes in TFP between two points/periods of time. In five out of the six studies by Reichmann (2000), Maniadakis and Thanassoulis (2000), Maniadakis et al. (1999), Tambour (1997), Prior (2006) and Sola` and Prior (2001), the CRS method was used to measure proposed change in TFP. Therefore, it appears that Jacobs et al.'s (2006, p. 138) assertion that most authors recommend the use of CRS implementation of DEA-MI to measure change in TFP is correctly drawn and it supports the method proposed.

2.3 Data Measuring Units and Variables for the LUH Wards' Calculations

2.3.1 Data Measuring Units

As asserted in the Introduction, a proper scope of measurement for changes in TFP (the word used was efficiency) is through measuring changes in the medical treatment phase in the hospital wards. The selected wards are referred to as Decision-Making-Units (DMUs), which Jacobs et al. (2006, p. 19) denote as the scope of measurements.

They also explain that DMUs must encompass the production process, e.g., reflect the converting of inputs into outputs. Furthermore, the measurements of the DMUs' activity must be comparable for the purpose of the DEA-MI. These requirements can affect the demarcation of the DMUs scope within hospitals and are often complex. The reason for this complexity is twofold; firstly, patients flow across units and, secondly, health care professionals (e.g., medical doctors) and inpatient ward staff are specialised in certain medical fields, which differ between wards when the DMUs under examination are within the same hospital.

2.3.2 Input Variables

The variables used for the TFP calculations at LUH were chosen in lieu of the limitations discussed above regarding the two types of DEA methods (parametric and non-parametric), while also taking into account the subject of this thesis. Therefore, the input variables for each ward in the model are as follows:

- Labour measured as full-time equivalency units;
- Number of beds as a proxy for capital;
- Operational goods: such as blood reserves, nursing supplies, computers, catering and medicine.

All measurements of inputs in the model are in physical units because Jacobs et al. (2006, p. 30) confer that the use of physical units can be appropriate if it is beyond the control of a DMU to set the input rate. The setting of input rates is beyond the control of the wards that are under examination here; moreover, the subject of this thesis is not to examine price inefficiency.

On the one hand, Jacobs et al. (2006, pp. 29-30) have explained that measuring inputs as total cost of the DMUs in one manner assumes that DMUs' types of inputs are changeable (given inputs relative prices) and, therefore, the use of total cost for inputs is the appropriate method for a long-term perspective. However, even though it might be possible, in terms of the wards production, to replace one type of input for another, there is the need for a minimum amount of each type of input such as beds, catering, medicine, etc., so that the ward will be able to adequately fulfil its function. Therefore, one might conclude that the use of each input is almost, but not completely, beyond the control of each ward's manager as a certain minimum is required. Jacobs et al. (2006, pp. 29-30) also explain that if the use of each type of input is beyond the control of the ward's manager and if the interest is to alter the mix within each type of input, then a separation of the cost (function) is more appropriate from a short-term perspective. This also concludes that it is possible to substitute more freely within each type of input than between different inputs. In summary, a definition of total cost as an input is not appropriate for this dissertation, rather, more appropriate definitions of inputs are labour, beds, operational goods and medicine, because (among other factors) the subject of interest in this dissertation is based upon a short term perspective.

If the measurement of labour input is in one dimension, it is logical to calculate a Full-Time Equivalent Unit (FTE) for the labour. Further, Jacobs et al. (2006, p. 30) point out that specifying labour as numerous inputs is appropriate if the interest is to calculate allocative efficiency (labour-mix), but use of physical inputs in this context assumes that the wage rate is beyond the DMUs under examination. Because the subject of this thesis is not to calculate allocative efficiency, the FTE units are an appropriate expression for the labour variable.

The use of capital as an input within the health care sector can be difficult to define and measure. The reason is that the definition of capital within the health care system can be described as direct capital within DMUs (such as beds and monitors in wards), indirect capital (like hallways and joint operating theatres), or human capital in the form of evidence based knowledge, education, and the skill of health care professionals. Additionally, Jacobs et al. (2006, pp. 31-32) explain that contributions in the form of investments within the health care system often last over relatively long periods. This means that investments contribute to production periods after the investments have taken place. For these reasons it is a complicated task to measure capital inputs in the DEA model. Nonetheless, the most common substitute for capital in the literature is beds as presented by Worthington (2004, p. 160) who reports that the number of beds is the most common indicator of capital in DEA models. As such, this thesis uses the number of beds as the basis in calculations when measuring changes in TFP at LUH.

Other factors, specifically operational goods and medicine, are generally more straightforward to measure than capital because the nature of these costs is less intricate and vague (i.e., one can measure them by paid cost). However, one should consider that the use of operational goods and medicine depends heavily on the symptoms category, which can affect each ward’s use of operational goods and medicine considerably.

2.3.3 Production Variables

The definition of each ward's production is based on output and activity by using three different definitions: the sum of the Work-Load-Index (WLI), Lay Day (LD), and Diagnosis Related Group (DRG) (see a further explanation in the Glossary). Beginning with WLI, these values can be explained as outputs because they measure patients' physical conditions, where the production of activity is to lower the WLI value for each patient, e.g., the object of the ward's activity is to transfer additional health to the patients. On the other hand, WLI also scales the ward's production because the patients receive services based upon the WLI yardstick, which indicates patients' needs for health care services.

In terms of the LDs, they are a simple measurement of the ward's activity, even though it might also be argued that each additional LD transfers additional health to a patient. The reason behind this inference is that the number of LDs does not give any indication about the patient‘s health status. Therefore, it is possible for a ward to count LDs for patients that receive little or no services, such as patients waiting to be discharged.

Lastly, the sum of Diagnostic Related Groups units (DRGs) is a pure measurement of ward activity because, relatively speaking, DRGs measure how many resources (inputs) the patient receives in monetary value, but DRGs also include a measurement of costs other than the ward's costs as is discussed later. In summation, measurements such as WLI, LD, and DRG are used as terms for the wards' outputs/activities/productions when calculating proposed TFP changes.

Regarding outputs and outomes, Jacobs et al. (2006, p. 22) distinguish between and explain these two terms. The expression of output is depicted in two ways: first, output is expressed as additional health transferred to the patient and, second, output is expressed as broader patient satisfaction related to the effect on health from treatment received. They consider outcomes as quality adjusted physical units. Jacobs et al. (2006, pp. 26-27) also note that a measurement of output (and outcome) contain certain difficulties and they emphasize that direct measurement of activities could be more preferable when one measures the production of the health care system.

Hollingsworth et al. (1999, p. 205) concluded from 188 efficiency[7] analysis studies, that an outcome measurement was only applied in 10 of them and the most common measurement of production was activity, such as inpatient days or discharges. Furthermore, Prior (2006, pp. 281,291) studied the effect of quality on efficiency and incorporated several types of infections as production variables, while Hofmarcher et al. (2002, p. 7) studied the evolution of efficiency and productivity in the hospital sector and employed the number of cases of mix-adjusted discharges and inpatient days. As previously mentioned, the purpose of the current study, the data availability, and the subject of the study modify what is defined as a product/output.

2.4 Measurement of Efficiency and Efficiency Change in Iceland

This literature review found no evidence indicating that a DEA-MI calculation has formerly been performed inside the Icelandic health care system. However, studies were conducted by Gunnarsdóttir (2010) as well as Johnsen and Jóhannsson (2003), where the efficiency of health care services was examined by DEA method by using cross-sectional data. The purpose of the former study was to explore the efficiency of Health Centres across Iceland and the purpose of the latter study was to explore the efficiency of medical doctors within Health Centres in Reykjavík.

2.5 Summary

The need for a measurement of TFP and related changes is overwhelming, both from the theoretical point of view and the practical point of view. The DEA-MI method is applied by researchers through analysing the impact of external intervention on hospitals (such as structural changes in the payment system), but the number of studies are relatively few and no studies were found regarding the impact of internal intervention such as reforms in managed patient flow. This is confirmed by reviewing Jacobs et al. (2006, p. 19), Worthington (2004, pp. 138-152), and Hollingsworth (2003, pp. 204-205), where the most common DMUs used in the literature are hospitals. This conclusion brings forward the significance of the suggested research,

[7] Some authors use the words efficiency as a synonym for all studies that deal with efficiency.

i.e., the importance of using the DEA-MI method to measure the TFP change of reforms in managed patient flow within one hospital, such as LUH.

As previously explained, the definition of wards’ production yardsticks is the same for all the wards, e.g., the measurement of wards’ activity is comparable even though patients have different diagnoses. The variable WLI measures both activity and outcome, which in fact provides a perspective in the discussion and conclusion to follow. Furthermore, all of the inputs used and recorded are considered local for each ward, except the cost of medical doctors, but that cost is distributed to each ward based on the diagnosis of each inpatient. For this reason, the selected DMUs are properly scoped according to definitions provided by Jacobs et al.

In Iceland, the use of economical and operational research is rare in hospitals. Additionally, hospitals are primitive in their lack of using proper benchmarks, which results in measurements only being taken for the parts that the managers require to make logical and realistic decisions about their activity. The measurement of changes in TFP could improve the LUH mangers knowledge and their formation of decisions about the hospital’s activity.

3 Research Methods

The purpose of this chapter is to describe by what means, from where, and specifically what data were collected. This section also includes information regarding how the data are screened and validated to help ensure accurate results. Furthermore, the mathematical expression of DEA equations is given and the MI and the decomposition of MI changes into technical change, technical efficiency change, pure efficiency change, and scale efficiency change are explained. Finally, several perspectives on limitations are discussed.

In order to answer the questions posed in the Introduction section, the research strategies include the examination of a mix of case studies, historical/contemporary research, and experimental research. According to Biggam (2008, pp. 83-84), a case study is a research strategy wherein the researcher examines, in depth, some research challenges with a quantitative method and a narrow perspective. Historical/contemporary research is a method that focuses on events that happened in the past (including recently). Finally, the experimental research involves the testing of a hypothesis through certain types of experiments. As previously, noted the focus of this dissertation is the reforms implemented (the case or event) during the years 2007 and 2009 at LUH. The focus of this study also "indirectly" examines a hypothesis on TFP changes in selected wards assumed to have resulted from reforms in managed patient flow; to be more straightforward, the main hypothesis is that the TFP has positively changed because of implemented reforms in inpatient flow.

3.1 Data Collection

The first data[8] set was collected from six wards 2008 (see the included variables in Table 1). The selected periods were January to March 2007 and January to March 2008. LUH's personnel who have knowledge and access to the all-inclusive patient-databases collected the data. This data set indicates slight changes in the variables, which raises suspicion about whether both the presentation and the implementation of

[8] All of the data was systematically collected from the hospital's databases, in accordance with ethical approval by the LUH Ethical Committee, (see Appendix C).

the managed patient flow reform was insufficient and not completely carried out. This suspicion was confirmed in an unofficial meeting with the chairperson of the Project Management Committee and because of the inadequate data set collected in the beginning, the estimated time of the data analysis was postponed.

The second data set was then collected a year later for the same six wards, in the summer of 2009, when the chairperson of the committee had confirmed that six wards at LUH had completely finished implementation of the managed inpatient flow. At this point, the data collected consisted of data for the period of January through March of the year 2007 and data for the period of January through March of the year 2009.

The data were categorised by nature into sections based on cost data, production data, and information about each inpatient. The variables that describe the production, e.g., numbers of WLIs, LDs, and DRGs, were collected for all discharged patients within the selected periods. The data from this data processing is defined as the *general data set* hereafter.

Further, a registered nurse (RN), Helga H. Bjarnadóttir,[9] counted the exact numbers of WLIs and LDs produced for each ward within the two periods (i.e., January through March of 2007 and January through March of 2009). This extra data collection was done after an informal discussion about strengths and weakness of the production variables in the general data set. These data were contained in a special database called LEGA[10]. A new data set, termed the *exact data set,* was created by replace the variables of WLIs and LDs in the general data set with these exact-counting production variables of WLIs and LDs. Please note that the only difference between the general data set and the exact data set lies in how the number of WLIs and LDs are counted. Therefore, variables other than WLIs and LDs in the general-data set are added to the exact data set as well.

The following categories and variables are displayed for the periods of January to March 2007 and January to March 2009 in both data sets in Table 1:

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[9] Helga H. Bjarnadóttir, a Registered Nurse (RN) and the project manager in the Department of Economic and Information at LUH, was in charge of and responsible for the entire data preparation process.

[10] “LEGA” is a nursing registration computer program.

Inpatients' Variables	Cost Variables	Production Variables
A patient's code, which refers to LUH's identification mark for each patient.	*Salary per profession except medical doctors in Kronas*	*Length of stay in Lay Days (LDs).**
Occasion for hospitalization, which is, explain how the patient arrives to the hospital i.e. acute or elective.	*Operational cost per month in Kronas.*	*Name and number of each patient's Diagnosis Related Group (DRG's) and the DRG's value.***
Calendar day of hospitalization.	*Medicine cost per month in Kronas.*	*Sum of each patient's Nursery Working Load Index (WLI) and Nursery Working Load Index pr. Day (AWLI).**
Hour and minute of hospitalization.	*Number of wards' beds.*	
Weekday of hospitalization (Monday, Tuesday e.t.c).	*Number of wards' square meters.*	
Fate, which explain what the fate of the patient is i.e. does he/she go home or is he/she transferred to other service or does he/she dies.	*Total Medical Doctor's cost.*	
Calendar day of discharge.		
Discharge ward.		
Patient's gender.		
Calendar day of discharge		
Hour and minute of discharge		
Weekday of discharge		
*This variable is counted differently in the general data set and exact data set. ** *See Definition in Glossary*		

Table 1: Collected Variables about Inpatients, Cost, and Activity

For the purposes of verifying the data, the wards' managers were individually interviewed. These interviews were conducted upon agreement with the managers, however, the interviews had not been registered by the formal ethical approval application. Due to this, it was strictly emphasized that all interviews be handled as approved through the ethical considerations in this thesis. Every department manager was informed about the purposes of this study and agreed to be interviewed. Each interview lasted approximately one hour with the intentions of, among other things, deepening the author's understanding of each ward's activity, aiding in estimating and/or confirming the real scope of each ward's activity regarding inpatients and inpatient flow, and obtaining each manager's opinion regarding proposed measurements of production.

3.2 Framework of the Data Analysis

The framework of the data analysis is in conformance with the purposes of this study. The data are analysed and expressed so that they can be used to calculate and measure the TFP changes of the wards at LUH between the referred periods. That includes reviewing and formulizing the data and further expressing it in a proper format.

As previously described, all six wards' managers were interviewed to increase the reliability of the data used. Following the interviews, one of the ward's managers demonstrated a lack of reliability of data because of poor registration of WLI in the manager's ward, and further, some of the ward's professionals provided services to both outpatients and inpatients and the ratio of the professionals' contributions to these two kinds of patients were not precisely recorded. Consequently, this ward was dropped from the former list of six selected wards due to the unreliable data, which might contribute to a bias in calculating the changes in TFP because of the implemented reforms. As such, the DMUs were reduced to five listed as: Ward of Respiratory Diseases (A-6), Ward of Infectious Diseases (A-7), Ward of Acute Geriatric (B-4), Ward of Cancer (11-E), and Ward of Blood Disorder (11-G).

As previously noted, there are two available data sets, the general data set and the exact data set, and the characteristics and features of these two data sets differ. For this reason, the data sets need to be screened to ensure that the appropriate one is selected for the DEA-MI calculation.

3.2.1 Production Data Set

Further alterations to the data were made when variations were found in some wards' records. During the screening process of the production variables, an analyst of LUH's Department of Economics and Information pointed out that the diagnosis of sleep apnoea was treated in ward A-6 in the year 2007, but not in the year 2009. The general data set was corrected by dropping out all patients with this diagnosis in the year 2007 and their enclosed values of WLIs, LDs, and DRGs. Therefore, the decreased value of WLIs is 143 units out of 2547 WLIs, or 5.6%; the decreased value of LDs is 144 out of 2277, or 6.3%; the decreased value of DRGs is 12 out of 236, or 5.0%. The values in the exact-data set for the production variables WLIs and LDs are decreased by the same ratio as the general data set. Table 2, below, demonstrates the production data for the first three months of 2007 and the first three months of 2009 from the general data set:

Ward Code	Number of WLIs 2007	Number of WLIs 2009	Number of LDs 2007	Number of LDs 2009	Number of DRGs 2007	Number of DRGs 2009
A-6	2405	1988	2133	1669	224	206
A-7	2425	2238	2272	1909	224	250
B-4	1962	1560	1490	1237	64	93
11-E	1377	1306	1269	1154	138	180
11-G	1417	955	1221	849	196	238
Grand Total	**9585**	**8048**	**8385**	**6818**	**845**	**966**

Table 2: Production Variables Based on Discharged Patients-Level Data sets, 2007$_{January - March}$ and 2009$_{January - March}$

Table 3 demonstrates the production data for the first three months of 2007 and 2009 from the exact data set (the exact count of the numbers of DRGs produced was unavailable):

Ward Code	Number of WLIs 2007	Number of WLIs 2009	Number of LDs 2007	Number of LDs 2009
A-6	2052	1819	1852	1669
A-7	2233	1962	2168	1817
B-4	2125	2224	1622	1751
11-E	1282	1178	1187	1061
11-G	1391	1149	1231	982
Grand Total	**9083**	**8332**	**8060**	**7280**

Table 3: Production Variables Based on Exact-Level Data Set within the Periods 2007$_{January\ -\ March}$ and 2009$_{January\ –\ March}$

A comparison of the two data sets reveals the following nominal and relative differences between the general data set and exact data set[11], which are shown in Table 4:

Ward Code	Difference of WLIs' Numbers 2007	Relative Difference of WLIs' Numbers 2007	Difference of WLIs' Number 2009	Relative Difference of WLIs' Number 2009	Difference of LDs' Number 2007	Relative Difference of LDs' Number 2007	Difference of LDs' Number 2009	Relative Difference of LDs' Number 2009
A-6	-353	-17%	-169	-9%	-281	-14%	0	0%
A-7	-192	-9%	-276	-14%	-104	-5%	-92	-5%
B-4	163	8%	664	30%	132	8%	514	29%
11-E	-95	-7%	-129	-11%	-82	-7%	-93	-9%
11-G	-26	-2%	194	17%	10	1%	133	14%
Grand Total	**-502**	**-6%**	**284**	**3%**	**-325**	**-4%**	**462**	**6%**

Table 4: Nominal Difference between the Patient-Level Data Set and Exact Data Set

It should be noted that the patients' characteristics could affect all the production variables, because both data sets are relatively small and medical speciality within

[11] Nominal difference is the exact-data set minus patient-level data, and the relative difference is as a ratio of the exact-data set.

each ward can vary between the two years. The possible biases are discussed further in the sub-section entitled Limitations.

