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Improving efficiency in surgical services:

A production planning and control approach

Antti Peltokorpi

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Abstract

The pressure to improve health while spending less money has forced healthcare organizations to find new ways of arranging their services. Healthcare organizations have widely discussed the needs of both evidence-based medicine and evidence-based management. Surgical operating units are cost-intensive, multi-professional parts of health-service production. Managing operating units efficiently is essential when hospitals and healthcare systems aim to maximize health outcomes with limited resources. The research questions this study addresses explore the phenomenon of efficiency and its improvement in operating units. The main objective is to define the features of production planning and control that maximize efficiency.

Based on a literature, several strategic and operative variables could promote high efficiency. However, performance measures recently applied to operating units fail to include all relevant phenomena that affect their total efficiency. The study developed economic and technical efficiency measures that include relevant aspects when measuring operating units' output and input. We tested the measure in single-case settings. After that, we tested, in a multi-hospital study that included 26 units, 12 hypotheses that propose connections between the use of strategic and operative practices and efficiency.

The study's results indicate that personnel incentive systems, especially for surgeons, and personnel flexibility improve efficiency most significantly. Units' size does not affect their performance. In general, the study reveals that operative practices, such as personnel management, case scheduling and performance measurement, affect efficiency more remarkably than do strategic decisions that relate to, e.g., units' size, scope or academic status. We also found that units with different strategic positions should apply different operative practices. Focused hospital units benefit most from hard-based practices such as sophisticated case scheduling, parallel processing and performance measurement; whereas central and ambulatory units with a wide range of services and specialties should apply soft-based initiatives, such as flexible working hours, incentives and multi-skilled personnel. This study highlights staffing issues' role in improving operating units' efficiency.

Keywords operating room management, surgical services, production planning and control, performance improvement, productivity

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Tiivistelmä

Paineet tuottaa parempaa terveyttä vähemmillä kustannuksilla pakottaa terveydenhuollon organisaatiot etsimään uusia keinoja palveluiden järjestämiseen. Näyttöön perustuvan lääketieteen rinnalle on noussut tarve ottaa käyttöön todennettuihin tuloksiin perustuvia johtamiskäytäntöjä. Leikkausyksiköt ovat kustannuksiltaan ja terveysvaikutuksiltaan merkittävä osa terveydenhuollon palvelutuotantoa. Siksi niiden suorituskyvyn parantaminen on keskeistä maksimoidessa koko järjestelmän tehokkuutta. Tässä tutkimuksessa tutkitaan tehokkuutta ja tuottavuutta ja niiden parantamista leikkausyksiköissä. Päätavoitteena on tunnistaa tuotannonohjauksen ja johtamisen menetelmiä, jotka mahdollistavat korkean tehokkuuden.

Kirjallisuuskatsauksen perusteella tunnistettiin useita strategiseen päätöksentekoon ja operatiiviseen johtamiseen liittyviä tehokkuuteen vaikuttavia käytäntöjä. Käytäntöjen soveltamisen ja tehokkuuden välisistä yhteyksistä muodostettiin 12 hypoteesia. Aikaisemmin käytetyt tehokkuusmittarit ovat puutteellisia huomioimaan keskeisiä tehokkuuteen vaikuttavia ilmiöitä. Tutkimuksessa rakennettiin taloudellisen ja teknisen tehokkuuden mittarit, jotka huomioivat toiminnan keskeiset panokset ja tuotokset. Mittaria testattiin yhdessä sairaalassa. Tämän jälkeen hypoteeseja testattiin 26 leikkausyksikön aineistolla.

Tulosten perusteella henkilöstön kannustinjärjestelmät ja henkilöstön joustavuus ovat merkitsevästi yhteydessä korkeaan yksikön tehokkuuteen. Strategiset päätökset, jotka liittyvät mm. yksikön kokoon, palveluvalikoimaan ja akateemiseen statukseen, vaikuttavat vähemmän tehokkuuteen kuin operatiiviset johtamiskäytännöt, kuten henkilöstön johtaminen, aikatauluttaminen tai suorituskyvyn mittaaminen. Havaittiin myös, että strategialtaan erilaiset yksiköt hyötyvät erilaisista johtamiskäytännöistä: Fokusoituneet yksiköt hyötyvät eniten teknologiaa soveltavista käytännöistä kuten kehittyneestä aikataulutuksesta, rinnakkaistuotannosta ja systemaattisesta suorituskyvyn seurannasta. Keskussairaalayksiköt ja päiväkirurgiset yksiköt, joiden potilasaines ja erikoisalakirjo ovat laajoja, hyötyvät eniten henkilöstön johtamisen käytännöistä kuten kannustimista, joustavista työajoista ja moniosaajista. Tutkimus korostaa henkilöstön johtamisen merkitystä leikkausyksikön korkean tehokkuuden saavuttamisessa.