The logical selection of data on which to focus is the exact data set because it precisely measures the activity of each ward within the period, whereas the general level data set consists of all discharged patients within the period and possibly contains some or all of the following biases. Firstly, when information is acquired in connection with discharged inpatients within a relatively short period (e.g., January – March), the effect of outliers can be enormous. For example, the variable LD might contain counts of LDs for inpatient(s) that have been hospitalized in a ward for months. Secondly, because the period of data collection is in the beginning of a new year, the pattern of hospitalization of inpatients usually varies between wards, for example, some wards close during the Christmas holiday while other wards minimize their activity and register patients during the first days into the new year. This can influence the number of patients who are discharges in the following month (January). For these two reasons, the final production data set used for the DEA-MI calculation is as follows in Table 5:

Ward Code	Number of WLIs 2007	Number of WLIs 2009	Number of LDs 2007	Number of LDs 2009	Number of DRGs 2007	Number of DRGs 2009
A-6	2052	1819	1852	1669	224	206
A-7	2233	1962	2168	1817	224	250
B-4	2125	2224	1622	1751	64	93
11-E	1282	1178	1187	1061	138	180
11-G	1391	1149	1231	982	196	238
Grand Total	**9083**	**8332**	**8060**	**7280**	**845**	**966**

Table 5: Production Data Set for the DEA-MI Calculation

As explained in the Literature Review section TFP calculation will be performed for each of the three production variables independently whereas the each one gives different view on the same production.

3.2.2 Input Data Set

Whereas during the screening process of the production variables the production variables was decreased, referring back to the changes noted in the activity of ward A-6, the input use of the ward is decreased by 5.6% for the year 2007. This ratio is the average decrease of the production yardsticks, e.g., WLIs (5.6%), LDs (6.3%), and DRGs (5.0%).

Measurement of the health care professionals' contributions is noted in FTE units (including the work of medical doctors). They are presented in physical units as explained in the Literature Review section. The method used to calculate the FTE units is the calculation of the total average salaries for all professionals in the years 2007 and 2009, where the health care professionals with the lowest salary for each year formed the base for counting numbers of FTEs. This method explains why the following numbers of FTEs for each ward appear to be enormous. The calculation of the FTE unit relies on information of each profession's salary, but an individual's salary information in Iceland is confidential, which explains why the calculations based on individuals' salaries are not revealed.

The number of beds at LUH is defined by "open beds" and presents physical units, whereas ancillaries and medicine are considered part of the total operational cost for each period by ward and are presented by index values through setting the lowest total operational cost as 1.0. By indexing, the total operational cost of each ward is then transformed into "physical units". One should take into consideration that the use of the above-mentioned inputs depends heavily on the categories of the patients' diseases, which, in turn, can affect each ward's use of operational goods and medicine. To correct for the price changes between the years 2007 and 2009, the cost of ancillary and medicine for the first three months of the year 2007 is multiplied by the change in the Consumer Price Index, or specifically, 1.26 (Hagstofa Íslands). Table 6, demonstrates the input data for the first three months of 2007 and 2009:

Ward Code	Number of Beds 2007	Number of Beds 2009	Number of FTEs 2007	Number of FTEs 2009	Magnitude of Ancillary and Medicine 2007	Magnitude of Ancillary and Medicine 2009
A-6	24	20	66	77	1.82	1.64
A-7	23	19	57	60	2.34	1.69
B-4	20	20	44	51	1.00	1.02
11-E	14	14	45	45	1.53	1.46
11-G	14	14	42	48	3.16	2.98
Grand Total	**95**	**87**	**253**	**281**	**9.85**	**8.78**

Table 6: Wards' Inputs 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$

Furthermore, to confirm the committee's conclusion on the implementation of the managed patient flow, which implied positive results based on the measurement of

ALOS, the real change for the selected wards, the ALOS, is calculated by using the production data set. This is done through the formula: $\mathrm{ALOS_i} = \frac{\text{Number of Lay Days}_\text{i}}{\text{Number of Patients}_\text{i}}$ where I represent the symbol for the selected ward (the result is displayed in the subsequent section entitled Result, Analysis and Discussion).

3.3 Framework of DEA-MI

In the Literature Review, it was explained how and why the DEA-MI method is used to calculate change in TFP over a period. Additionally, it was rationalized that the CRS implementation with the IO variation is the proper method to calculate alleged TFP changes in LUH wards because the managers of the selected wards were unable to determine the demands for the services; in short, it is assumed that they can only plan and control the use of input. The appropriate mathematical expression is adopted by Jacobs et al. (2006, pp. 136-137) in conjuction with Zhu's (2003, pp. 278-279) expression of equations for the proposed DEA calculations:[12]

$$\frac{1}{D_i^t(x_{i,n}^{\,t}, y_{i,m}^t)} = min_{\phi\lambda}\phi_i$$ **(DEAMI-CRS I[13])**

Subject to: (t = 2007 January - March)

$$\phi_i x_{i,n}^t - \sum_{i=1}^{5} X_{i,n}^t \lambda_i \geq 0$$ (n = 1, 2, 3)

$$-y_{i,m}^t + \sum_{i=1}^{5} Y_{i,m}^t \lambda_i \geq 0$$ (m = 1)

$$\lambda_i \geq 0$$ (i = 1, 2, 3, 4, 5)

$$\frac{1}{D_j^{t+1}(x_{j,n}^{\,t+1}, y_{j,m}^{t+1})} = min_{\phi\lambda}\phi_j$$ **(DEAMI-CRS II)**

Subject to: (t+1 = 2009 January - March)

$$\phi_j x_{j,n}^{t+1} - \sum_{j=6}^{10} X_{j,n}^{t+1} \lambda_j \geq 0$$ (n = 1, 2, 3)

$$-y_{j,m}^{t+1} + \sum_{j=6}^{10} Y_{j,m}^{t+1} \lambda_j \geq 0$$ (m = 1)

$$\lambda_j \geq 0$$ (j = 6, 7, 8, 9, 10)

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[12] DEA-MI calculation is executed in two phases. First, DEA calculation is executed and, second, the MI calculation is executed.

[13] CRS I = Data Envelopment Analysis for Malmquist Index – Constant Return to Scale Equation I.

$$\frac{1}{D_i^t(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = min_{\phi\lambda}\phi_j$$ **(DEAMI-CRS III)**

Subject to: (t = 2007$_{\text{January - March}}$)

(t+1 = 2009$_{\text{January - March}}$)

$\phi_j x_{j,n}^{t+1} - \sum_{i=1}^{5} X_{i,n}^t \lambda_i \geq 0$ (n = 1, 2, 3)

$-y_{j,m}^{t+1} + \sum_{i=1}^{5} Y_{i,m}^t \lambda_i \geq 0$ (m = 1)

$\lambda_i \geq 0$ (i = 1, 2, 3, 4, 5)

(j = 6, 7, 8, 9, 10)

$$\frac{1}{D_j^{t+1}(x_{i,n}^t, y_{i,m}^t)} = min_{\phi\lambda}\phi_i$$ **(DEAMI-CRS IV)**

Subject to: (t = 2007$_{\text{January - March}}$)

(t+1 = 2009$_{\text{January - March}}$)

$\phi_i x_{i,n}^t - \sum_{j=6}^{10} X_{j,n}^{t+1} \lambda_j \geq 0$ (n = 1, 2, 3)

$-y_{i,m}^t + \sum_{j=6}^{10} Y_{j,m}^{t+1} \lambda_j \geq 0$ (m = 1)

$\lambda_j \geq 0$ (i = 1, 2, 3, 4, 5)

(j = 6, 7, 8, 9, 10)

As also discussed in the Literature Review, technical efficiency change can be split into pure efficiency change, which indicates the ward's distance from the current technically efficient frontier (under the VRS method) from one period to the next, and scale efficiency change, which captures the change in deviation between the VRS and CRS methods. To be able to calculate these sizes, the following VRS equations are also required:

$$\frac{1}{D_i^t(x_{i,n}^t, y_{i,m}^t)} = min_{\phi\lambda}\phi_i$$ **(DEAMI-VRS I)**

Subject to: (t = 2007$_{\text{January - March}}$)

$\phi_i x_{i,n}^t - \sum_{i=1}^{5} X_{i,n}^t \lambda_i \geq 0$ (n = 1, 2, 3)

$-y_{i,m}^t + \sum_{i=1}^{5} Y_{i,m}^t \lambda_i \geq 0$ (m = 1)

$\sum_{i=1}^{5} \lambda_i = 1$ (i = 1, 2, 3, 4, 5)

$\lambda_i \geq 0$

$$\frac{1}{D_j^{t+1}(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = min_{\phi\lambda}\phi_j \qquad \textbf{(DEAMI-VRS II)}$$

Subject to: (t+1 = 2009$_{\text{January - March}}$)

$$\phi_j x_{j,n}^{t+1} - \sum_{j=6}^{10} X_{j,n}^{t+1}\lambda_j \geq 0 \qquad (n = 1, 2, 3)$$

$$-y_{j,m}^{t+1} + \sum_{j=6}^{10} Y_{j,m}^{t+1}\lambda_j \geq 0 \qquad (m = 1)$$

$$\sum_{j=6}^{10}\lambda_j = 1 \qquad (j = 6, 7, 8, 9, 10)$$

$$\lambda_j \geq 0$$

Where:

i is an index for the five wards at time t.

j is an index for the same five wards but at time t+1.

n is an index for the three definite types of inputs.

m is an index for the one definite type of output.

ϕ_i and ϕ_j are vectors that measures the efficiency of the ward's use of input(s) at time t and t+1 respectively, comparing to the frontiers at time t+1 and t.

λ_i and λ_j are vectors of efficiency elements (weights) for the wards at time t and t+1 respectively.

$X_{i,n}^{t}$ and $X_{j,n}^{t+1}$ are input matrices at time t (or t+1) for all the wards.

$Y_{i,m}^{t}$and $Y_{j,m}^{t+1}$ are output matrices at time t (or t+1) for all the wards.

$x_{i,n}^{t}$ and $x_{j,n}^{t+1}$ are input vectors at time t (or t+1) for the ward under comparison.

$y_{i,n}^{t}$ and $y_{j,n}^{t+1}$ are output vectors at time t (or t+1) for the ward under comparison.

If a ward under calculation is efficient, then the relevant λ is one (1) for that ward, but if the ward is not efficient, then the method, according to Jacobs et al. (2006, p. 98), creates a composite peer ward by a linear combination of other wards under calculation. Further, with reference to the discussion in the Literature Review, the MI_{IO} index[14] is expressed with its partials (MI = P x S x T) as:

$$MI_{IO} = \frac{\text{DEAMI−VRS II}}{\text{DEAMI−VRS I}} \text{ x } \frac{\frac{\text{DEAMI−CRS II}}{\text{DEAMI−VRS II}}}{\frac{\text{DEAMI−CRS I}}{\text{DEAMI−VRS I}}} \text{ x } \left[\frac{\text{DEAMI−CRS III}}{\text{DEAMI−CRS II}} \text{ x } \frac{\text{DEAMI−CRS I}}{\text{DEAMI−CRS IV}}\right]^{½}$$

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[14] MI_{IO} = Malmquist Index based on input oriented equations.

The inverse of the CRS-IO method-variation is the CRS-OO variation. Therefore, to be able to verify the CRS-IO calculation, the following CRS-OO equations are also calculated, including neccesary VRS-OO equations for the MI:

$$\frac{1}{D_i^t(x_{i,n}^t, y_{i,m}^t)} = max_{\rho\lambda}\rho_i$$ **(DEAMI-CRS V)**

Subject to: (t = $2007_{\text{January - March}}$)

$x_{i,n}^t - \sum_{i=1}^5 X_{i,n}^t \lambda_i \geq 0$ (n = 1, 2, 3)

$-\rho_i y_{i,m}^t + \sum_{i=1}^5 Y_{i,m}^t \lambda_i \geq 0$ (m = 1)

$\lambda_i \geq 0$ (i = 1, 2, 3, 4, 5)

$$\frac{1}{D_j^{t+1}(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = max_{\rho\lambda}\rho_j$$ **(DEAMI-CRS VI)**

Subject to: (t+1 = $2009_{\text{January - March}}$)

$x_{j,n}^{t+1} - \sum_{j=6}^{10} X_{j,n}^{t+1} \lambda_j \geq 0$ (n = 1, 2, 3)

$-\rho_j y_{j,m}^{t+1} + \sum_{j=6}^{10} Y_{j,m}^{t+1} \lambda_j \geq 0$ (m = 1)

$\lambda_j \geq 0$ (j = 6, 7, 8, 9, 10)

$$\frac{1}{D_i^t(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = max_{\rho\lambda}\rho_j$$ **(DEAMI-CRS VII)**

Subject to: (t = $2007_{\text{January - March}}$)

(t+1 = $2009_{\text{January - March}}$)

$x_{j,n}^{t+1} - \sum_{i=1}^5 X_{i,n}^t \lambda_i \geq 0$ (n = 1, 2, 3)

$-\rho_j y_{j,m}^{t+1} + \sum_{i=1}^5 Y_{i,m}^t \lambda_i \geq 0$ (m = 1)

$\lambda_i \geq 0$ (i = 1, 2, 3, 4, 5)

(j = 6, 7, 8, 9, 10)

$$\frac{1}{D_j^{t+1}(x_{i,n}^{t}, y_{i,m}^{t})} = max_{\rho\lambda}\rho_i \qquad \textbf{(DEAMI-CRS VIII)}$$

Subject to: (t = $2007_{\text{January - March}}$)

(t+1 = $2009_{\text{January - March}}$)

$x_{i,n}^{t} - \sum_{j=6}^{10} X_{j,n}^{t+1}\lambda_j \geq 0$ (n = 1, 2, 3)

$-\rho_i y_{i,m}^{t} + \sum_{j=6}^{10} Y_{j,m}^{t+1}\lambda_j \geq 0$ (m = 1)

$\lambda_j \geq 0$ (i = 1, 2, 3, 4, 5)

(j = 6, 7, 8, 9, 10)

$$\frac{1}{D_i^{t}(x_{i,n}^{t}, y_{i,m}^{t})} = max_{\rho\lambda}\rho_i \qquad \textbf{(DEAMI-VRS III)}$$

Subject to: (t = $2007_{\text{January - March}}$)

$x_{i,n}^{t} - \sum_{i=1}^{5} X_{i,n}^{t}\lambda_i \geq 0$ (n = 1, 2, 3)

$-\rho_i y_{i,m}^{t} + \sum_{i=1}^{5} Y_{i,m}^{t}\lambda_i \geq 0$ (m = 1)

$\sum_{i=1}^{5} \lambda_i = 1$ (i = 1, 2, 3, 4, 5)

$\lambda_i \geq 0$

$$\frac{1}{D_j^{t+1}(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = max_{\rho\lambda}\rho_j \qquad \textbf{(DEAMI-VRS IV)}$$

Subject to: (t+1 = $2009_{\text{January - March}}$)

$x_{j,n}^{t+1} - \sum_{j=6}^{10} X_{j,n}^{t+1}\lambda_j \geq 0$ (n = 1, 2, 3)

$-\rho_j y_{j,m}^{t+1} + \sum_{j=6}^{10} Y_{j,m}^{t+1}\lambda_j \geq 0$ (m = 1)

$\sum_{j=6}^{10} \lambda_j = 1$ (j = 6, 7, 8, 9, 10)

$\lambda_j \geq 0$

Where:

$\rho_i$and $\rho_j$are vectors that measures the efficiency of the ward's use of output at time t and t+1 respectively, comparing to the frontiers at time t+1 and t.

Former description above of all other variables is also valid here.

Consequently, the presentation of the MI index will alter in that its formulation depends on whether the input or output orientation is used:

$$\mathrm{MI_{OO}} = \frac{\text{DEAMI-VRS IV}}{\text{DEAMI-VRS III}} \text{ x } \frac{\frac{\text{DEAMI-CRS VI}}{\text{DEAMI-VRS IV}}}{\frac{\text{DEAMI-CRS V}}{\text{DEAMI-VRS III}}} \text{ x } \left[\frac{\text{DEAMI-CRS VII}}{\text{DEAMI-CRS VI}} \text{ x } \frac{\text{DEAMI-CRS V}}{\text{DEAMI-CRS VIII}}\right]^{½}$$

Although the MI values are calculated for each ward, a measurement of the TFP change needs to be further developed.

3.4 Analysis of the TFP Change

A proposed measurement of TFP change between January – March 2007 and January – March 2009 is a weighted average productivity change of each ward's relative size. First, the Relative Size of each Ward (RSW) is calculated as follows:

$$RSW_i = \frac{\frac{(NoBeds\ 2007 + NoBeds\ 2009)_i}{(TNoBeds\ 2007 + TNoBeds\ 2009)} + \frac{(NoFTEs\ 2007 + NoFTEs\ 2009)_i}{(TNoFTEs\ 2007 + TNoFTEs\ 2009)}}{2}$$

Where:
NoBeds = Number of beds.
NoFTEs = Number of FTEs.
TNoBeds = Total number of beds.
TNoFTEs = Total number of FTEs.
i = ward i where i = 1, 2,…,5.

Secondly, the Total Factor Productivity's Weighted Average (TFPWA) is calculated according to the following formula:

$$TFPWA = \sum_{i=1}^{5} RSW_i \text{ x } TFP_i$$

This value gives an inference about whether the implemented reforms on managed inpatient flow result in increased or decreased productivity for the LUH as a "whole" i.e. does the TFP in the inpatient flow at the hospital increased because of the reform in the inpatient flow even though the TFP increased or decreases in individual wards? It should be noted that this method will also be applied on the MI sub indices.

3.5 Limitations and Issues

There are several possible limitations and issues in connection with the methods used in this study, which are discussed in detail in the following subchapters. These limitations and issues are primarily related to the possibility of slacks, whether to use weights of inputs and outputs in the model, environmental factors, the model specification, the data collection process, and variables used in the model. The existence of limitations can result in bias of the model's result and/or decrease reliability as well as decreased validity.

3.5.1 Issue of Slacks

In the methods used there is no attempt made to determine whether there is a slack in either the input or the output constraint. According to Jacobs et al. (2006, p. 33), that alone can lead to an overestimation of technical efficiency. Therefore, if there is any slack at all, this can clearly be a limitation to the method used..

3.5.2 Issue of Weight Restriction

There appears to be no obvious argument for applying weight restriction to the inputs or outputs in the model, such as weighting FTEs as two (2) and weighting operation cost as one (1) and weighting beds as 0.5. The reasons they are not weighted is that the used values are weighted physical values and there is only one production variable calculated in each model.

3.5.3 Environmental Limitations

Environmental limitations consist in the structure of LUH, as well as the medical techniques available to each ward and each ward's group of patients, however, Jacobs et al. (2006, p. 33) defines environmental constraints as the DMU's exogenous factors that are beyond its control. Furthermore, Jacobs et al. (2006, pp. 19-20) define a weak definition of the DMU as a system that plays an organising function, which means that the DMU does not completely control how it transforms inputs to outputs (production) nor does it have independent discretion about its technological processes. In this sense, LUH's ward managers have limited power to control the productivity and therefore the efficiency; in other words, they are forced to behave within the confines of the governing body of LUH. The production of a hospital ward is a derivative of counter-professional decisions and, therefore, the measurement of the productivity of each ward is a measurement of how well the collective decision-makers or the interest-groups perform in using available resources within each specialty. Furthermore, there are technical factors such as extent of knowledge, medical methods, devices, instruments, equipment and medicine, as well as external variables, which are beyond the control of the wards' managers. Finally, each ward's group of patients is different in terms of diseases and disease severity, i.e., it is a possibility that the nature of diseases can affect how "efficiently" it is possible to cure them. All these environmental factors, LUH's organisational structure, the medical techniques available to each ward, and the nature of the patients' ailments can weaken the comparability of wards.

3.5.4 Limitations by the Model Specification

The specification of the model (or method) used in this dissertation is a limitation in some perspectives, but not in others. The inputs used in the applied model are only used to produce each ward's production, therefore, the model is exhaustive and exclusive with the exception of the production variable DRG. However, according to Jacobs et al. (2006, p. 113) this means that "*the inputs alone must influence the outputs and only those outputs used in the model (exhaustiveness)*". This position is based on the fact that inputs are exploited geographically by each ward with the exception of the cost of medical doctors, but the cost of medical doctors is transferred on each patient by applying rules of cost distribution. Further, the influence of inputs on productions (i.e., WLI, LD, and DRG) is different regarding each variable. The DRG variable is influenced by many factors other than the types of inputs used and, in fact, consists of costs accumulated through each patient's stay (for example, the cost of surgery). Therefore, the DRG variable is not exclusive. The effort put into nursing care, which is measured by the WLI, takes place within each ward and the count of LDs are also within each ward, as such, these variables are exclusive. For this inference, the reader should be aware of the possibility that in some wards, the use of external inputs can affect the measurement of WLI and LDs in an indirect way, for example, in the case of a surgery that is carried out in an operational theatre.

This dissertation proposes that the model is isotonic, which, according to Jacobs et al. (2006, p. 114), means that there is a negative relationship between a higher use of inputs and efficiency while there is a positive relationship between increasing outputs and efficiency. For example, when the use of FTEs is increased, the efficiency is assumed to decrease, whereas a higher value of WLI will increase the efficiency.

The number of variables used in the DEA-MI model is not applicable. Jacobs et al. (2006, p. 112) suggest that the number of DMUs, according to the number of inputs and outputs, should be three times larger, however, they also state that there is no analytical support for the suggested rule about the ratio between the number of DMUs according to the number of input and output. In this dissertation, the ratio of the number of wards according to inputs and outputs in the model is 5:4, but, as discussed further in the chapter Result and Discussion, this ratio seems not to bias the result.

The number of wards used in the model is relatively low, but no assumptions are made regarding the effect of this on the results. According to Jacobs et al. (2006, p. 112), the result is sensitive if one of the measurements of the production is unique for one or more wards within a small sample. I conclude that none of the measurements of production used is unique to one or more specific ward(s), even though it can be speculated that some measurements are more suitable for some kind of diseases above others and, therefore, for some wards above others.

3.5.5 Limitations of the Data Collection Process

The main limitation with the data collection is that during the collection process the data obtained could not be verify/validate because access to LUH’s Patient-Data-System is restricted for security reasons. Furthermore, it is questionable whether the effect of reforms on the efficiency in the inpatient flow had emerged in the period between January to March of 2007 and of 2009 because the period is relatively short. In other words, this may not be a long enough period within which the full effects of the reforms are realized.

By interviewing the wards’ managers, through interaction with the staff at LUH’s Department of Economics and Information, and from personal experience as a former LUH’s Director of Economics and Information, I attempted to verify that the data and the collection process were reliable. As previously discussed, this effort, especially regarding the collection and frame working of the production data, resulted in alterations to the comparative periods (i.e., 2008 was change to 2009) as the managed inpatients flow was still an on-going process. Secondly, a more detailed data collection was conducted for WLIs and LDs inside a special database within LUH’s main database (LEGA). This alone signals that the data has limitations in connection with the definition and the collection of the production. However, the strength of the data used is derived in that it was chosen after thorough review and, moreover, it is assumed that the limitation of the data collection will not affect the result but, rather, that these facts should be considered when the result is presented.

3.5.6 Limitations of the Variables

Also through the data collection process, through interaction with staff at LUH's Department of Economics and Information, and from personal experience as a former LUH Director of Economics and Information, I estimate, subjectively, the reliability of the used data. To rate the reliability of the data sets, the following scales were used to grade each variable as Very Reliable Data, Reliable Data, Less Reliable Data, and Non-Reliable Data.

There are areas in which errors are conspicuous, such as the measurement error in the variable for beds. As previously denoted, beds are counted on the number of what LUH defines as *open beds*. Table 7 reveals the relative usage of open beds:

Ward Code	Number of LDs per Bed 2007	Number of LDs per Bed 2009	Available Number of LDs per Bed 2007 and 2009	Relative Usage per Bed 2007	Relative Usage per Bed 2009
A-6	83,2	88,3	90	92%	98%
A-7	99,4	102,2	90	110%	114%
B-4	83,3	90,5	90	93%	101%
11-E	90,6	81,5	90	101%	91%
11-G	93,2	75,2	90	104%	84%

Table 7: Relative Usage per Bed 2007$_{January - March}$ and 2009$_{January - March}$

As reflected in the data on the utilization of open beds, wards A-7, B-4, 11-E, and 11-G have higher rates of usage for open beds than is possible, e.g., there is more than 100% utilization. This implies that either the count of number of LDs is incorrect or the count of open beds is miscalculated. During the collection process, RN, Helga H. Bjarnadóttir, informed and verified that the data on open beds are not reliable. For this reason, the count of open beds is considered Non-Reliable Data. This discrepancy in the figures is responded to by adding a bed, or beds, until the relative utilization of beds is less than 100% at relevant wards. This will result in the following numbers of beds and changes in the relative use of beds as shown in Table 8 following:

Ward Code	Beds 2007 Before Correction	Beds 2009 Before Correction	Beds 2007 After Correction	Beds 2009 After Correction	Relative Usage per Bed 2007 Before Correction	Relative Usage per Bed 2009 Before Correction	Relative Usage per Bed 2007 After Correction	Relative Usage per Bed 2009 After Correction
A-6	24	20	24	20	92%	98%	92%	98%
A-7	23	19	26	22	110%	114%	98%	98%
B-4	20	20	20	21	93%	101%	93%	96%
11-E	14	14	15	14	101%	91%	94%	91%
11-G	14	14	15	14	104%	84%	97%	84%
Grand Total	**95**	**87**	**100**	**91**	**100%**	**98%**	**94%**	**94%**

Table 8: Correction of the Numbers of Beds 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$

It is estimated that the number of beds is a less reliable variable after the correction because the correction is not built on a reliable reference; it is simply an adaptation of what seems to be reasonable according to the author.

There is the possibility of a minor measurement error in the variable FTE. FTE variables include, but are not limited to, medical doctors, which have certain relevant features. Firstly, medical doctors' costs are divided proportionally between services, for example, between a ward or wards and an operational theatre. Secondly, the total cost for medical doctors working on each ward is allocated evenly upon each patient. Thirdly, the distribution ratio of medical doctors' costs between the ward(s) and the other forms of services differs between specialties. Fourthly, the length of a patient's stay can affect the wards' costs for medical doctors. For example, when a patient is waiting to be discharged, and receives no services during waiting time from doctors, then the ward is at the same time credited for the cost of medical doctors, which has not been provided in this instance. These factors can lead to some biases related to the medical doctors' costs, which in turn can lead to biases in the estimation of FTEs. According to the explanations previously provided regarding the calculation of FTEs for other professions, there seems to be no specific vulnerability involved with that data. For that reason, it is concluded that the calculation of the FTE units provide Very Reliable Data. This inference is based on the number of FTEs that resulted in the calculation of medical doctors FTEs, which is relatively low.

The variable of Operational Cost embraces the expenditure resulting from ancillaries (including ancillary services) and medicine, where the inclusion of medicine is questionable because different regulations regarding medicine are on-going. For example, one ward may be almost free from paying medicinal costs for their patients if regulations claim that patients pay for their own medicine, while another ward is obliged to pay for their patients' use of medicine (which in some instances might be very expensive depending on the symptoms treated). Furthermore, certain diseases are exclusively handled with medicine while health care professional, physiotherapy, etc. handle other diseases with different combined methods such as interviews, but that expenditure might be paid for by yet another ward. The proportion of ancillary and medicine is displayed for the years 2007 and 2009 in Table 9:

Ward Code	Ancillary 2007	Medicine 2007	Ancillary 2009	Medicine 2009
A-6	90%	10%	84%	16%
A-7	85%	15%	83%	17%
B-4	90%	10%	92%	8%
11-E	80%	20%	73%	27%
11-G	74%	26%	68%	32%

***Table 9: Proportion of Ancillary and Medicine 2007**$_{January\ -\ March}$ **and 2009**$_{January\ -\ March}$*

As revealed above, the lowest ratio of medicine cost is 8% for B-4 in the year 2009, while the highest ratio is 32% for 11-G in the same year. From this, I conclude that the comparability of medicinal costs for patients is somewhat vulnerable, e.g., the possible bias might be significant and that leads to Less Reliable Data regarding the medicine cost. On the contrary, the information about the cost of ancillary is estimated to be Very Reliable Data because that cost is sufficiently recorded. Overall, due to factoring in the medicine costs with the ancillaries, OC is estimated to be Less Reliable Data as a whole.

As explained in the Glossary, the WLI is an index based on registered nurses' estimations of each patient's physical status and that by itself creates the risk of biases due to the nature of such a subjective method. Firstly, registered nurses' qualifications, skills, and competence to perform such tasks differ. Secondly, biases can stem from how patients act during registered nurses' estimations (e.g., some individuals are on their best behaviour while others may request more care than is required for their condition). Thirdly, possible biases might originate from the instrument used to estimate the physical status of patients, for example, the instrument may not correctly or appropriately measure the patient's physical status. Fourthly, external factors such as the culture of each ward may have an effect, for example, how enthusiastic registered nurses are to use the instruments (a factor that can lead to some systematic biases). When the data collection process was on-going, RN Helga H.

Bjarnadóttir, explained that when a patient is positioned as an inpatient in LUH's Emergency Room for several days during his/her stay, the WLI counts the patient's original ward while LDs count the Emergency Room. This can lead to an overestimation of WLI for a ward, especially if a patient has spent relatively more days of his stay at the hospital in the Emergency Room compared to other wards under examination. Information gained from the interviews with the managers of the wards under examination, as well as from RN Helga H. Bjarnadóttir, confirmed that it is logical to estimate some biases in the WLI, but it is not simple (nor is it obvious) to find existing methods to estimate the magnitude of such a bias. Based on the discussion above, the WLI data set is estimated to be Reliable Data.

Even though several wards have more utilization of open beds than is actually possible (i.e., more than 100% utilization), it is estimated that there is (almost) no measurement error in the variable LD. This is mainly because I concluded that the count of the number of open beds was weak through examination of the findings, and, therefore, LDs are classified as Very Reliable Data.

There is a greater chance of measurement error in the variable DRG than for other output variables used. The count of DRGs was conducted by counting DRG units for patients discharged during the two periods examined, i.e., January to March 2007 and January to March 2009. This datum is significantly vulnerable to bias because the number of patients discharged within mentioned periods may not have received services. Furthermore, the DRG system measures the total resource cost used by each patient within the hospital. Patients that receive several services outside of a specific ward attribute DRG units to their inpatient ward even though the resources of the ward are not used to "produce" the DRG units.

During the data collection process, RN, Helga H. Bjarnadóttir, explained that registrations and classifications of inpatients into DRG categories had improved dramatically between the two years (i.e., between 2007 and 2009). This was mostly because LUH's DRG system was in a developmental phase and professionals were learning and coordinating procedures for the DRG system. By comparing the DRGs' weights between the two years it is revealed that out of 352 DRG elements (weights and DRG number within each ward), 244 elements did not exist in either year and the average change of DRG weights for 103 elements is 12% (absolute value). The remaining elements showed a change in DRG weights in the range of 144% to 300%. Based on this information, the data for measurement of production as DRG weights is

Non Reliable Data. Although DRG data are classified as Non Reliable Data, the DEA-MI calculation is executed by usage of that variable. The purpose of this is to provide a wider perspective with which to illuminate the results.

4 Results, Analysis, and Discussion

In this chapter, the results of the calculations based on the MI are presented, analysed, and discussed. In addition, an analysis of the calculations is discussed and linked to the content of the Literature Review. This section also examines the validity of the results, the perspectives on data and findings, and the appropriateness of the model, method, and variations used. Please note that all figures displayed are also found in the tables of Appendix B.

According to the framework that was introduced in the Literature Review and Research Methods sections, the results are calculated using the DEA-MI CRS method for both IO variation and OO variation (the result for OO is expressed in Appendix B. The result will be according to MI_{IO} in the Research method section. The CRS-OO method variation is calculated only to confirm that calculation by the CRS-IO method-variation is completed properly, however, both methods variations measure the relative changes equally.

The values calculated are the TFP change by MI along with its sub-indices. The sub-indices consist of change in scale efficiency (S), change in pure technical efficiency (P), and, therefore, the change in technical efficiency change (E) (equal to S * P), as well as technical change (T). The MI and its sub-indices are calculated for the production variables of WLIs, LDs, and DRGs.

Färe, et al. (1994, p. 71), explain, by using the OO variation, that if the MI value is equal to 1.0 for a DMU under examination, then no change has occurred in the DMU's TFP between the two periods. With OO variation, they also conclude that if the MI value is greater than 1.0, the DMU's TFP between the two periods has improved and if the MI value is less than 1.0, the DMU's TFP between the two periods has declined. These interpretations are also valid for the MI's sub-indices. On the contrary, by using the IO variation, the interpretations of indices values are the opposite, i.e., if the value of the MI is greater than 1.0 for a DMU, then its TFP has declined and if the value of the MI is less than 1.0 for a DMU, then its TFP has improved. This conclusion is also supported Zhu (2003, pp. 279-280) and Maniadakis et al. (1999, p. 76).

4.1 Results and Analysis

4.1.1 Average Length of Stay

Before the results and analysis of the DEA-MI calculation is presented, the real change of ALOS is calculated to confirm the committee's conclusion about the implementation of the managed patient flow, which implied positive results based on the measurement of ALOS. The result is displayed in the following Table 10:

Ward Code	ALOS 2007	ALOS 2009	Relative Change 2007 - 2009
A-6	8,3	8,6	**3,4%**
A-7	9,1	7,3	**-19,9%**
B-4	18,9	15,0	**-20,6%**
11-E	7,2	6,6	**-8,9%**
11-G	8,4	7,0	**-16,8%**

Table 10: Average Length of Stay by Exact-Data Set, 2007$_{January - March}$ and 2009$_{January - March}$

The table shows that the ALOS decreased significantly between January to March of 2007 and January to March of 2009.

4.1.2 Ward A-6

The results of the calculations of the MI indices and its sub-indices calculated for the three definitions of productions for the Ward A-6, with CRS-IO method-variation, are as follows[15] in Figure 4:

[15] Unfortunately, it is not possible to express the MI-axis with full stop as in 1.0. As such, it is expressed with a comma (i.e., 1,0).

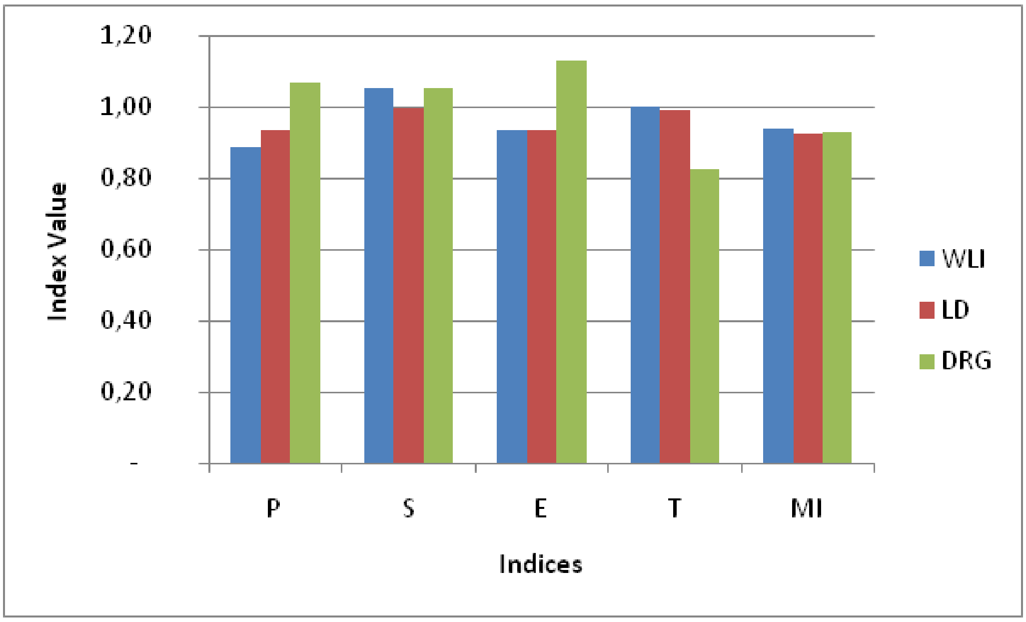

Figure 4: Result of DEA-MI Calculation for Ward A-6

As shown, the results are consistent between the different definitions of production whereas all the MI values are below 1.0. However, due to the non-reliability of the DRG variable as noted in the subchapter "Limitations of the Data", the value of DRG will not been used to calculate averages values of the indices either here or hereafter. Therefore, the MI value for applicable definitions of product (WLI and LD) by the CRS-IO method-variation is 0.93. Through further analysis, this value shows that the TFP of A-6 between the periods of January to March 2007 and January to March 2009 has improved by around 7%.