Asiasanat leikkausyksikön johtaminen, kirurgian palvelut, tuotannonsuunnittelu ja –ohjaus, suorituskyvyn parantaminen, tuottavuus

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Espoo, May 2010

Antti Peltokorpi

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Definitions

The following definitions are used in this dissertation:

- *Allocated OR time* = Hours of OR time reserved for different specialties, surgical groups and individual surgeons. This is the time into which operations are scheduled.
- *Cancellation due to the patient* = Cancellation of scheduled elective surgery on the day of the surgery, due to a patient no-show, an improvement in condition, or insufficient preparation.
- *Cancellation due to the system* = Cancellation of scheduled elective surgery due to a lack of personnel or OR overload.
- *Delayed emergency operation* = A decision to perform emergency surgery on a later date because of the patient's condition or a lack of resources on the day of arrival.
- *Economic efficiency* = Daily total cost of staffing, overtime work and delayed surgery divided by standardized OR time of operations performed.
- *Elective surgery* = Surgery for which a patient can wait at least three days without sustaining additional morbidity.
- *Emergency surgery* = Surgery for which a patient cannot wait more than three days without sustaining additional morbidity.
- *Office hours* = 8.00 am – 3.30 pm, weekdays.
- *Operating room (OR) time* = The time elapsed from when a patient enters the operating room and to the time he or she leaves it.
- *OR block time* = The sum of office hours of the operating rooms in which operations have been performed during the day. OR block time might be more or less than allocated OR time.
- *Overused OR time* = The amount of time from the end of office hours (3.30 pm) until the time the last patient leaves the OR.
- *Planned OR utilization rate* = Estimated daily sum of operating-room time for planned elective and estimated emergency surgery, to be performed during office hours, divided by the daily allocated OR time.
- *Realized OR utilization rate* = Realized OR time of daily operations performed during office hours, divided by the daily allocated OR time.
- *Straight personnel* = Personnel dedicated to operating rooms (anesthesiologists, anesthesia nurses and OR nurses) in an operating unit.
- *Surgery time* = Time between the first incision and wound closure.
- *Technical efficiency* = Daily standardized OR time of operations performed divided by the total number of operating-unit personnel hours.
- *Total personnel* = Total personnel in an operating unit.
- *Underused OR time* = The amount of time from the last patient's exit from the OR and the end of office hours (3.30 pm).

1 Introduction

1.1 Background

Healthcare systems are facing increasing pressure to provide objective evidence of the quality and efficiency of their organization (Lungen and Lapsley 2003; Kujala et al. 2006; Sajid and Baig 2007; American College of Physicians 2008). In Europe, demographic changes, including the aging of the population, are changing disease patterns and putting financial pressure on health systems (EU 2007).

A common ambition, especially in publicly funded healthcare systems, has been to keep people healthy and safe at an affordable price (Jacobs and Coddard 2002; Berwick 2005). The United Kingdom has put considerable effort into improving medical quality and access to care (NHS 2000), whereas in Finland the major concerns are related to observations about reductions in hospital productivity (Stakes 2007).

The pressure to improve health while spending less money has forced healthcare organizations to find new ways of arranging their services. Management principles such as operations management (Vos et al. 2007), statistical process control (Thor et al. 2007) and lean production (Bush 2007) have been adopted in order to improve quality and efficiency. The needs of both evidence-based medicine and evidence-based management have been widely discussed in healthcare organizations (Sackett et al. 1996; Shortell et al. 2007). The practice of evidence-based medicine means integrating individual clinical expertise with the best available external clinical evidence from systematic research (Sackett 1997). Although managers and policymakers have been quick to encourage clinicians to adopt an evidence-based approach, they have been slower to apply the same ideas to their own practice (Walshe and Rundall 2001).

The potential for improvement through the adoption of evidence-based management in the healthcare system is presumably highest in the most expensive and highest-volume treatments. Surgical operating units are cost-intensive, multi-professional parts of health-service production. According to an American study, operating rooms (ORs) account for more than 40 percent of a hospital's total revenues and a similarly large proportion of its total expenses (HFMA 2005). Therefore, managing ORs efficiently is essential when hospitals and healthcare systems aim to maximize health outcomes with limited resources. When a service provider's goal is to maximize profit, managing surgery efficiently leads to competitive advantage.