The sources of the TFP change between 2007 and 2009 are inconsistent for different definitions of production used to calculate the technical efficiency change and technical change. The results for P, E, and T are more alike for the WLI and LD variables than the DRG variable. These values for WLI and LD imply that the pure efficiency increased, technical efficiency increased, and the efficiency of the technology was unchanged, whereas the scale efficiency (S) decreased or was almost unchanged between the periods measured.

4.1.3 Ward A-7

For the three definitions of productions for Ward A-7 with CRS IO method-variation, the results of the calculations of MI values are displayed in the following Figure 5:

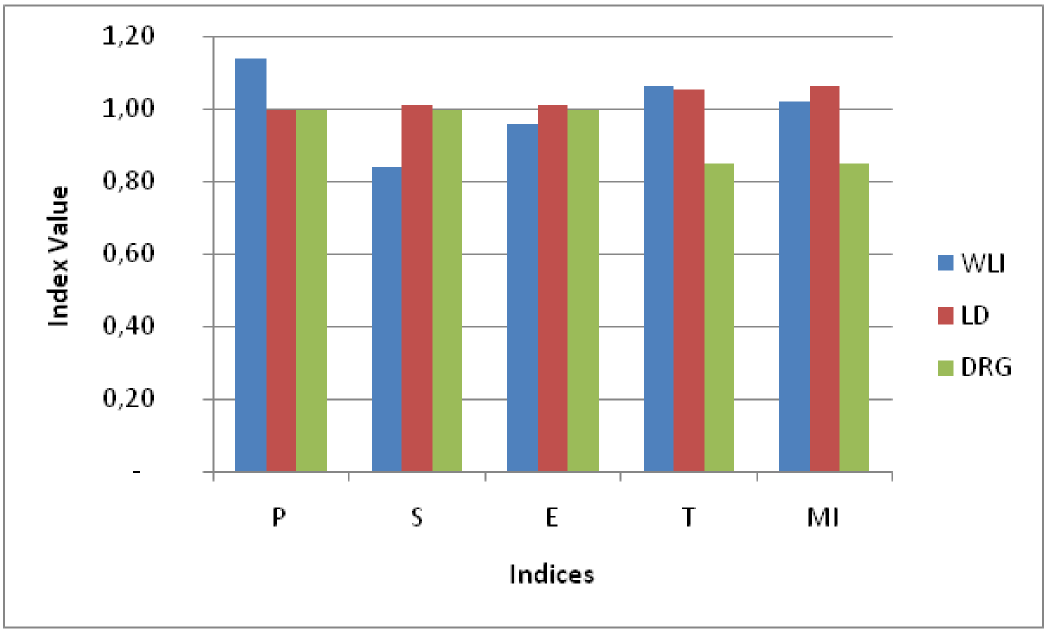

Figure 5: Result of DEA-MI Calculation for Ward A-7

The calculation for Ward A-7 gives a different estimation of the total changes in TFP by the production definitions of WLI and LD compared to the DRG. The average MI value, for the WLI and LD variables is 1.04 and the MI value for the DRG is 0.85. Based on this, one may conclude that the TFP of Ward A-7 has decreased by approximately 4% between January to March 2007 and January to March 2009. Furthermore, by analysing these results (i.e., the average of indices values for WLI and LD) it is calculated that the P-value is 1.07, the S-value is estimated to be 0.93 and, therefore, the E-value is 0.99. Finally, the T-value is 1.06. These values imply that the pure efficiency has decreased, the scale efficiency has increased, and the technical efficiency has decreased slightly, however, the efficiency change from the production technology was negative between the years 2007 and 2009.

4.1.4 Ward B-4

The results of the calculations of MI values calculated for the three definitions of productions for Ward B-4 with CRS IO method-variation are displayed in Figure 6 below:

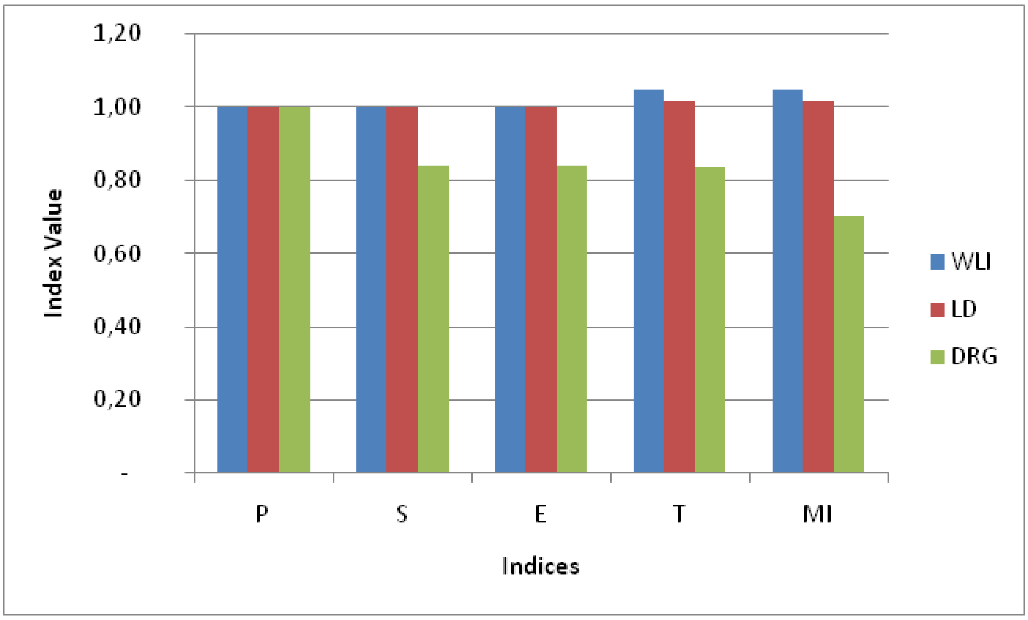

Figure 6: Result of DEA-MI Calculation for Ward B-4

As displayed, the MI values for WLIs and LDs are higher than 1.0 but the value for the DRGs is considerably lower than 1.0. The consistent solutions of WLI and LD result in the average MI value of 1.03, but the MI value for the DRG definition of production is 0.7. Therefore, the TFP of B-4 between January to March 2007 and January to March 2009 has decreased by 3%.

The calculated P-values for the variables WLI, LD, and DRG are relatively consistent, or rather; they are 1.00 for all definitions of production used. The average S-value for the production definitions of WLI and LD are also 1.00. Therefore, the E-value is calculated to be 1.00, while the average T-value for the variables WLI and LD is 1.03. These values imply that the pure efficiency is unchanged, as well as the scale efficiency and the technical efficiency, but at the same time, the efficiency from the production technology has decreased in the measured period.

4.1.5 Ward 11-E

The results for the calculations of MI values for the three definitions of productions for Ward 11-E with CRS-IO method-variation are shown in Figure 7 as follows:

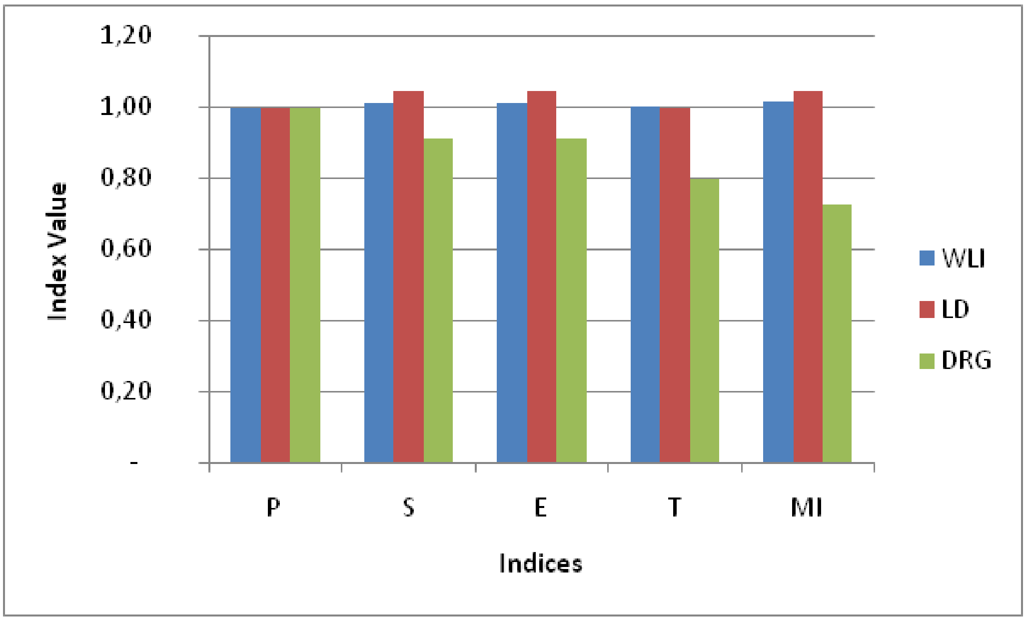

Figure 7: Result of DEA-MI Calculation for Ward 11-E

The above figure demonstrates that the CRS-IO method-variation yielded results that are higher than 1.0 for the calculations of the MI values for WLIs and LDs. Additionally, the MI value for LDs is slightly higher than the MI value for the production variable WLI. The calculation of TFP change for products WLI and LD yields the average MI of 1.03, correspondingly, the MI value for the product definition DRG is 0.73. Therefore, it is estimated that the TFP of 11-E in the measured period has decreased by 3%.

The average P-value is 1.00, the average value for S is 1.03, and, therefore, the E-value is 1.03. The value for T is 1.00. These values imply that there is no change in pure efficiency, the scale efficiency decreases, and the technical efficiency, therefore, decreases. Furthermore, the technology is unchanged between January to March 2007 and January to March 2009 in Ward 11-E.

4.1.6 Ward 11-G

The results of the calculations of MI values for the three definitions of productions for Ward 11-G with CRS IO method-variation are shown in Figure 8:

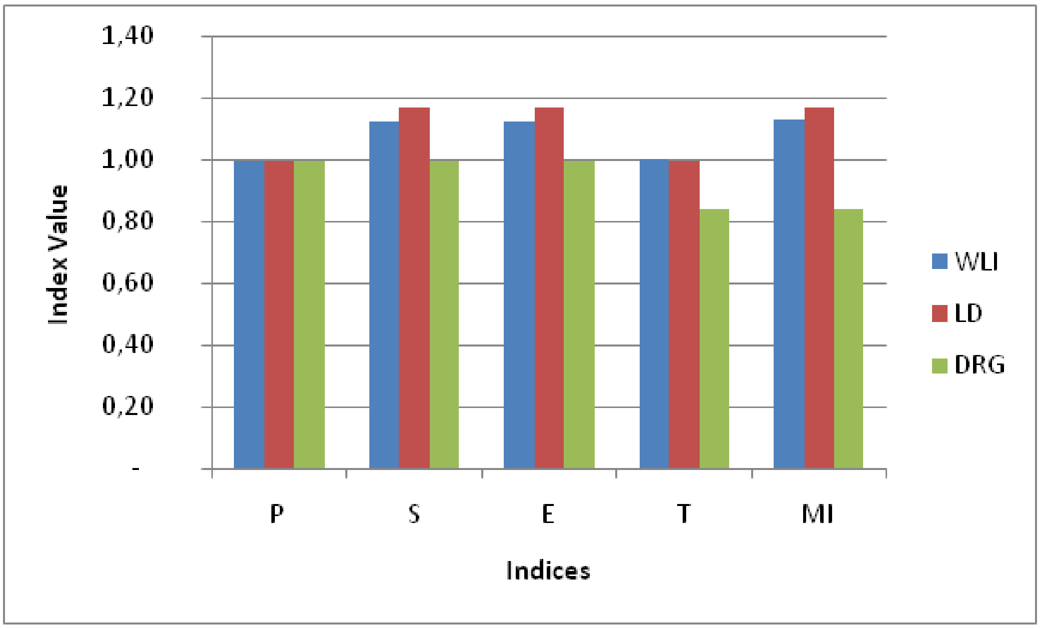

Figure 8: Result of DEA-MI Calculation for Ward 11-G

There is a consistent result for the production definitions of WLIs and LDs, i.e., the MI values are significantly above 1.0 for these definitions of the ward's productions. On the contrary, the MI value for the DRGs is considerably lower than 1.0. The average MI value for WLI and LD is 1.15 whereas the MI value for the DRG variable is 0.84. Review of the results show that the TFP of Ward 11-G has decreased in the measured period. The size of the TFP loss is about 15% when the frame of reference is the production variables WLI and LD.

In terms of calculating the TFP values, which are the average of the WLI and LD the average P-value is 1.00 and the average S-value is 1.15, and, therefore, the average E-value is 1.15. Lastly, the average T-value is 1.00. These values indicate that there is only a negative efficiency change in the scale efficiency between January to March 2007 and January to March 2009, but other sources of change in the productivity remain the same.

4.1.7 “Overall” Estimation of TFP Changes

By calculating the weighted average efficiency changes, it is possible to broaden the perspective of interpretation and conclusion of the implemented reforms on LUH’s inpatient flow. Therefore, as explained in the chapter Research Methods, the relative size of each ward is firstly calculated by beds and FTEs, and is presented in Table 11 as follows:

Ward Code	Relative Contribution of Beds	Relative Contribution of FTEs	Relative Size of the Ward
A-6	24,0%	26,7%	25,3%
A-7	23,1%	21,8%	22,5%
B-4	22,0%	17,8%	19,9%
11-E	15,4%	16,9%	16,2%
11-G	15,4%	16,8%	16,1%

Table 11: The Relative Size of Each Ward

As revealed, the Ward A-6 is measured as the relatively largest one and 11-E as well as 11-G is relatively small. Therefore, Ward A-6 weights relatively high compared to other wards in the weighted average changes in the MI and its sub-indices. In accordance with the explanation in the Research Methods section, each index value is calculated by multiplying the relevant ward’s index by its relative size and summing the fractions for each type of index. The following chart in Figure 9 displays calculated indices’ values by the average values of WLI and LD:

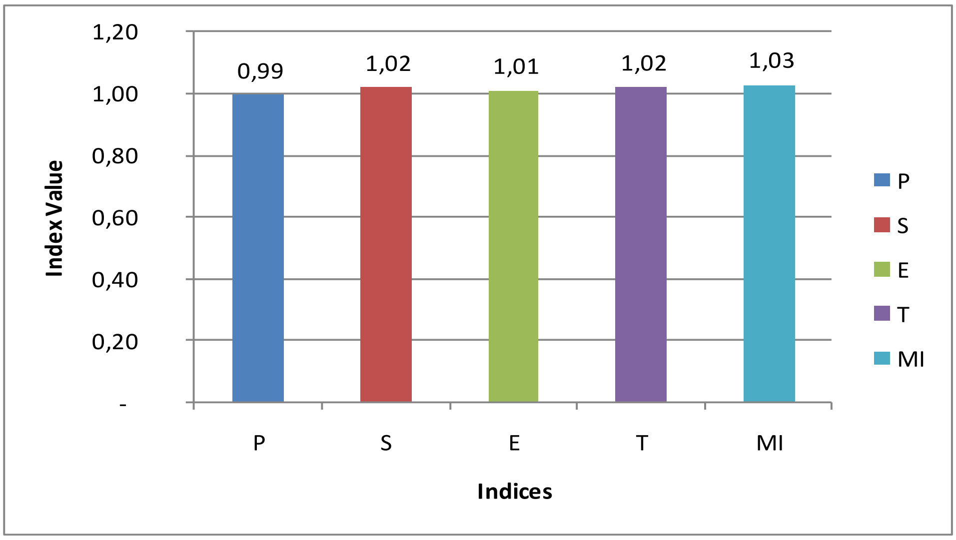

Figure 9: The Average Values of the Malmquist Index Elements

An analysis reveals that there is no dramatic change in each type of index by calculating the weighted average change for all the wards examined. On average, the value of the pure efficiency change scale increases by 1%, the scale efficiency change decreases by about 2%, the technical efficiency decreases by approximately 1%, the technical change decreases by about 2% and, lastly, the TFP decreases by almost 3%.

By analysing the causes of TFP individually by the production variables for the variables WLI and LD individually the following figure 10 is presented:

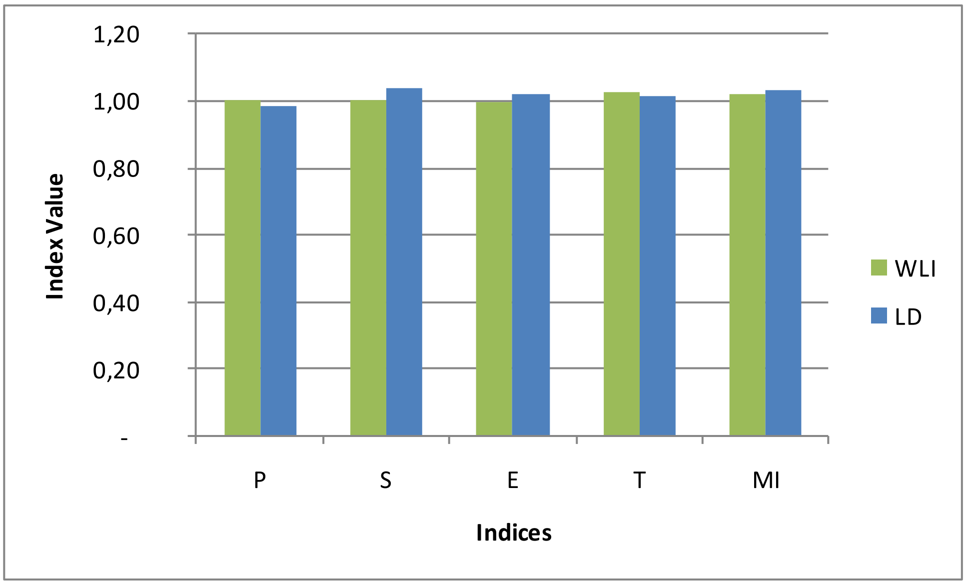

Figure 10: The Average Values of the Malmquist Index Elements by WLI and LD

The source of decreasing TFP is more traceable to the technical decreases by using the variable WLI, which indicate that the productivity level of the wards has decreased relative to the most productive ward, i.e., the usage of the inputs has decreased given the same technology of all wards. For the variable LD, the origin of decreasing productivity is mainly traceable to the decreasing scale efficiency in that the efficiency, with respect to the sizes of the wards, has decreased in the two periods under examination.

As discussed above, the measurements for the MI values by using WLI and LD as definitions of products (i.e., the size and the signal of the MI value) are similar between the periods under examination as well as the measurement by the cause defined as technical change. Yet, as noted by analysing each ward's cause of change in TFP, the result of measurements of the causes of the TFP change are different between the definitions of production used in pure technical efficiency and scale efficiency. The change in scale efficiency seems cause more change in TFP than the change in pure technical efficiency. A manner in which to verify this statement is to scatter each input against WLIs and LDs and draw the CRS and VRS frontiers in order to “visually estimate” the shapes of the frontiers at a given year. In Appendix C, WLIs and LDs are scattered against their inputs and then the frontiers are drawn via the appropriate points. In consideration of the definition of S, and upon review of the scatters in Appendix C, it is evident that the ratios that are presented in the S-equation are more profound (or larger) for LDs than WLIs. This corresponds with the bars in Figure 9 (above) where the bar for the weighted average S-value is higher than that of the weighted average P-value.

The results and the conclusions reveal how important it is to measure TFP change when one is measuring the result of interventions of manager reforms at LUH. However, in spite of the above-noted postulations, the calculated 3% overall decline in TFP has various causes of origin as the calculation of the variables WLI and LD originated from different causes, i.e., decreases in technical efficiency and scale efficiency, respectively. Therefore, more reliable and verifiable results are required to indicate what exact causes decreased productivity.

4.2 Discussion

The purpose of this subchapter is to discuss several subjects noted previously in this dissertation, especially to realize the strengthens and weaknesses of the accomplished work done up to this point. Special focus is given to the validity of the results, credibility of the data, and appropriateness of the model, method and variations used.

4.2.1 Validity of the Results

It has been repeatedly demonstrated that the DRG variable is non-reliable and inconsistent with the calculations and therefore is the result yielded by using the DRG variable as a definition of production not valid. As revealed above, the MI values for the WLI and LD variables provide similar results for the estimated change of all the wards’ TFPs but the values for the DRG variables are inconsistent with the other two formerly mentioned variables.

The validity of the results and the analysis of weighted average change in TFP between the two periods, e.g., January to March 2007 and January to March 2009, by using the LD and WLI, are overall questionable. This is because the results' distributions of the wards' changes in TFP provoke reasonable doubt about the strength of the results. By examine the attributes of the results, according to Jacobs et al. (2006, p. 144), the characteristics of the calculated (un-weighted) MI by the CRS-IO method-variation for all products variables are as follows in Table 12:

Scale	WLI	LD	DRG
Mean	1.03	1.04	0.81
Standard Deviation	0.07	0.09	0.10
Minimum	0.94	0.93	0.70
Maximum	1.13	1.17	0.93
Number of Wards with the value of MI >= 1	4	4	0
Number of Wards with the value of MI < 1	1,00	1,00	5,00

Table 12: Statistical Attributes of the Average Values of Malmquist Index for the Definitions of Products

These values indicate that the decreasing TFP between the periods examined by the wards on average is not an absolutely valid result because the range of the result's distribution is quite wide. The estimated values for two standard deviations for the variable WLI are 0.89 (lower limit) to 1.17 (upper limit) and the estimated values for two standard deviations for the variable LD are 0.86 (lower limit) to 1.22 (upper limit). These values also indicate that the result for decreasing productivity between the periods examined is not absolutely valid due to the lack of accuracy, however, one should keep in mind that the number of selected wards within the sample is relatively low so the accuracy of the calculated standard deviation is low. It should be noted that according to Tambour (1997, pp. 68-69), it is possible to use algorithms to produce some distributions for the estimated scales. That would be preferable as it would increase the validity of the results and the result of the estimated change in productivity would not need to be retested more formally to ensure accuracy.

4.2.2 Perspectives on Data and Findings

Based on review of the data, it appears that the DRG is a non-credible variable. As discussed in the Research Methods section, the distribution of the DRG's weights between the periods appears to be significantly different because the wards were relatively small in terms of DMUs and the DRG measurement is suspected of being non-reliable according to the data collection method. In addition, the implementation of the DRG in the hospital appeared to be undeveloped, especially in the year 2007 when the hospital was in an “experimental phase” with the DRG implementation, therefore, the variable DRG is not credible.

As noted previously, the number of beds was found to be incorrect (e.g., measurement error) when the count of LDs was completed. Therefore, from a critical perspective, one can question the credibility of the amount of the LDs due to the changes of bed numbers. In consideration of this, an attempt to support the credibility of this study's data (and findings) was by way of the data screening process implemented, which, as discussed previously, was made possible with the cooperation of the hospital staff at LUH.

The interviews with the wards’ managers created doubts regarding the accuracy of the WLI’s reliability and resulted in one ward being removed from the sample. Please note that noise and/or a measurement error, especially on the WLI, is possible because there are different cultures and attitudes towards the registration process within each ward as was revealed in interviews with wards’ managers.

As described in the Method section, all health care professionals’ wages are scaled to create one variable for the FTEs of each ward. It is debateable whether one should balance or calculate these different wages for all health care professionals into one number or not; the fact is, these five different wards use different resources to produce “health” or take care of different diseases. Furthermore, it is assumed that the relative contribution of each professional is reflected in their relative wages and other differences between the ward’s production functions, which are mirrored in different uses of inputs (e.g., beds, FTEs, and Operational Costs). It is further assumed that the scaling of variables used in the DEA-MI model is properly performed.

One possible critique about the results and conclusions is the time span of the data used. In this study, I assumed that the effect of change regarding the management of patient flow did in fact become evident over a few months and the ALOS supports this assumption. When managers implement changes in processes, such as reforms in managed patient flow, it affects the working habit of the people, the culture, and so on. Generally, it takes time for the real effect of such reforms to occur, especially in terms of the activity’s productivity, because implementation of managed patient flow is also a learning process. Moreover, part of that process is to discover and use the right yardsticks to measure the result and, in general, control the activity on a daily basis. The length of the period/interval used in this study to measure the productivity change resulting from the reforms is likely too short because it takes time for the mangers to verify the proper yardsticks. In other words, the mangers must become familiar with the proper yardsticks and be able to change the use of inputs before the full effects of reforms can be determined.

This discussion reveals the importance of the reliability and the validity of the data, and suggests that the results be screened in detail when one performs DEA-MI studies. To gain reliability and validity, one possible solution for the researcher(s) is to invest heavily in the data generating process but, in that case, there is the need for developing methods to perform quality checks (in order to gain credibility).

4.2.3 Appropriateness of the Model, Method and Variation Used

It should be noted that throughout the experimental phase of the calculations, it was discovered that the number of variables used in the DEA-MI calculation could, in fact, affect the validity of the DEA-MI calculation. In the first model, seven inputs were used in the calculation: one for the beds, five for each type of profession by FTE units, and one for the ancillary and medicine. In the second model, the DEA-MI calculation was repeated with three inputs: one for the beds, one for the FTEs (normalized as described in the Methods section), and one for Operational Costs. The effect of decreasing the number of inputs was that the number of inefficient wards increased. This result is in accordance with that surmised by Jacobs et al. (2006, p. 112), which state that when more variables are included in the DEA calculation, the method discriminates less precisely between the efficient ward and the inefficient ward. Jacobs et al. also suggest that the number of DMUs, according to the number of inputs and outputs, should be three times larger. In this dissertation, the ratio of the number of wards according to inputs and outputs in each model is 5:4, which seems to provide a reasonable result. This is also supported by Jacobs et al. (2006, p. 144) who state that there is no analytical support for the suggested rule about the ratio between the number of DMUs according to the number of inputs and outputs. Therefore, the number of variables used in the DEA-MI model is applicable.

Throughout the first version of this dissertation as described in the Introduction section, the following process was also executed (see Appendix A). First, the VRS-IO method was applied because it is believed that the different sizes of the wards (e.g., different number of beds and so on) can affect the shape of the calculated frontier. Furthermore, it is assumed that the managers can only control the input but not the throughput (quantity of production) when it is the patients right, according to Icelandic Acts, to be hospitalized if needed regardless of whether the hospital is considered capable of providing the best service for the patient or not. Second, the VRS-OO method was applied because the VRS-IO method did not provide feasible solutions for all DMUs. Third, Benchmark models criteria were used to form conclusions about the locations of the wards, according to a benchmark frontier. Fourth, the CRS-IO method was applied because the theories suggest that the CRS-IO method yields the “right result”. Fifth, the CRS-OO method was applied to confirm that the calculation of the CRS-IO method was correctly executed. Therefore, by performing the above five steps to disclose the TFP change between the first three months in the year 2007 and the first three months in the year 2009, the probability of yielding reasonable results, analysis, and conclusions was increased.

As discussed and rationalized in the subsection entitled Framework of the Wards Production, all of the models used in this dissertation provide definitions of productions and explain inputs, which are applied into the models. However, it is prudent to recognize that the wards managers had differing opinions of what is the appropriate definition for productions of their wards. They also emphasized in their interviews that both the patients and the activities of the departments are specialized and each ward might therefore be classified as unique. This can be interpreted as a sign of weakness in the model specification, but, as rationale for the production variable used, one can look at least at the WLI as a measurement of individuals’ health statuses (i.e., their individual needs for health care services). Furthermore, this is further rationalized by the argument that the wards lower each individual WLI to some minimum at discharge and, therefore, the difference of the WLI at hospitalization and at discharge is the outcome of the service. Even though this difference is not measured and estimated as a production/output variable, the concept of using the WLI links the factor of inpatients’ health statuses into the model specification. In conclusion, the definitions of the product variables used in the DEA-MI models need to be more conclusively defined.

4.3 A Reflection of the Results

In spite of not finding any study where the DEA-MI calculation has been executed, and where a comparison is made in the productivity between different wards in the same hospital, this dissertation can be related to, or compared partly with, studies carried out with DEA-MI calculations between hospitals. Such studies, similar to this one, aim to find out the effectiveness of interventions on changing productivity. For example, Reichmann (2000) studied the impact of hospital financing reforms on hospitals productivities during the years 1994 to 1998 in Austria. The intervention was designed to implement new activity-based financing on a system of credit points. The main conclusion of Reichmann's study was that the technology (T) of the 22 hospitals under examination improved considerably, but the technical efficiency (E) did not also significantly change. From this, Reichmann concludes that the change in the technology was the result of an activity-based hospital financing system, as the hospitals managers were motivated to increase their numbers of credit points in order to possibly increase their share of funds.

In another study, Maniadakis and Thanassoulis (2000) evaluated the performance of 75 hospitals after the implementation of an "internal market", where the main intervention was to split between the providers and the purchasers in the health care services, e.g., to define and constitute sellers and buyers of health care services. The authors used data from the financial years 1991/1992 to 1995/1996 inclusive. The main result was that the productivity increased two years after the implementation of the "internal market" intervention but this interference did not lead to a long-term, significant improvement regarding productivity inside the National Health Service. Additionally, Maniadakis, et al. (1999) had evaluated the same intervention - the effect of the internal market reforms in the UK in the early 1990s. Their conclusion was that the reforms did not have considerable effect on hospital efficiency.

Tambour (1997) studied the impact of "the maximum waiting time rule" on productivity, which was imposed in Sweden in 1992. The intervention included a maximum waiting time guarantee for 12 procedures and if the patient did not receive services within the maximum waiting time, he or she had the right to be treated in another hospital at the cost of the initial/home hospital. In this study, Tambour used data from 20 ophthalmology departments from different hospitals. The data period was from 1988 to 1992. The conclusion of Tumour's study was that positive changes in productivity were mainly due to positive changes in technology rather than technical efficiency.

As described in the Introduction, reforms on managed inpatient flow were implemented at LUH during the years 2007 and 2009. In spite of the reforms, the average change in the TFP of the selected wards' (in terms of ward activity) was slightly lower during the later period of January to March 2009, than in the former period of January to March 2007. Therefore, in general, the impacts of interventions in the hospital sector seem to have only minimal effects on productivity. Notably, the studies show minor or sometimes negative impacts on technical efficiency whereas the effect on technical changes seems to be profound.

5 Conclusion

The focus of this study's research is to determine whether the TFP of selected inpatient wards at LUH changed following reforms in managed inpatient flow and, furthermore, if it did change, what caused those changes. Throughout the above chapters of this dissertation, the prerequisite and the platform for this study have been constructed and the data collection process, as well as the data used, have been described in detail and screened. Additionally, the necessary calculations have been executed and the results have been described, filtered, and analysed. What follows is a summarised conclusion based on the research question and the related subjects, in addition to recommendations for further work within this area and discussion about what this dissertation has added to further our knowledge in this area. The rationale for the use of certain methods within this dissertation is also further explained with additional discussion regarding the subject matter in the final chapter.

5.1 Summary of Findings and Conclusions

In the Results, Analysis and Discussion section, it was noted that the TFP of the wards during the aforementioned periods declined by approximately 3% on average between the periods of January to March 2007 and January to March 2009. More precisely, the TFP of four out of the five examined wards declined despite the fact that the ALOS decreased dramatically in all selected wards except one at LUH in the same period. The main conclusion based on these findings is that the TFP in the selected wards' activities was *slightly* lower on average *after* the reforms in inpatient flow were implemented (only one ward, A-6, is an exception because that ward increased its TFP while the ALOS increased remotely).

Also in the Results, Analysis and Discussion it was revealed that the measurements for the cause of changes in TFP are different between the DEA-MI calculation of the variables WLI and LD. The decrease in technical change is the most influential cause of measured TFP decreases when using average indices value of the variable WLI as a production variable in the DEA-MI calculation. However, the decrease in scale efficiency is the main cause of measured TFP change when using the average indices value of the variable LD as a production variable in the DEA-MI calculation. Therefore, it is concluded that the cause of the decreased TFP change is almost undistinguishable.

In summation of the above, the TFP of the selected wards decreased slightly or at least was unchanged after reforms on managed patient flow were implemented, despite the decrease in ALOS. This result seems to be somewhat misleading. However when one considers that the use of inputs, especially that the use of FTEs, increased between the two periods (refer to Table 6 in the Research Method section), this result is reasonable. Furthermore, the cause of the change in TFP is ambiguous, although the measured origin of the changes in TFP were different according to the use of the production variables WLI and LD in the period between January to March 2007 and January to March 2009.

Finally, this study indicates the relevance of measuring the change in TFP. Considering the case of LUH and the implemented reforms, incorrect or misleading conclusions might be drawn if basing those conclusions of success solely on measurements of ALOS. This can in turn, lead to incorrect actions being taken by LUH's managers. Furthermore, there are multiple reasons for measuring TFP (and efficiency) and its changes within the health care sector, such as, to develop a proper yardstick to measure the performance within this sector as well as to get indications regarding quality changes in health care services. The measurement of changes in TFP can be regarded as one of such proper yardsticks.

5.2 Recommendations

Based on the conclusions above, some theoretical recommendations are hereafter suggested, which are considered to be appropriately linked to the limitations of this dissertation. First, there is a need for further research on the suitability of using the DEA-MI method to measure the TFP change in many and various types of inpatient wards inside the same hospital. Regarding this suggestion, a researcher might ask and attempt to answer multiple questions related to the methodology, such as the following: Is it appropriate or reliable to use the same measurement (e.g., WLI) for LUH's wards in the same study because different wards serve multifarious types of activities and patients? How many wards are required for an accurate measurement? How many inputs and outputs are relevant to use in a study like this? In addition, what factors should the researcher(s) be aware of when performing such a study? These are just a few examples of questions to be answered.

When executing the measurement of TFP change in order to determine the effect of an intervention, it is essential that the intervention has evolved in order to determine that interventions full capability. As noted previously, the time span of the data used is overall questionable and, therefore, it is recommended that when a researcher measures the effect of some intervention he/she ensures that the intervention has come into full effect. If an intervention has not been fully realized then any measurements on positive effects on TFP may be flawed.

Furthermore, it is a recommendation, although a theoretical challenge, to develop a holistic method to form appropriate reactions based on the results and conclusions produced from the DEA-MI calculations. Part of developing a holistic method, is to develop a broad spectrum of operational research methods as well as managerial methods. These include, but are not limited to, the development of a simulation test to simulate the activity under examination and the adoption of a management's philosophy, such as the theory of constraints posited by Goldratt (2004).

It is strongly recommended that LUH's managers use and elaborate on relevant success factors, including a measurement of change in TFP for the hospital's wards, in order to ensure appropriate focuses and accurate decision-making regarding the management of the inpatient flow. According to Solà and Prior (2001, pp. 219-220), from an economical perspective, indicators such as economy (inputs), capacity (throughputs), efficiency, efficacy (outputs), and effectiveness (outcomes), must be measured precisely in order to determine all dimensions of success inside the health care arena. To measure and focus on ALOS exclusively is similar to concentrating solely on the turnover rate of stock, which might lead to increased inefficiency over a certain amount of time. Similarly, if a warehouse manager focuses solely on logistics and turnover of an activity, he or she ignores many other cost factors that affect the total cost of holding an inventory, such as order cost, capital cost, labor cost, and so on. By considering only the logistics and the turnover of the inpatients, a realistic estimation of cost is missing and the focus on ALOS is therefore, misleading, e.g., the comprehensive cost and the benefit are not calculated simultaneously. Furthermore, quality factors, administration factors, analysis of principals and agents, as well as the economic environment in the health care sector should be given consideration. These factors, among many others, signify that dimensions of success inside the health care sector are multiple and, indeed, it is a complicated task to accurately measure the effect of interventions or reforms.

It is also a recommendation that the managers of LUH develop a *forecast tool* for the demand of the inpatient services, which can in turn improve the efficiency of managed inpatient flow. Such a tool helps the managers to deal with the human aspect, technical aspect, artificial variation and natural variation of the activity by setting objectives. Further adding to this complexity of managed inpatient flow, one can divide management and application of managed patient flow into two categories: a category that relates to the human aspect and a category that relates to the technical aspect. Human aspects concern culture, traditions, habits, routines, customs, and norms, which all contribute to the human resource capability of an organisation. Technical aspects concern knowledge, methods, organisational structure, devices, instruments, equipment, and designs of information channels, all of which contribute to the technical capability of an organisation. However, this distinction is not pure because human aspects and technical aspects are interrelated and interdependent.

Furthermore, according to Haraden and Resar (2004, pp. 3-15), managed patient flow depends on two types of variations, namely, *natural variation* and *artificial variation*. Natural variation has its origins in the randomness of diseases, differing levels of staff competencies, and clinical abilities. These origins may be examined and new developments made by using historical data, regulations, and hospital requirements, respectively. A natural variation can affect patient flow but commonly plays a smaller role than artificial variation and tends to become relatively constant in the system. Haraden and Resar (2004, pp. 3-15) define artificial variation as personal preferences. They postulate that this variation is difficult to manage and needs to be eliminated because in the health care system, personal preferences are widely accepted but are challenged by clinical guidelines.