The patient process in an operating unit typically includes anesthesia, surgical preparations, the operation itself, and between one and three hours of post-operative recovery before discharge or transfer to a ward unit (Torkki et al. 2006). The primary aim of an operating unit is to perform high-quality surgery (Dexter et al. 2004). Operating unit activities also have a remarkable impact on demand for other services and waiting times, such as for imaging and post-operative care in ward units (Testi et al. 2007).

Given the complexity of most surgery and the high requirements for personnel skill, operating units are typically organized as separate entities with their own core personnel, rooms and equipment (Alfredsdottir and Bjornsdottir 2008). Their isolation from other hospital activities allows them to be viewed as processes with limited and measurable inputs, defined resources, planning and management algorithms and standardized output. They could also be seen as value-adding process (VAP) businesses, which can be organizationally separated from the units making the diagnoses and in which customers can be charged on the basis of output rather than input (Christensen et al. 2009).

There is no clear consensus of opinion about measures of OR efficiency. Some studies focus on access to care (e.g., Oudhoff et al. 2007), and others examine the number of operations performed (e.g., McGowan et al. 2007) or overtime costs (e.g., Dexter and Macario 2002). The measures are typically not derived from the fundamental purpose of the healthcare system to maximize the produced health with the given resources; they are rather intermediate components or means. There is also a lack of studies in which such measures are used in comparing efficiency between different operating units.

The efficiency measures proposed to date are rarely implemented in hospitals. Furthermore, even if they are implemented it has been argued that performance levels are well below the achievable targets at most hospitals (CAB 2001). Low performance rates rarely lead to policy improvements. For example, it has been found that performance indicators never or seldom lead to measures such as notification, changes in allocations or recruitment in half of hospitals (Marjamaa and Kirvelä 2007).

If the aim of a healthcare system is to produce better health with less money (Berwick 2005), reengineering must start at the bottleneck phase of the processes (Goldratt 1984). In the surgical context the OR process is typically cited as the main bottleneck (Jebali et al. 2006;

Torkki et al. 2006). Despite extensive literature on OR management, however, in practice surgical units typically operate below optimal efficiency (HFMA 2005). There is a need for a better understanding of the relevant performance measures in operating units, and of how performance is driven by decisions and events in the planning and execution process.

Operations management is a field of study that focuses on the effective planning, use, and control of a manufacturing or service organization (APICS 2004). Within this field production planning and control focuses on the production part of the organization's or the company's overall strategy (Vollman et al. 1997). Adopting concepts and principles from both of these areas has structured the evaluation of healthcare service systems (Vissers et al. 2001). An OR is perhaps the part of the system that is best suited to operations management applications. It resembles a factory or workshop with closed boundaries, reasonably well-established sequences and procedures, and measurable steps. The main difference from manufacturing is that the process times cannot be reasonably well defined in advance, which hampers the planning and scheduling.

It is posited in this study that considering operating units and surgical services from the perspective of operations management, and production planning and control provides a basis for improving performance.

1.2 Research objectives and scope

Increasing efficiency in surgical services, and especially in ORs, has been challenging for most hospitals. The research questions addressed in this study explore the phenomenon of efficiency and its improvement in operating units. The main objective is to define the features of production planning and control that enable maximum OR efficiency. The sub-objectives relate to the identification of such features in surgical services and to the definition of relevant efficiency measures. In summary, the aim of this study is to formulate answers to the following research questions:

1. *What are the specific features of production planning and control systems in surgical services?*
2. *What are valid measures for evaluating and comparing the productivity of an operating unit?*

3. *What is the effect of the identified features of production planning and control on the operating unit's productivity?*

4. *What are the most suitable features of different production strategies?*

It is essential to study the first two research questions in order to identify the best operating unit features and practices. Production planning and control typically involves creating an overall production strategy, the detailed planning of capacity and material needs, and executing these plans (Vollman et al. 1997). The management of surgical services has specific features that relate to the division of personnel resources among several professions, for example. Those features have to be mapped and analyzed in terms of how they would potentially affect efficiency. On the other hand, essential measures of OR efficiency also need to be defined. Such measures should avoid sub-optimization and enable comparisons between units with different case mixes.

The third and fourth research questions relate to practical applications in healthcare organizations. It is unrealistic to assume that there is one pathway to increased OR efficiency. Instead, as in manufacturing organizations (Schroeder and Flynn 2001) there may be several. On the operative level, which includes capacity and resource planning (e.g., Vollman et al. 1997), an appropriate policy may be a matter of organizational history, system-level features such as laws and labor policy, or production strategy with regard to the range and volume of services, for example.