The definitions of the human aspect and the technical aspect of managed patient flow are related to the definitions of variation; the technical aspect can partly be regarded as a natural one, whereas the human aspect can be regarded as an artificial one. As these aspects are related to the variation, they are relevant in the construction of a structure design of managed patient flow. Haraden and Resar (2004, pp. 3-15), recommend that, in order to improve inpatient flow, variations in processes (i.e., on-going changes related to the flow) must be reduced and smoothed. But mapping, analysing, designing, and implementing a managed patient flow system in order to make the managed patient flow efficient throughout a hospital includes several extensive aspects of work, such as redesigning work structure and changing the management’s processes. To this point, one should keep in mind that an improved managed patient flow is not necessarily based only on increasing resources and/or harder work; it is about working with innovative thinking in planning and organising the working processes.

Although the human aspect (the artificial variation) of the managed patient flow is regarded as a greater challenge than the technical aspect, the health care system also needs methods and tools to improve the technical capabilities of health care organisations. This conclusion is based on research into the knowledge of the staff at LUH, which is relatively high when it comes to the human aspect and artificial variations, i.e., many of the managers are highly educated in different disciplines and possess formal degrees in human resource management. However, the knowledge regarding natural variations is relatively low in comparison and it is, therefore, recommended that the managers of LUH develop a forecast tool, which in turn improves both the technical aspect and human aspect of the organisation along with decreases in natural and artificial variation within LUH.

As discussed above the validity and credibility of some variables used are questionable and, therefore, the result and conclusion should be critically reviewed. This fact leads to a final recommendation that the managers of LUH further examine how data regarding the hospital's activities are defined, recorded, and collected.

5.3 Contribution to Knowledge

In the literature reviewed for this dissertation, no references were discovered where such a small "sample" of wards were used to perform DEA-MI analysis as in this dissertation. In addition, the idea of studying wards where inpatient managed flow was implemented at the same time in several wards, with different activities and within the same hospital, seems to be yet unexplored. Furthermore, the calculation of VRS-IO and VRS-OO method-variations and the use of the Benchmark model in the Appendix A explores why the CRS method is more preferable than the VRS method, as claimed by the scholars. Therefore, this dissertation has broadened the interpretation of the Benchmark model and, further, the fact that the CRS method gives more reliable and/or usable result than the VRS method has been confirmed by results based on real data.

5.4 Self-Reflection

The research into this subject and the completion of this dissertation has not been a straightforward task. The idea for this research question arose approximately five years ago and, since that time, significant effort has gone into the collection and processing of the related data. Substantial consideration has also been given to discovering a proper method with which to answer the research question. In addition, considerable time and effort has gone into writing this dissertation in a foreign language and that partly explains why this dissertation was withdrawn after viva in October 2010.

In the end, to write this MSc dissertation has been altogether a learning process about the academic way of thinking, as well as the adoption of academic methodologies and working processes. The challenges of the work, particularly the challenge of learning from mistakes and continuing the search for knowledge, give purpose to all of the effort it entails. Without discovering that purpose, I believe it would be difficult to complete a dissertation such as this one.

Glossary

Bjarnadóttir and Herbertsdóttir (2009, p. 1) introduce the patient classification system which is in LUH. The patient classification system is based upon a methodology originating from Medicus/Quadramed. The patient classification system is used to estimate what level of nursing care service each inpatient needs on a daily basis and consists of 36 factors regarding need for nursing, which are assessed once in every 24 hour period to estimate the physical status of the inpatient.

Nursing-Load-Index (NLI) is used to describe the nursing weight for an individual patient. Nursing weight is estimated according to what level of nursing care each patient needs; the nursing need is based on the health status of the patient. The NLI is categorized into one out of six groups by the number of points earned by the 36 nursing need-factors. The groups are classified by point intervals, see the following table for further information. The groups indicate how much nursing time each patient in every nursing category needs within the next 24 hour period. One NLI equals to 4.5 hours of nursing care.

Work-Load-Index (WLI) is the accumulated sum of all wards' patients' NLI. Bjarnadóttir and Herbertsdóttir (1997, pp. 12-13) give the following example of how a patient or patients is or are categorized according to NLI and WLI.

Category of NLI	Number of Patients	NLI	WLI
Category 1:	8	0.7	5.6
Category 2:	10	1.0	10.0
Category 3:	6	1.5	9.0
Category 4:	1	2.3	2.3
Category 5:	0	3.1	0
Category 6:	0	4.6	0
Sum	**25**		**26.9**

Table 13: Example of the WLI Calculation

From this information, the average NLI for ward A is calculated as 26.9 / 25 = 1.08. The total nursing hours required are: 26.9 * 4.5 = 121 hours.

Diagnosis-Related Group System (DRG) is a system used to classify hospital cases. According to the homepage of LUH, landspitali.is (N/A) the system consists of approximately 520 groups, where each group/category include diagnoses that are expected to use similar hospital resources as part of the prospective payment system, i.e., the DRG system is used to estimate the complete cost of each inpatient in a certain diagnosis group/category while hospitalized. Among fundamental components inside the DRG system used for the approximation of the cost are: International Classification of Diseases (ICD), procedures, age, sex, discharge status, and the presence of complications/co-morbidities. The DRG system has been in the developmental phase for the last decade at LUH.

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Appendix A: Calculation by the VRS Method

Introduction

Appendix A provides an overview of the VRS method, including calculating the TFP change by using the VRS method, exploring/analysing the results, and finally, drawing conclusions from the results. Such aforementioned conclusions include whether the VRS method gives a reliable result with which to calculate the MI and, therefore, with which to draw conclusions about the change in TFP for the wards under examination. Furthermore, the conclusions are discussed relative to the concepts put forth by Jacobs et al. (2006, p. 138) in which they propose that using the VRS method to calculate the MI may not correctly measure the changes in TFP.

Scale of the Wards under Examination

As illustrated in the Literature Review section, it is appropriate to apply the VRS method when scale inefficiency exists inside the production units, which is a common situation in the health care sector. Furthermore, the wards' sizes were relatively different, as displayed in the following tables. Table A. 1 and Table A. 2 show each ward's relative size of inputs and the ward's relative size production calculations:

Ward Code	Percentage of the Biggest Ward - Number of Beds 2007	Percentage of the Biggest Ward - Number of Beds 2009	Percentage of the Biggest Ward - Number of FTE´s 2007	Percentage of the Biggest Ward - Number of FTEs 2009
A-6	100%	100%	100%	100%
A-7	97%	95%	86%	78%
B-4	85%	100%	66%	67%
11-E	59%	70%	68%	59%
11-G	59%	70%	64%	62%

Table A. 1: Relative Sizes of the Wards According to the Numbers of Beds and Numbers of FTEs 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$

Ward Code	Precentage of the Biggest Ward - Number of WLIs 2007	Precentage of the Biggest Ward - Number of WLIs 2009	Precentage of the Biggest Ward - Number of LDs 2007	Precentage of the Biggest Ward - Number of LDs 2009	Precentage of the Biggest Ward - Number of DRGs 2007	Precentage of the Biggest Ward - Number of DRGs 2009
A-6	92%	82%	85%	92%	100%	83%
A-7	100%	88%	100%	100%	100%	100%
B-4	95%	100%	75%	96%	28%	37%
11-E	57%	53%	55%	58%	61%	72%
11-G	62%	52%	57%	54%	87%	95%

Table A. 2: Relative Sizes of the Wards According to WLIs, LDs and DRGs 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$

These differences in the wards' sizes indicate that it is possible that some wards were not operating at optimal scale. A manner with which to determine the effect of size on the context between input and output is by plotting input and output variables. For example, the number of beds and number of WLIs are shown in Figure A. 1 below:

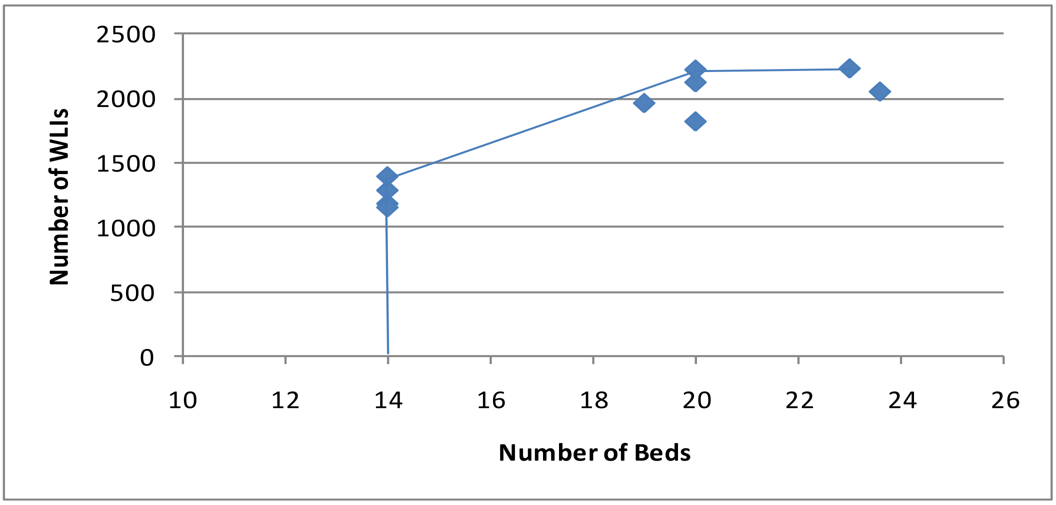

Figure A. 1: Relation between Number of Beds and Number of WLIs

There is a strong indication that the productivity (efficiencies) of the wards are possibly affected by the wards' sizes because the chosen frontier is shaped like the VRS frontier, shown in Figure 2 in the Literature Review section. Therefore, the VRS method seems to be suitable for the proposed DEA-MI calculation.

Methods

The VRS-IO method variation is preferred according to the deduction that the IO variation is appropriate in the calculation because the wards managers can only control the use of inputs but not the quantity of outputs produced. Therefore, Jacobs et al. adopt the appropriate mathematical expression (2006, pp. 136-137)[16] and shown in the following calculations:

$$\frac{1}{D_i^t(x_{i,n}^t, y_{i,m}^t)} = min_{\phi\lambda}\phi_i$$ **(A.DEAMI-VRS I)**

Subject to: (t = 2007$_{\text{January - March}}$)

$$\phi_i x_{i,n}^t - \sum_{i=1}^{5} X_{i,n}^t \lambda_i \geq 0$$ (n = 1, 2, 3)

$$-y_{i,m}^t + \sum_{i=1}^{5} Y_{i,m}^t \lambda_i \geq 0$$ (m = 1)

$$\sum_{i=1}^{5} \lambda_i = 1$$ (i = 1, 2, 3, 4, 5)

$$\lambda_i \geq 0$$

$$\frac{1}{D_j^{t+1}(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = min_{\phi\lambda}\phi_j$$ **(A.DEAMI-VRS II)**

Subject to: (t+1 = 2009$_{\text{January - March}}$)

$$\phi_j x_{j,n}^{t+1} - \sum_{j=6}^{10} X_{j,n}^{t+1} \lambda_j \geq 0$$ (n = 1, 2, 3)

$$-y_{j,m}^{t+1} + \sum_{j=6}^{10} Y_{j,m}^{t+1} \lambda_j \geq 0$$ (m = 1)

$$\sum_{j=6}^{10} \lambda_j = 1$$ (j = 6, 7, 8, 9, 10)

$$\lambda_j \geq 0$$

$$\frac{1}{D_i^t(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = min_{\phi\lambda}\phi_j$$ **(A.DEAMI-VRS III)**

Subject to: (t = 2007$_{\text{January - March}}$)

(t+1 = 2009$_{\text{January - March}}$)

$$\phi_j x_{j,n}^{t+1} - \sum_{i=1}^{5} X_{i,n}^t \lambda_i \geq 0$$ (n = 1, 2, 3)

$$-y_{j,m}^{t+1} + \sum_{i=1}^{5} Y_{i,m}^t \lambda_i \geq 0$$ (m = 1)

$$\sum_{i=1}^{5} \lambda_i = 1$$ (i = 1, 2, 3, 4, 5)

$$\lambda_i \geq 0$$ (j = 6, 7, 8, 9, 10)

[16] DEA-MI calculation is executed in two phases. First, DEA calculation is executed and, second, the MI calculation is executed.

$$\frac{1}{D_j^{t+1}(x_{i,n}^{t}, y_{i,m}^{t})} = min_{\phi\lambda}\phi_i$$ **(A.DEAMI-VRS IV)**

Subject to: (t = $2007_{\text{January - March}}$)

(t+1 = $2009_{\text{January - March}}$)

$\phi_i x_{i,n}^t - \sum_{j=6}^{10} X_{j,n}^{t+1}\lambda_j \geq 0$ (n = 1, 2, 3)

$-y_{i,m}^t + \sum_{j=6}^{10} Y_{j,m}^{t+1}\lambda_j \geq 0$ (m = 1)

$\sum_{j=6}^{10} \lambda_j = 1$ (i = 1, 2, 3, 4, 5)

$\lambda_j \geq 0$ (j = 6, 7, 8, 9, 10)

$$\frac{1}{D_i^{t}(x_{i,n}^{t}, y_{i,m}^{t})} = min_{\phi\lambda}\phi_i$$ **(A.DEAMI-CRS I)**

Subject to: (t = $2007_{\text{January - March}}$)

$\phi_i x_{i,n}^t - \sum_{i=1}^{5} X_{i,n}^{t}\lambda_i \geq 0$ (n = 1, 2, 3)

$-y_{i,m}^t + \sum_{i=1}^{5} Y_{i,m}^{t}\lambda_i \geq 0$ (m = 1)

$\lambda_i \geq 0$ (i = 1, 2, 3, 4, 5)

$$\frac{1}{D_j^{t+1}(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = min_{\phi\lambda}\phi_j$$ **(A.DEAMI-CRS II)**

Subject to: (t+1 = $2009_{\text{January - March}}$)

$\phi_j x_{j,n}^{t+1} - \sum_{j=6}^{10} X_{j,n}^{t+1}\lambda_j \geq 0$ (n = 1, 2, 3)

$-y_{j,m}^{t+1} + \sum_{j=6}^{10} Y_{j,m}^{t+1}\lambda_j \geq 0$ (m = 1)

$\lambda_j \geq 0$ (j = 6, 7, 8, 9, 10)

Where:

i is an index for the five wards at time t.

j is an index for the same five wards but at time t+1.

n is an index for the three definite types of inputs.

m is an index for the one definite type of output.

ϕ_i and ϕ_j are vectors that measures the efficiency of the ward's use of input(s) at time t and t+1 respectively, comparing to the frontiers at time t+1 and t.

λ_i and λ_j are vectors of efficiency elements (weights) for the wards at time t and t+1 respectively.

$X_{i,n}^t$ and $X_{j,n}^{t+1}$ are input matrices at time t (or t+1) for all the wards.

$Y^t_{i,m}$ and $Y^{t+1}_{j,m}$ are output matrices at time t (or t+1) for all the wards.

$x^t_{i,n}$ and $x^{t+1}_{j,n}$ are input vectors at time t (or t+1) for the ward under comparison.

$y^t_{i,n}$ and $y^{t+1}_{j,n}$ are output vectors at time t (or t+1) for the ward under comparison.

λ_i is a vector of efficiency elements (weights) given ward number i in the calculation. If a ward under calculation is efficient, then λ is one (1) for that ward, but if the ward is not efficient, then the method, according to Jacobs et al. (2006, p. 98), creates a composite peer ward by a linear combination of other wards under calculation.

As explained in the Literature Review, Jacobs et al. (2006, p. 132), note the components of the Malmquist Index as MI = P x S x T. Therefore, by using the equations above, an adaption of MI to the VRS-IO implementation gives:

$$\text{A.MI}_{\text{IO}} = \frac{\text{A.DEAMI}-\text{VRS II}}{\text{A.DEAMI}-\text{VRS I}} \text{ x } \frac{\frac{\text{A.DEAMI}-\text{CRS II}}{\text{A.DEAMI}-\text{VRS II}}}{\frac{\text{A.DEAMI}-\text{CRS I}}{\text{A.DEAMI}-\text{VRS I}}} \text{ x } \left[\frac{\text{A.DEAMI}-\text{VRS III}}{\text{A.DEAMI}-\text{VRS II}} \text{ x } \frac{\text{A.DEAMI}-\text{VRS I}}{\text{A.DEAMI}-\text{VRS IV}}\right]^{½}$$

The inverse of the VRS-IO method-variation is the VRS-OO variation. Therefore, to be able to compare the VRS-IO calculation, the following VRS-OO equations are also calculated:

$$\frac{1}{D^t_i(x^{\,t}_{i,n}, y^t_{i,m})} = max_{\rho\lambda}\rho_i$$ **(A.DEAMI-VRS V)**

Subject to: (t = $2007_{\text{January - March}}$)

$$x^t_{i,n} - \sum_{i=1}^{5} X^t_{i,n}\lambda_i \geq 0$$ (n = 1, 2, 3)

$$-\rho_i y^t_{i,m} + \sum_{i=1}^{5} Y^t_{i,m}\lambda_i \geq 0$$ (m = 1)

$$\sum_{i=1}^{5} \lambda_i = 1$$ (i = 1, 2, 3, 4, 5)

$$\lambda_i \geq 0$$

$$\frac{1}{D_j^{t+1}(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = max_{\rho\lambda}\rho_j$$ **(A.DEAMI-VRS VI)**

Subject to: (t+1 = $2009_{\text{January - March}}$)

$x_{j,n}^{t+1} - \sum_{j=6}^{10} X_{j,n}^{t+1}\lambda_j \geq 0$ (n = 1, 2, 3)

$-\rho_j y_{j,m}^{t+1} + \sum_{j=6}^{10} Y_{j,m}^{t+1}\lambda_j \geq 0$ (m = 1)

$\sum_{j=6}^{10} \lambda_j = 1$ (j = 6, 7, 8, 9, 10)

$\lambda_j \geq 0$

$$\frac{1}{D_i^{t}(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = max_{\rho\lambda}\rho_j$$ **(A.DEAMI-VRS VII)**

Subject to: (t = $2007_{\text{January - March}}$)

$x_{j,n}^{t+1} - \sum_{i=1}^{5} X_{i,n}^{t}\lambda_i \geq 0$ (t+1 = $2009_{\text{January - March}}$)

(n = 1, 2, 3)

$-\rho_j y_{j,m}^{t+1} + \sum_{i=1}^{5} Y_{i,m}^{t}\lambda_i \geq 0$ (m = 1)

$\sum_{i=1}^{5} \lambda_i = 1$ (i = 1, 2, 3, 4, 5)

$\lambda_i \geq 0$ (j = 6, 7, 8, 9, 10)

$$\frac{1}{D_j^{t+1}(x_{i,n}^{t}, y_{i,m}^{t})} = max_{\rho\lambda}\rho_i$$ **(A.DEAMI-VRS VIII)**

Subject to: (t = $2007_{\text{January - March}}$)

(t+1 = $2009_{\text{January - March}}$)

$x_{i,n}^{t} - \sum_{j=6}^{10} X_{j,n}^{t+1}\lambda_j \geq 0$ (n = 1, 2, 3)

$-\rho_i y_{i,m}^{t} + \sum_{j=6}^{10} Y_{j,m}^{t+1}\lambda_j \geq 0$ (m = 1)

$\sum_{j=6}^{10} \lambda_j = 1$ (i = 1, 2, 3, 4, 5)

$\lambda_j \geq 0$ (j = 6, 7, 8, 9, 10)

$$\frac{1}{D_i^{t}(x_{i,n}^{t}, y_{i,m}^{t})} = max_{\rho\lambda}\rho_i$$ **(A.DEAMI-CRS III)**

Subject to: (t = $2007_{\text{January - March}}$)

$x_{i,n}^{t} - \sum_{i=1}^{5} X_{i,n}^{t}\lambda_i \geq 0$ (n = 1, 2, 3)

$-\rho_i y_{i,m}^{t} + \sum_{i=1}^{5} Y_{i,m}^{t}\lambda_i \geq 0$ (m = 1)

$\lambda_i \geq 0$ (i = 1, 2, 3, 4, 5)

$$\frac{1}{D_j^{t+1}(x_{j,n}^{t+1}, y_{j,m}^{t+1})} = max_{\rho\lambda}\rho_j \qquad \textbf{(A.DEAMI-CRS IV)}$$

Subject to: (t+1 = $2009_{\text{January - March}}$)

$$x_{j,n}^{t+1} - \sum_{j=6}^{10} X_{j,n}^{t+1}\lambda_j \geq 0 \qquad (n = 1, 2, 3)$$

$$-\rho_j y_{j,m}^{t+1} + \sum_{j=6}^{10} Y_{j,m}^{t+1}\lambda_j \geq 0 \qquad (m = 1)$$

$$\lambda_j \geq 0 \qquad (j = 6, 7, 8, 9, 10)$$

Where:

$\rho_i$and $\rho_j$are vectors that measures the efficiency of the ward's use of output at time t and t+1 respectively, comparing to the frontiers at time t+1 and t.