The focus in this dissertation is on process management and efficiency in operating units. There is remarkable potential for improved efficiency due to the fact that these units are a very cost-intensive part of hospitals. In the hospital context it is also reasonable to start from the operating unit due to its relatively isolated role in the organization, which makes the development work easier. The research work for the thesis was conducted mainly in Finland. Data was also gathered from the USA (San Francisco, California) and Germany (Berlin region) in order to increase the generalizability of the study and to analyze system-level features that affect production strategy and operative practices.

1.3 Research environment

This study was carried out in the HEMA (Healthcare Engineering, Management and Architecture) Institute at Helsinki University of Technology. The HEMA Institute employs healthcare-focused researchers whose aim is to apply technical, managerial and architectural knowledge to healthcare.

This study was a part of the TAPPO (Planning and Control of Regional Healthcare Service Systems) and T3 (Healthcare Operations Management) projects at the HEMA Institute. The overall aim of the TAPPO project was to develop new service-delivery models for regional healthcare systems. The T3 project, in turn, focused on developing tools and models for applying industrial engineering practices to health-service management. The main project partners in this study were the Jorvi and Töölö hospitals in the Helsinki and Uusimaa Hospital Districts (HUS), Kymenlaakso Hospital District, Keski-Suomi Hospital District, and the Finnish Funding Agency for Technology and Innovation (TEKES).

The focus of the study was on managing operating units as separate systems in a hospital. The processes inside the operating unit constituted the units of analysis. Paulus Torkki studied patient processes among selected operative patients in connection with the same TAPPO and T3 research projects. The most notable difference between Torkki's study and this one is that this one considers surgical services from the perspective of the operating unit manager, whereas Torkki investigated the overall care process of certain surgical patients from the perspective of patient group management. Table 1 summarizes the main research areas and approaches in the two dissertations based on these projects.

Table 1 Principal research areas and research approaches in studies related to surgical services in the HEMA research group.

Main research areas and approaches	*Peltokorpi*	*Torkki*
Operating room management inside hospitals	X	
The management of surgical patient groups in networks of hospitals		X
Focus on resource management and cases in operating rooms	X	
Focus on the patient process from examination to preparation, surgery and recuperation		X
Focus on efficiency measures in operating unit processes	X	
Focus on efficiency measures in hospital care processes		X

HEMA researchers have published several scientific theses and articles in international journals on the management of surgical services. I have been a leading or second author in most of those articles.

Torkki's Master's thesis, entitled "Surgical process reengineering - anesthesia induction outside the operating room" (Torkki 2005) dealt with parallel processing and performance measurement in the operating unit. It recommended the use of parallel processing in anesthesia induction, and also introduced an efficiency metric covering output produced and resources used.

Torkki et al. (2006) evaluated the effects of a process management approach on care for trauma patients. As a result, the anesthesia induction was performed outside the operating room, better process guidance was developed, and patient flow was reorganized. Articles around the theme "patient-in-process" investigated different effects of waiting times on costs and on the conditions of surgical patients (Kujala et al. 2006; Peltokorpi and Kujala 2006).

The aim in Peltokorpi et al.'s (2008b) paper was to create a model for evaluating organizational-change initiatives from a stakeholder-resistance perspective. The model's practical validity was tested in the screening of change initiatives to improve OR productivity. Two studies analyzed the effect of three process interventions on costs in ORs performing open-heart surgery (Peltokorpi et al. 2008a; Peltokorpi et al. 2008c). Simulation was utilized as a method for evaluating the effect of parallel processing and higher accuracy in OR time forecasting on overall productivity, for example.

The publications most closely related to this dissertation are my licentiate thesis (Peltokorpi 2008), and an article based on the same study (Peltokorpi et al. 2009) addressing the two first questions of this thesis: a) defining the production planning and control system for operating units and b) developing valid productivity measures. In summary, previous publications about surgical services in HEMA cover the following themes: performance measurement, change evaluation and management, and system modeling.

1.4 The structure of the thesis

As mentioned in the previous section, I have published several articles around the phenomenon in question. This thesis could have been based on a compendium of the articles. However, I selected the monograph form for two main reasons: First, it makes it possible to write a consistent story that does not require jumping between the manuscript and the articles in the appendixes. I considered consistency in the text especially important in that I was also writing for practitioners and managers. Secondly, the most recent data used in this thesis was gathered during spring 2009. If I had first published results based on this data as an article the completion of the thesis would have been delayed for as much as one year. Nevertheless, although the thesis is written as a monograph, there is close reference in many parts to my peer-reviewed articles. This is assumed to strengthen both the validity and reliability of the study.

This thesis has the following structure. Chapter 2 comprises a literature review of the investigated phenomena. The surgical patient process is briefly described, and the existing theories of operations management, and production planning and control and their applications in healthcare are reviewed. Measures used previously are also analyzed. The most major gaps in the current literature are identified in the chapter summary.

Chapter 3 builds up a framework system for operating unit planning and control, the aim being to answer the first research question concerning the specific features of planning and control systems in surgical services. The framework is based on the theory of healthcare operations management and specific features in operating unit processes, the idea being to describe all the relevant features that affect OR performance. It is used in the following chapters in formulating the research hypotheses.

Specific research hypotheses based on the research objectives, the literature review, and the developed framework are formulated in Chapter 4. Chapter 5 introduces and justifies the research methodology selected to test the hypotheses, and describes the research process and the data gathering and analysis.

Chapter 6 focuses on the study results. The first sub-chapter charts the development of the valid performance measurement. The focus then turns to the results of testing the measure and hypotheses in real-life settings.

Chapter 7 presents the conclusions of the study, and discusses the results, and their validity and reliability. Finally, the main arguments and managerial implications of the study are summarized in Chapter 8.

2 Literature review

The literature review focuses on the three research areas. The first of these concerns operations management and production planning and control, and its application in service production in general, and especially in surgical services. The second area covers efficiency measurement in surgical services, the main focus being on evaluating currently used measures and their general applicability. The third and most extensive part of the review covers the core literature on planning and control in surgical services. The overall aim is to find known unknowns in the theory of efficiency measurement and management.

2.1 Operations management and production planning and control

Operations management is “the field of study that focuses on the effective planning, scheduling, use, and control of a manufacturing or service organization through the study of concepts from design engineering, industrial engineering, management information systems, quality management, production management, inventory management, accounting, and other functions as they affect the organization” (APICS 2004). It concerns the production, distribution and project-management activities carried out in an organization.

2.1.1 Production planning and control in manufacturing

Within operations management, production planning and control focuses on the production part of the organization’s or the company’s overall strategy. Vollman et al. (1997) divide the process into three phases. The first phase involves the creation of an overall production plan, which is described in terms such as end items and product options. The second phase is the detailed planning of capacity and material needs, and the third is the execution of these plans.

Figure 1 depicts a simplified production planning and control system. Front-end activities aim at creating the overall plan. The *Engine* in the figure refers to the set of systems that will be used for carrying out the detailed material and capacity planning, and the *Back end* depicts the execution system. (Vollman et al. 1997)

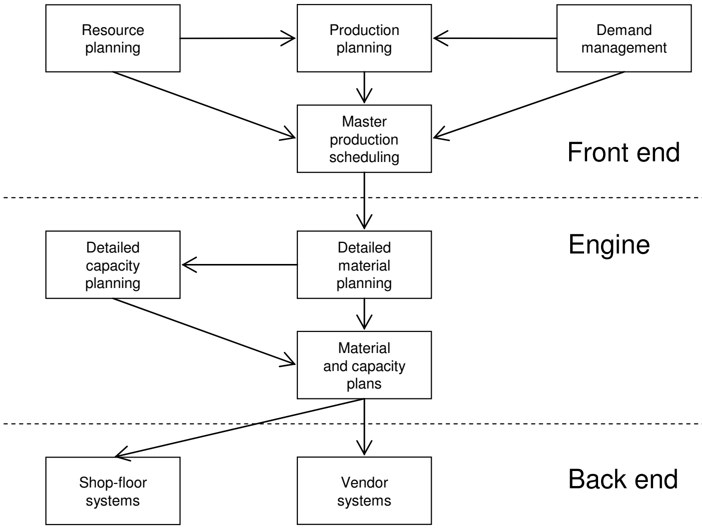

Figure 1 A simplified manufacturing planning and control system (Vollman et al. 1997)

According to Bertrand et al. (1990), there are three focal functions in a production control system: (1) coordination between supply and demand (boundary control), (2) goods-flow and production-unit control (horizontal control), and (3) the control of aggregate flows and details (vertical control). In all these functions decisions must be made about how to reconcile contradictory perspectives. For example, it is essential to implement a horizontal control practice that maximizes the combination of the smooth flow of goods with a high resource-utilization rate.