Former description above of all other variables is also valid here.

Consequently, the presentation of the MI index will alter in that its formulation depends on whether the input or output orientation is used:

$$\text{A.MI}_{\text{OO}} = \frac{\text{A.DEAMI}-\text{VRS VI}}{\text{A.DEAMI}-\text{VRS V}} \text{ x } \frac{\frac{\text{A.DEAMI}-\text{CRS IV}}{\text{A.DEAMI}-\text{VRS VI}}}{\frac{\text{A.DEAMI}-\text{CRS III}}{\text{A.DEAMI}-\text{VRS V}}} \text{ x } \left[\frac{\text{A.DEAMI}-\text{VRS VII}}{\text{A.DEAMI}-\text{VRS VI}} \text{ x } \frac{\text{A.DEAMI}-\text{VRS V}}{\text{A.DEAMI}-\text{VRS VIII}}\right]^{½}$$

A further elaboration of the equations above reveals that a calculation of equations A:DEAMI-VRS III, A.DEAMI-VRS IV, A.DEAMI-VRS VII and A.DEAMI-VRS VIII yields a result with no feasible solution within the equations' constraints. In the Literature Review section, the possible reasons were explained along with discussion on the Zhu benchmarking models.

Result and Analysis

The results and the analysis are modified by the purpose of the calculation, i.e., in order to conclude on the usefulness of the VRS method, the results of calculations by the CRS method are presented as well. All of the results' values are viewable in Appendix B.

Ward A-6

For Ward A-6, feasible solutions exist for all methods-variations except for the VRS-IO method-variation for calculation of the LD production variable. It is concluded, by analysing the VRS-IO and VRS-OO calculation of the LD variable, that the production level of A-6 for the year 2007 is the largest one compared to the frontier of the year 2009. Moreover, the results are consistent between different definitions of productions and by variation, i.e., both the VRS-IO and CRS-IO method-variation give MI values below 1.0 and both the VRS-OO and CRS-OO give MI values above 1.0. The average MI values for the applicable definitions of products by the VRS-IO method-variation is 0.96. It is 0.93 by the CRS-IO method variation, 1.06 by the VRS-OO method-variation, and 1.07 for CRS-OO. According to these values, the VRS method estimates the MI value to be fairly similar to the MI value by the CRS method, which indicates that the VRS method gives a reasonable estimation of the MI.

Ward A-7

A calculation of proposed TFP change for Ward A-7 by the VRS-IO method-variation for all variables of production (e.g., WLI, LD, and DRG) results in no feasible solution. A feasible solution exits for all other methods-variation. By referring to the benchmark method in Research Methods, it is concluded that the output level by A-7 for the year 2007 is the largest compared to the frontier of the year 2009 for the calculation of the WLI, LD, and DRG definitions of production.

The calculation by VRS-OO method-variation results in feasible solutions for all production variables, however, these results are inconsistent. The average MI value for the WLI and LD production variables is 0.83 when the MI value for the DRG variable is 1.19. There is also an inconsistency when calculating different variables of production, specifically when the CRS-IO method-variation is applied. The average MI value, by applying the CRS-IO method variation for the WLI and LD variables is 1.04 and the MI value for the DRG is 0.85. In addition, these same values when calculated by the CRS-OO method are 0.96 and 1.18. From these figures, analysis of the results for the change of TFP of Ward A-7 is ambiguous by comparing the results of CRS method and VRS method.

Ward B-4

By calculating the TFP change of Ward B-4 by VRS-IO method-variation, there exist feasible solutions for all the definitions of the products. However, correspondingly, there exists no feasible solution when conducting the calculations by the VRS-OO method. The results for B-4 are inconsistent, both between methods-variations and between definitions of productions. Firstly, there is a difference between the VRS-IO and CRS-IO methods-variations for WLIs and LDs. Secondly, the MI value for DRGs is lower than 1.0, both for VRS-IO and CRS-IO, while WLI is higher than 1.0 for the CRS-IO method. The MI value for the LDs is higher than 1.0, both for VRS-IO and CRS-IO methods. Notably, these calculations give no feasible solutions for all the definitions of productions by the VRS-OO. Analysis performed by the VRS-IO and the VRS-OO methods reveal that the input level for B-4 for the year 2007 is the smallest one compared to the benchmarking frontier in the year 2009 for the calculations of the productions WLI, LD, and DRG.

Calculation by the VRI-IO method-variation gives 0.84 as a MI value. Subsequently, when the CRS-IO method-variation is used, it gives consistent solutions when WLI and LD are defined as B-4 ward productions, i.e., the average MI value is 1.03. However, when it comes to the DRG definition of production, the MI value is 0.7. The calculation of CRS-OO method-variation gives MI values that are 0.97 and 1.43, respectively. Similar to the conclusion for Ward A-7, the results regarding the change of TFP between the first three months in the year 2007 and the first three months in the year 2009 for Ward B-4 are rather ambiguous when comparing the methods used.

Ward 11-E

The results for Ward 11-E show that the VRS-IO and CRS-IO methods yield results for the calculations of the MI value for LDs that are higher than 1.0, while the result for DRGs is lower than 1.0. The calculation for the WLIs is slightly more ambiguous because the VRS-IO method gives a value that is below 1.0, while the CRS-IO method gives a value that is higher than one 1.0. Similarly to B-4, calculation by the VRS-OO method does not give a feasible solution for any of the definitions of the ward's productions. Analysis carried out by the VRS-IO and VRS-OO methods reveal that the input level for 11-E for the year 2007 is the smallest one compared to the benchmark frontier in the year 2009, and vice versa for the calculations of all defined productions (e.g., WLI, LD, and DRG).

The analysis of the calculated MI values using the VRS-IO method is slightly ambiguous because the MI values for the products WLI and LD are 0.99 and 1.03, respectively, while the calculated MI value for the product variable DRG is 0.90. The calculation of TFP change by CRS-IO method-variation for products WLI and LD yields the average MI of 1.03, correspondingly, the MI value for the product definition

DRG is 0.73. The MI values for the average values of the WLI and LD by the CRS-IO method-variation and VRS-IO method-variation seem to give similar results.

Ward 11-G

As for Wards B-4 and 11-E, the VRS-OO calculation does not provide feasible solutions for any of the definitions of the productions for Ward 11-G. Furthermore, the VRS-IO provides no feasible solution for the DRGs variable. There is, however, a consistent result for the production definitions of WLIs and LDs by the VRS-IO and CRS-IO methods-variations, i.e., the MI values are above 1.0 for these definitions of the ward's productions. On the contrary, the MI values by the CRS-IO method-variation for DRGs is lower than 1.0. Analysis of the VRS-IO and VRS-OO methods reveal that the input level for 11-G for the year 2007 is the smallest compared to the frontier of the year 2009, and vice versa for the calculation of the WLI, LD, and DRG.

The average MI value is 1.17 for the variables WLI and LD by the VRS-IO method-variation. The CRS-IO method-variation for WLI and LD gives the average MI of 1.15 and the MI value for the DRG variable is 0.84. The same values for the CRS-OO method are 0.87 and 1.19, respectively. An analysis of the results shows that the outcomes between the various methods seem to be similar.

Conclusion

The results and the analysis reveal that the VRS method is not appropriate to apply to the present material due to a lack of reliable solutions and likeliness of non-feasible solutions. The lack of reliable solutions was found in situations where there was a difference between the results of the VRS-IO method-variation and the VRS-OO method-variation. The manifestation of this conclusion is that the VRS-IO method-variation does not measure the scale and pure efficiency distance equal to VRS-OO method-variation because the boundary of the λ constraint ($\sum_i^0 \lambda_i = 1$) on the efficiency frontiers forces the shape and, therefore, the location of calculated efficiency frontiers. Furthermore, a difference in the results between the VRS-IO method-variation and CRS-IO method-variation creates a suspicion of the non-reliability of the results in VRS along with the former explanation. The lack of solution resulting from a situation of "non-feasible solutions" alone explains why the VRS method is not beneficial.

Based on the above premises, as well as confirmations from other authors (Jacobs et al., 2006, p.138), use of the VRS method for the calculation of the MI may not correctly measure the changes in total factor productivity (e.g., efficiency) and, therefore, the CRS implementation of DEA-MI is a more reliable alternative with which to measure efficiency change.

Appendix B: Tables of Result

Result for CRS Input Oriented Calculations

Ward (WLI)	P	x	S	=	E	x	T	=	M
A-6 2007 - 2009	0.89	x	1.05	=	0.94	x	1.00	=	0.94
A-7 2007 - 2009	1.14	x	0.84	=	0.96	x	1.06	=	1.02
B-4 2007 - 2009	1.00	x	1.00	=	1.00	x	1.05	=	1.05
11-E 2007 - 2009	1.00	x	1.01	=	1.01	x	1.00	=	1.02
11-G 2007 - 2009	1.00	x	1.13	=	1.13	x	1.00	=	1.13
Average	**1.01**		**1.01**		**1.01**		**1.02**		**1.03**

Table B. 1: Result for DEA-MI 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$; CRS-IO Method for WLI

Ward (LD)	P	x	S	=	E	x	T	=	M
A-6 2007 - 2009	0.94	x	1.00	=	0.93	x	0.99	=	0.93
A-7 2007 - 2009	1.00	x	1.01	=	1.01	x	1.06	=	1.07
B-4 2007 - 2009	1.00	x	1.00	=	1.00	x	1.02	=	1.02
11-E 2007 - 2009	1.00	x	1.04	=	1.04	x	1.00	=	1.04
11-G 2007 - 2009	1.00	x	1.17	=	1.17	x	1.00	=	1.17
Average	**0.99**		**1.04**		**1.03**		**1.01**		**1.04**

Table B. 2: Result for DEA-MI 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$; CRS-IO Method for LD

Ward (DRG)	P	x	S	=	E	x	T	=	M
A-6 2007 - 2009	1.07	x	1.06	=	1.13	x	0.83	=	0.93
A-7 2007 - 2009	1.00	x	1.00	=	1.00	x	0.85	=	0.85
B-4 2007 - 2009	1.00	x	0.84	=	0.84	x	0.84	=	0.70
11-E 2007 - 2009	1.00	x	0.91	=	0.91	x	0.80	=	0.73
11-G 2007 - 2009	1.00	x	1.00	=	1.00	x	0.84	=	0.84
Average	**1.01**		**0.96**		**0.98**		**0.83**		**0.81**

Table B. 3: Result for DEA-MI 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$; CRS-IO Method for DRG

Result for CRS Output Oriented Calculation

Ward (WLI)	P	x	S	=	E	x	T	=	M
A-6 2007 - 2009	0.94	x	1.14	=	1.07	x	1.00	=	1.06
A-7 2007 - 2009	0.88	x	1.18	=	1.04	x	0.94	=	0.98
B-4 2007 - 2009	1.00	x	1.00	=	1.00	x	0.95	=	0.95
11-E 2007 - 2009	1.00	x	0.99	=	0.99	x	1.00	=	0.98
11-G 2007 – 2009	0.98	x	0.91	=	0.89	x	1.00	=	0.88
Average	**0.96**		**1.04**		**1.00**		**0.98**		**0.97**

Table B. 4: Result for DEA-MI 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$; CRS-OO Method for WLI

Ward (LD)	P	x	S	=	E	x	T	=	M
A-6 2007 – 2009	1.06	x	1.01	=	1.07	x	1.01	=	1.08
A-7 2007 – 2009	1.00	x	0.99	=	0.99	x	0.95	=	0.94
B-4 2007 – 2009	1.00	x	1.00	=	1.00	x	0.98	=	0.98
11-E 2007 – 2009	1.00	x	0.96	=	0.96	x	1.00	=	0.96
11-G 2007 – 2009	0.93	x	0.92	=	0.85	x	1.00	=	0.85
Average	**1.00**		**0.98**		**0.97**		**0.99**		**0.96**

Table B. 5: Result for DEA-MI 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$; CRS-OO Method for LD

Ward (DRG)	P	x	S	=	E	x	T	=	M
A-6 2007 – 2009	0.89	x	1.00	=	0.89	x	1.21	=	1.07
A-7 2007 – 2009	1.00	x	1.00	=	1.00	x	1.18	=	1.18
B-4 2007 – 2009	1.00	x	1.19	=	1.19	x	1.20	=	1.43
11-E 2007 – 2009	1.00	x	1.10	=	1.10	x	1.26	=	1.38
11-G 2007 – 2009	1.00	x	1.00	=	1.00	x	1.19	=	1.19
Average	**0.98**		**1.06**		**1.03**		**1.21**		**1.25**

Table B. 6: Result for DEA-MI 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$; CRS-OO Method for DRG

Result for VRS Input Oriented Calculations

Ward (WLI)	P	x	S	=	E	x	T	=	M
A-6 2007 – 2009	0.89	x	1.05	=	0.94	x	1.01	=	0.95
A-7 2007 – 2009	1.14	x	0.84	=	0.96	x	NFS	=	NFS
B-4 2007 – 2009	1.00	x	1.00	=	1.00	x	0.73	=	0.73
11-E 2007 – 2009	1.00	x	1.01	=	1.01	x	0.98	=	0.99
11-G 2007 – 2009	1.00	x	1.13	=	1.13	x	1.01	=	1.14
Average	**1.01**		**1.01**		**1.01**		**0.94**		**0.95**

Table B. 7: Result for DEA-MI 2007$_{January - March}$ and 2009$_{January - March}$; VRS-IO Method for WLI

Ward (LD)	P	x	S	=	E	x	T	=	M
A-6 2007 – 2009	0.94	x	0.17	=	0.16	x	NFS	=	NFS
A-7 2007 – 2009	1.00	x	1.01	=	1.01	x	NFS	=	NFS
B-4 2007 – 2009	1.00	x	1.00	=	1.00	x	0.95	=	0.95
11-E 2007 – 2009	1.00	x	1.04	=	1.04	x	0.99	=	1.03
11-G 2007 – 2009	1.00	x	1.17	=	1.17	x	1.02	=	1.19
Average	**0.99**		**0.88**		**0.88**		**0.98**		**1.06**

Table B. 8: Result for DEA-MI 2007$_{January - March}$ and 2009$_{January - March}$; VRS-IO Method for LD

Ward (DRG)	P	x	S	=	E	x	T	=	M
A-6 2007 – 2009	1.07	x	1.06	=	1.13	x	0.86	=	0.97
A-7 2007 – 2009	1.00	x	1.00	=	1.00	x	NFS	=	NFS
B-4 2007 – 2009	1.00	x	0.84	=	0.84	x	1.01	=	0.85
11-E 2007 – 2009	1.00	x	0.91	=	0.91	x	0.88	=	0.80
11-G 2007 – 2009	1.00	x	1.00	=	1.00	x	NFS	=	NFS
Average	**1.01**		**0.96**		**0.98**		**0.92**		**0.87**

Table B. 9: Result for DEA-MI 2007$_{January - March}$ and 2009$_{January - March}$; VRS-IO Method for DRG

Result for VRS Output Oriented Calculations

Ward (WLI)	P	x	S	=	E	x	T	=	M
A-6 2007 – 2009	0.94	x	1.14	=	1.07	x	1.00	=	1.06
A-7 2007 – 2009	0.88	x	0.85	=	0.75	x	1.01	=	0.76
B-4 2007 – 2009	1.00	x	1.00	=	1.00	x	NFS	=	NFS
11-E 2007 – 2009	1.00	x	1.01	=	1.01	x	NFS	=	NFS
11-G 2007 – 2009	0.98	x	1.10	=	1.07	x	NFS	=	NFS
Average	**0.96**		**1.02**		**0.98**		**1.00**		**0.91**

Table B. 10: Result for DEA-MI 2007$_{January - March}$ and 2009$_{January - March}$; VRS-OO Method for WLI

Ward (LD)	P	x	S	=	E	x	T	=	M
A-6 2007 - 2009	1.06	x	1.01	=	1.07	x	0.97	=	1.04
A-7 2007 - 2009	1.00	x	0.99	=	0.99	x	0.91	=	0.90
B-4 2007 - 2009	1.00	x	1.00	=	1.00	x	NFS	=	NFS
11-E 2007 - 2009	1.00	x	0.96	=	0.96	x	NFS	=	NFS
11-G 2007 - 2009	0.93	x	0.92	=	0.85	x	NFS	=	NFS
Average	**1.00**		**0.98**		**0.97**		**0.94**		**0.97**