The principles and tools of production planning and control provide a basis for bringing a high level of quality and efficiency to the management of operating units. However, surgeries are services, and the special characteristics of services must be accounted for when defining operations management and production planning and control in this context.

2.1.2 Service operations management

Johnston and Clark (2005) define service as the combination of outcomes and experiences delivered to and received by a customer. The aim in service operations management is to manage and integrate outcomes and experiences. Many service operations process customers. The customer sees much of this process, and in many cases plays a key role in it. The service process can be separated into front-office and back-office tasks. Customers are involved only in the former, and rarely see the latter. The overlap of the process and the customer's experience makes service operations management challenging.

Service processes fall into different types based on their operational characteristics. Operational process design is influenced by two key parameters: the volume of transactions to be performed per period per unit, and the variety of tasks to be carried out by a given set of people and processes. Low-variety/high-volume processes are referred to as commodity processes, whereas high-variety/low-volume processes are called capability processes. The major challenges in the latter relate to managing productivity and making the best use of highly skilled and knowledgeable individuals (Johnston and Clark 1997).

The challenges related to service processes reside in the management of surgical services, where patients are the customers. Although the patient is generally unconscious during surgery, his body acts as his representative. In addition, there are many activities involved, such as pre-examinations and decisions about the day of surgery, in which the customer is highly involved. The surgeon and the ward unit could also be seen as operating unit customers, and front-office activities between provider and customer include capacity allocation and scheduling.

It is relevant to consider operating unit management in the context of service operations management. The biggest exception to Vollman et al.'s (1997) model is that material planning has a less prominent role in the planning of surgical services (Figure 2). As typical in services, personnel capacity management is emphasized due to the system's personnel-dominated cost structure. Capacity planning and scheduling are also emphasized because, as in any service production system, inventories and buffers in the downstream process cannot compensate errors and inaccuracies in the planning phase.

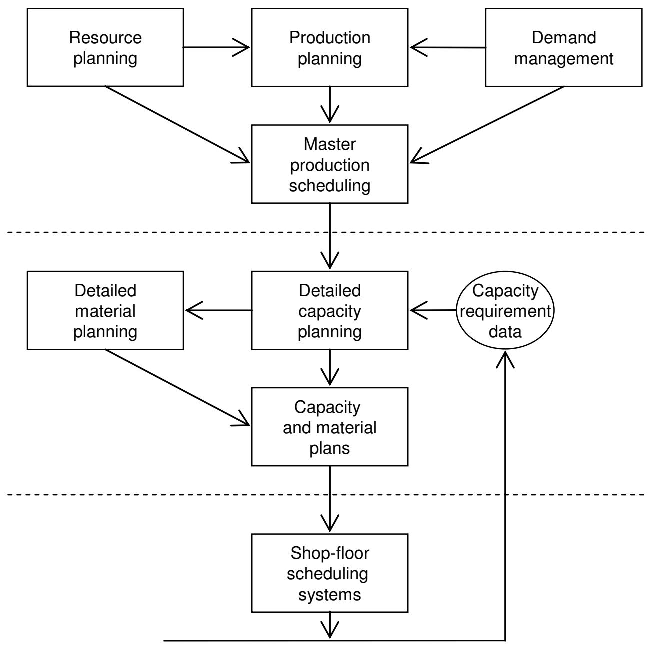

Figure 2 A simplified system for surgical production planning and control

This simplified picture of production planning and control must be augmented with more detailed information about the activities that constitute the planning phases, and should include the characteristics of the system environment that affect the overall performance of the operating unit.

2.1.3 Surgical service operations

Surgical services have several universal characteristics. The care of a surgical patient can be divided into three phases (Saleh et al. 2009): pre-operative, operative, and post-operative (Figure 3). The pre-operative process includes the patient's arrival at a healthcare facility, physician examinations, the decision to operate, and care and examination before surgery. The operative phase begins with the anesthesia and surgical preparations. Patients who are considered for surgery but do not undergo it are included in the pre-operative phase.

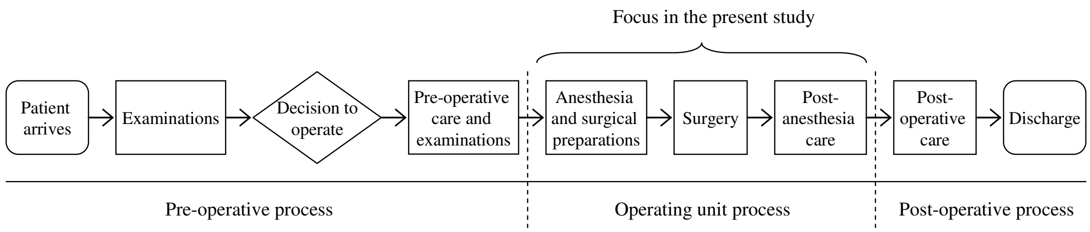

Figure 3 The main phases of the care process for surgical patients

The operative process includes phases that are typically conducted in the operating unit. The patient is anesthetized with a local or general anesthetic. Next the skin near the incision site is cleaned and the patient is positioned for the operation. Surgery is the phase from the first incision to the last suture. Between surgery and post-anesthesia care the wound is dressed and the patient typically awakens. Post-anesthesia care includes patient monitoring, pain management, and recovery in the post-anesthesia care unit (PACU), which is a part of the operating unit.

Next the patient is usually moved to an inpatient ward unit where post-operative care aims at recovery from surgery. Ward units typically have also non-surgical patients in conservative care. Finally, the patient is discharged to his home or moved to less intensive care in another service area.

Surgical processes mix with conservative care processes in pre- and post-operative care. The operating unit is dedicated exclusively to surgical patients. The main focus in this study is on the planning and control of operating unit processes, as part of the entire process of surgical patient care.

2.1.4 A framework for healthcare production planning and control

The importance of considering the balance between the availability of services and the level of utilization of resources is highlighted in the management of healthcare organizations (Vissers et al. 2001). Several studies have focused on developing a hierarchical framework for planning and control that takes account of this balance between access and efficiency (Smith-Daniels et al. 1988; Rhyne and Jupp 1988; Butler et al. 1992; Roth and van Dierdonck 1995; Vissers et al. 2001; Van Merode et al. 2004).

Smith-Daniels et al. (1988), in their extensive review study on capacity management in health care, make a distinction between decisions on resource acquisition and allocation. Rhyne and Jupp (1988) focused on modifying the closed-loop manufacturing resource planning (MRP II) system to satisfy healthcare requirements. Although their study operates on a fairly general level, it suggests tight connections from production planning to performance measurement and cost control. Butler et al. (1992) developed a framework that included four levels of planning, beginning from strategy formation and ending with procedures for the detailed execution of plans and performance measurement. Facilities planning and fixed capacity allocation were also essential levels in their framework.

Roth and Van Dierdonck (1995) conclude from their study in two hospitals that traditional materials-driven planning logic has shortcomings in the healthcare domain. Capacity resources dominate materials management in hospitals. The hospital delivery process is more like a project, and if there are stages they are more like project milestones. Under their hospital resource planning DRGs (diagnoses related groups) are products with a 'bill of resources' (BOR) structure that incorporates necessary capacity and materials.

Vissers et al. (2001) developed a framework for production control in healthcare organizations, especially in hospitals, in which there are five levels that include different planning decisions and time horizons. The levels are: a) strategic planning, b) patient-volume planning and control, c) resources planning and control, d) patient-group planning and control, and e) patient planning and control. They suggest that patient groups, on account of their specific resource needs and service requirements, should be focal units in hospital planning and control. They also argue that specialist time is the most essential bottleneck resource in a hospital, and that its allocation to patient groups is therefore the most important element in the production planning process.

In recent years the research has focused more on developing methods and practices for evaluating and optimizing the healthcare system instead of developing the managerial framework further. Jack and Powers (2004) applied previously used frameworks in developing volume-flexible strategies in health services, and Eklund (2008) evaluated resource constraints in different healthcare-service areas. Van Merode et al. (2004) also utilized previously developed frameworks (e.g., Roth and van Dierdonck 1995; Vissers et al. 2001) in reviewing the potential of enterprise resource planning (ERP) systems for healthcare-delivery organizations. Kujala et al. (2006) present a conceptual framework for applying time-based competition (TBC) and work-in-process (WIP) concepts in the design and management of patient processes. However, they place less emphasis on the efficient use of resources inside the production system.

The literature on the development of hierarchical frameworks for healthcare production planning and control is mainly focused on the application of general operations management concepts to healthcare settings. In addition to dividing planning levels on the basis of strategic, tactical, and operative decisions, the current literature highlights the management of fixed resources and patient groups. In order to investigate more thoroughly the effect of different planning and control variables in operating unit environment, more detailed framework about decisions at each planning level in surgical services should be defined. The detailed framework is also needed when taken into account the specific space, equipment and personnel requirements that are typical for operating units and that set specific constraints for tactical and operative decisions in the production system.