Table B. 11: Result for DEA-MI 2007$_{January - March}$ and 2009$_{January - March}$; VRS-OO Method for LD

Ward (DRG)	P	x	S	=	E	x	T	=	M
A-6 2007 - 2009	0.89	x	1.00	=	0.89	x	1.21	=	1.07
A-7 2007 - 2009	1.00	x	1.00	=	1.00	x	1.19	=	1.19
B-4 2007 - 2009	1.00	x	1.19	=	1.19	x	NFS	=	NFS
11-E 2007 - 2009	1.00	x	1.10	=	1.10	x	NFS	=	NFS
11-G 2007 - 2009	1.00	x	1.00	=	1.00	x	NFS	=	NFS
Average	**0.98**		**1.06**		**1.03**		**1.20**		**1.13**

Table B. 12: Result for DEA-MI 2007$_{January - March}$ and 2009$_{January - March}$; VRS-OO Method for DRG

Appendix C: Figures of Frontiers

Frontiers: WLIs Scattered Against Input

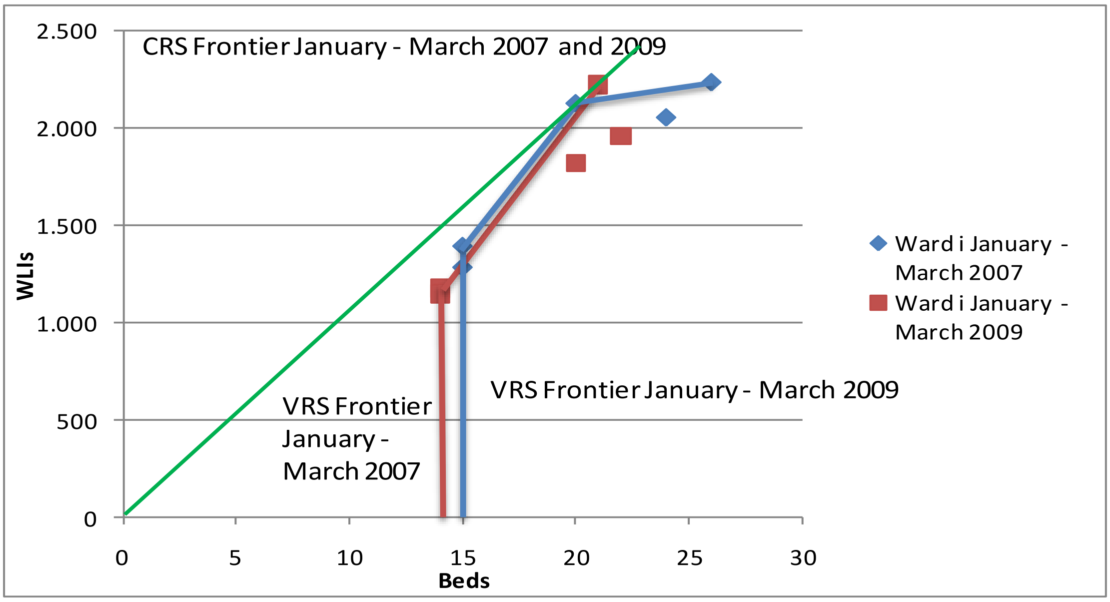

Figure C. 1: VRS and CRS Frontiers in the WLIs-Beds Spectrum 2007 $_{January\ -\ March}$ and 2009 $_{January\ -\ March}$

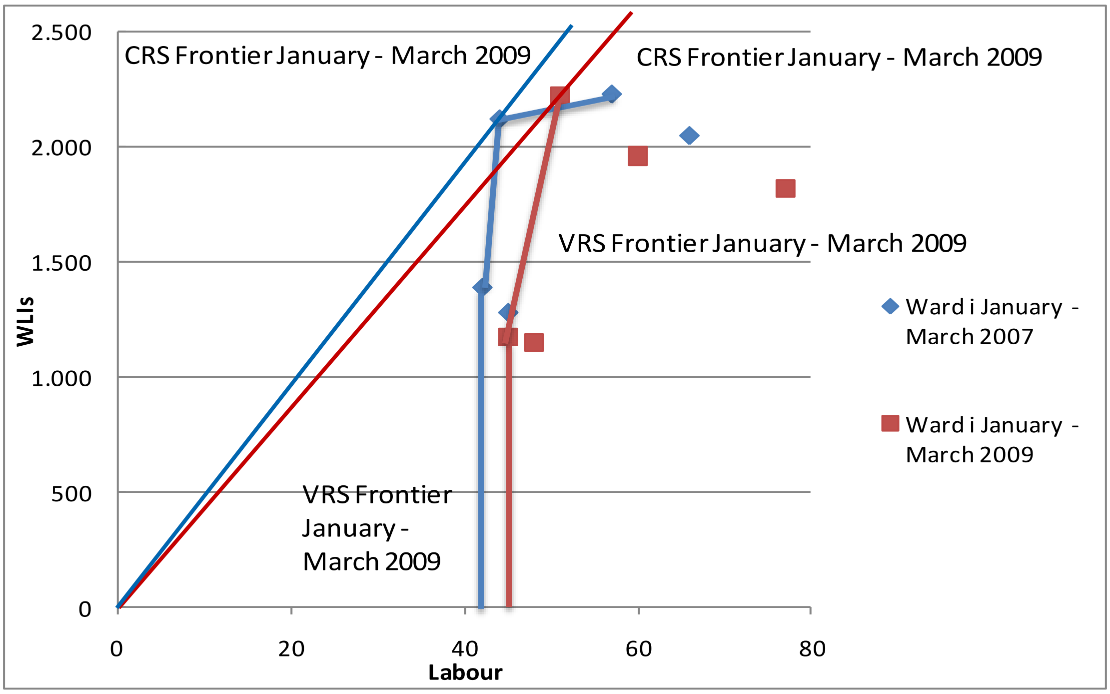

Figure C. 2: VRS and CRS Frontiers in the WLIs-Labour Spectrum 2007 $_{January\ -\ March}$ and 200 $_{January\ -\ March}$

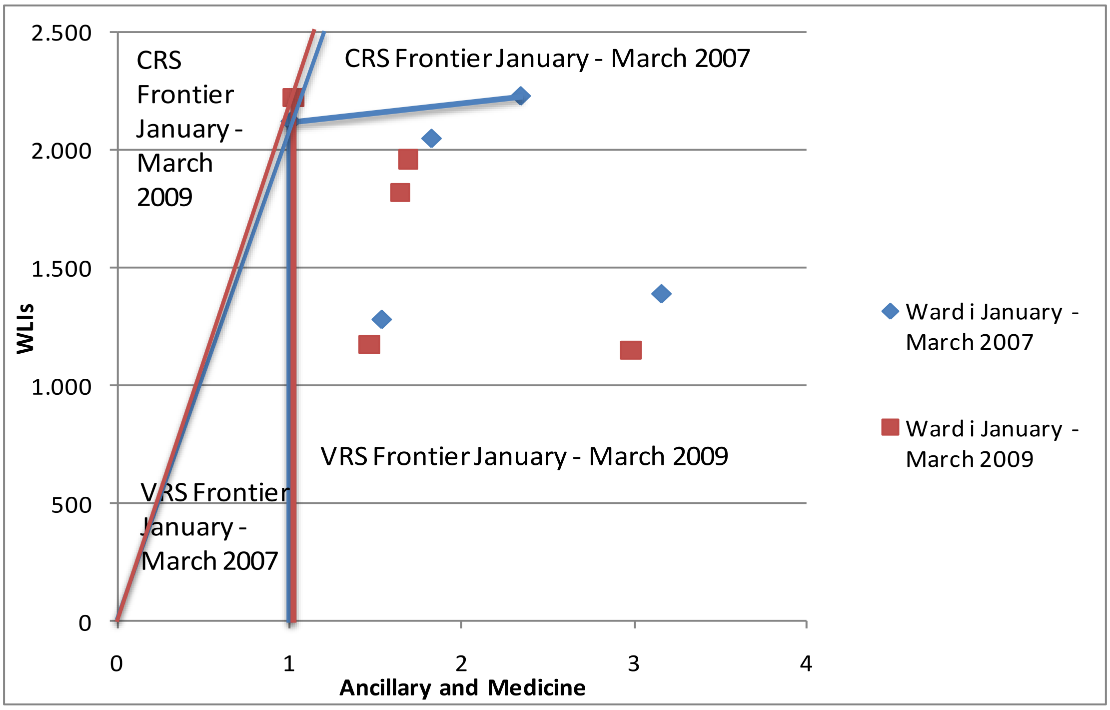

Figure C. 3: VRS and CRS Frontiers in the WLIs-Ancillary and Medicine Spectrum 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$

Frontiers: LDs Scattered Against Input

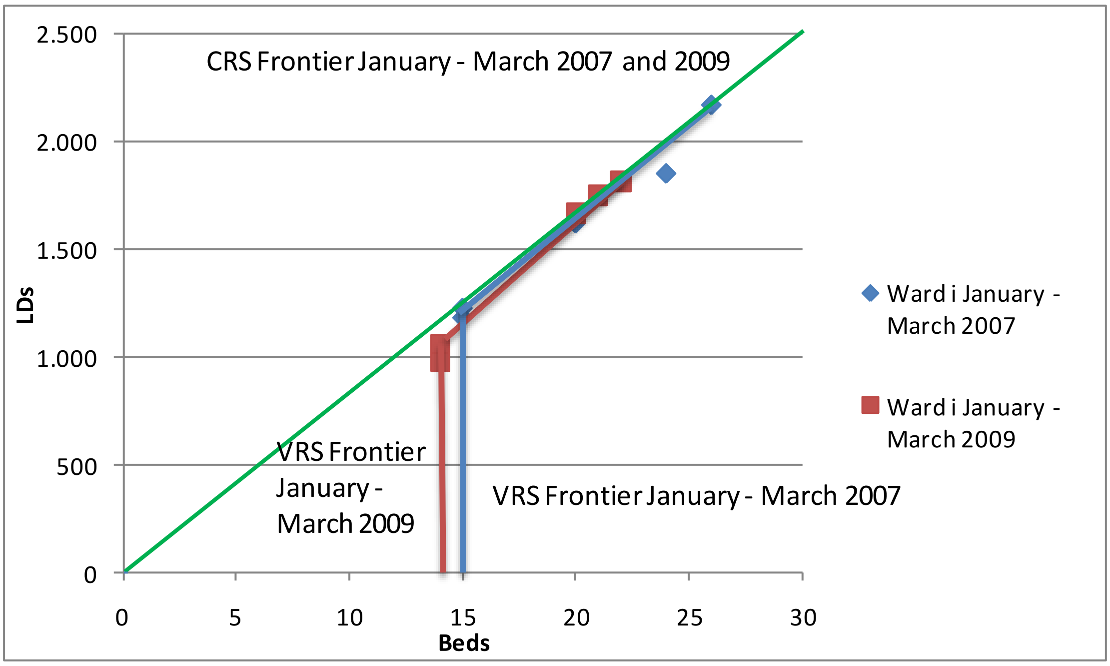

Figure C. 4: VRS and CRS Frontiers in the LDs-Beds Spectrum 2007$_{January\ -\ March}$ and 2009$_{January\ -\ March}$

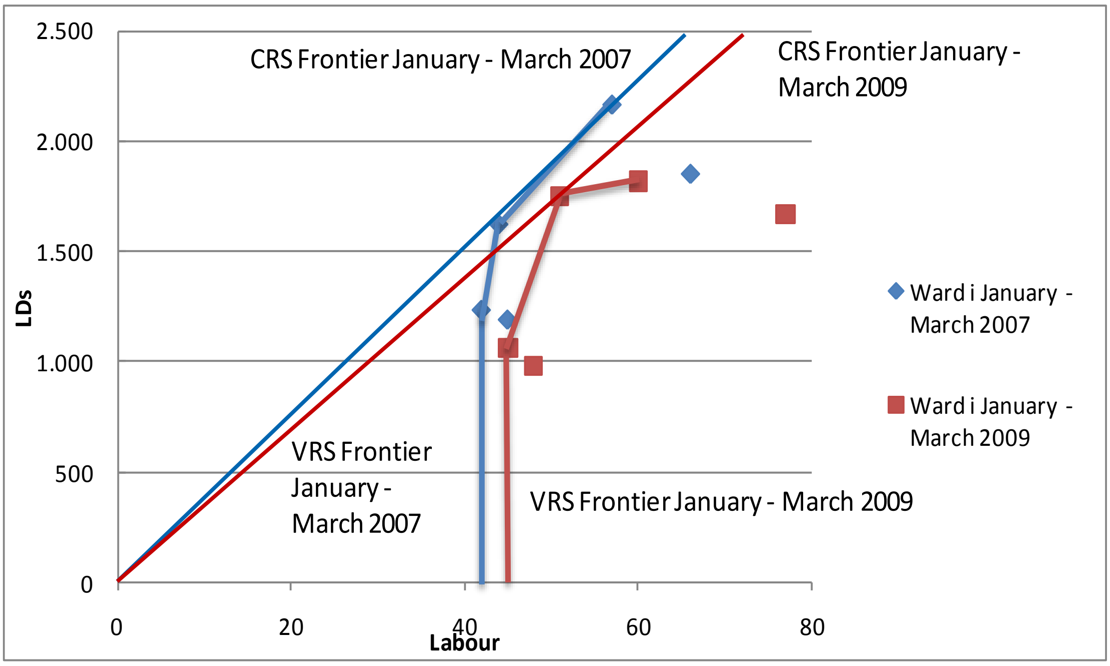

Figure C. 5: VRS and CRS Frontiers in the LDs-Beds Spectrum 2007$_{January - March}$ and 2009$_{January - March}$

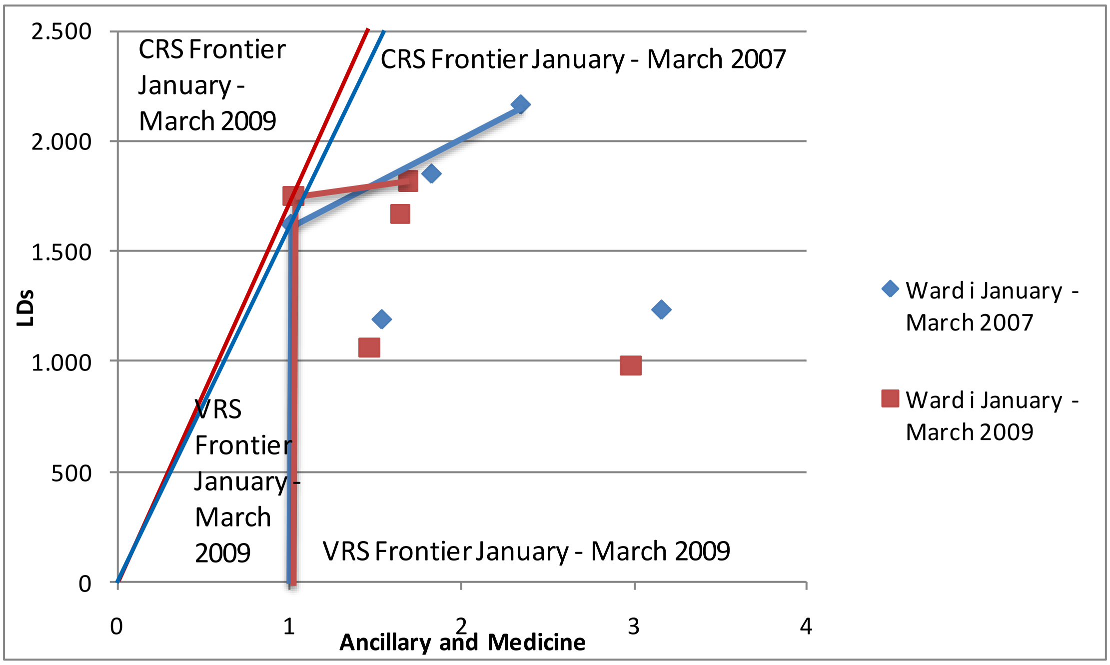

Figure C. 6: VRS and CRS Frontiers in the WLI-Ancillary and Medicine Spectrum 2007$_{January - March}$ and 2009$_{January - March}$

Appendix D: Ethical Approval by LUH's Ethical Research Governance Committee

LANDSPÍTALI
HÁSKÓLASJÚKRAHÚS

Guðmundur I Bergþórsson
Öldugranda 1
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Reykjavík, 8. júlí 2008

Varðar: Erindi 16/2008 til siðanefndar stjórnsýslurannsókna á LSH
Managed patient Flow. Estimation of Improvement of the Efficiency of Inpatient Service production Processes at Selected Wards at Landspitali

Hef móttekið viðbótarupplýsingar þínar dags. 7. júlí s.l. og svara þær fyrirvara nefndarinnar frá 12. júní s.l. með fullnægjandi hætti.

Gangi þér vel við rannsóknarstörfin.

Virðingarfyllst, fyrir hönd siðanefndar stjórnsýslurannsókna á LSH,

Oddur Gunnarsson

Siðanefnd stjórnsýslurannsókna,
Skrifstofu starfmannamála
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Appendix E: Approval by LUH's Chief Medical Executive

LANDSPÍTALI
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Guðmundur I. Bergþórsson
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11.06.2008
Tilv. 16
BZ/ei

Efni: Managed Patient Flow. Estimation of Improvement of the Efficiency of Inpatient Service Production Processes at Selected Wards at Landspitali

Ágæti Guðmundur.

Vísað er til bréfs þíns til undirritaðs, dags. 11.06.2008 þar sem þú óskar heimildar til að framkvæma ofangreinda rannsókn á Landspítala – háskólasjúkrahúsi. Fram kemur að rannsóknin er hluti af MSc verkefni þínu við viðskipta- og hagfræðideild Háskóla Íslands. Ábyrgðarmaður rannsóknarinnar er Helga H. Bjarnadóttir, verkefnastjóri á hag- og upplýsingasviði LSH.

Hér með er veitt leyfi til að ofangreind rannsókn verði framkvæmd á LSH undir stjórn Helgu H. Bjarnadóttur. Leyfi þetta er háð því að fyrir liggi samþykki siðanefndar stjórnsýslurannsókna á LSH og Persónuverndar en fram kemur að sótt hefur verið um hið fyrrnefnda.

Með kveðju og ósk um gott rannsóknargengi,

Björn Zoëga
framkvæmdastjóri lækninga

Afrit:
Formaður siðanefndar stjórnsýslurannsókna á LSH
Forstjóri Persónuverndar

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