2.2 Measuring the performance of surgical services

Generally speaking, the success of service operations managers is not simply about performing a technical task well (Johnston and Clark 2005). It is also about making a wider contribution to the success of the organization, particularly a) providing customer value, b) delivering brand value, c) making a financial contribution, and d) delivering an organizational contribution.

Many of the mechanisms related to these four contributions are missing in the production of surgical services, at least in public-funded systems. For example, true customer value is not tested because there is practically no competition. “Brands” in terms of hospital districts or hospitals are weak or similar. Budgetary policy prevents hospitals and units from making real financial contributions, and the organizational contributions of the operating units are blurred because the missions and goals are unclear.

Porter and Olmsted Teisberg (2006) argue in their book about the value chain in healthcare systems that the objective function of organizations consists of several components, such as quality, safety, patient satisfaction, cost containment, equity and access, and that it differs for different actors in the system. They emphasize that patient-health outcomes per unit of money spent should be the primary value measure at any level.

2.2.1 The value chain in health care

It is necessary to understand the healthcare value chain in order to evaluate the performance of its operations. Porter (1985) defines the term value chain as the entire production chain from the input of raw materials to the output of the final product consumed by the end user. Products pass through all activities of the chain in order, gaining some value during each one.

It is possible to approach the performance of healthcare services from the value-chain perspective (e.g., Burns 2001; Lillrank et al. 2004; Eklund 2008; Peltokorpi 2008) (Figure 4). The primary aim in healthcare systems is to have a positive effect on a patient's health. This effect is called the outcome of the system, and is a fundamental element in the patient's perception of the whole service (his *value perception)*. His perception is affected not only by the outcome but also by his expectations, and by non-medical issues such as perceived quality of and access to care.

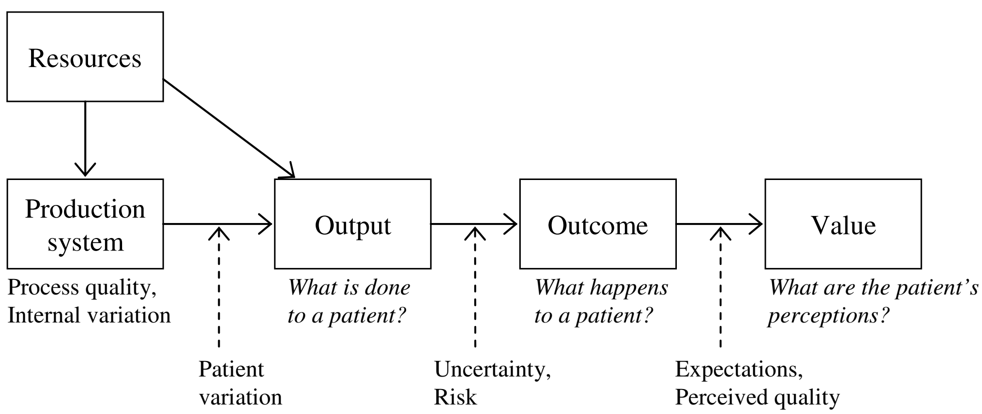

Figure 4. The value chain in health care

In the upstream process medical science is looking for the best treatment methods for different illnesses. Considered purely from the medical point of view, it can be assumed that the best method is the one that leads to the best outcome with an accepted level of uncertainty and risk. In practice the process output – treatment that is provided to a patient – might depend on the availability of resources and production competence. Available resources are typically organized in the form of a production system. Patient variation and internal variation in the system affect the success of treatments.

It could be argued that the role of perceived value in the value chain is emphasized in customer-oriented healthcare organizations. If patients can choose their service providers they will favor the ones that have delivered the best total value in the past. The customer value of the process, including the best access to care, can be measured in terms of revenue that providers can obtain. From the provider's point of view, the primary measure of success is a contribution margin, the gap between revenue and costs (e.g., McIntosh et al. 2006).

Publicly funded organizations are typically responsible for treating illnesses that emerge among a defined population. In the long term they have two contradictory aims: they must maximize outcomes yet minimize costs. Developing new treatment methods is time-consuming and expensive, and in the medium and short term organizations typically aim to maximize output and minimize medium- and short-term costs. Finnish law defines maximum waiting times for treatment in publicly funded organizations (Finlex 2004). Furthermore, all patients with certain indications must be treated according to a certain method. Therefore, the medium- and short-term focus in the system is to manage efficiency within certain waiting times and given treatment indications.

Outcome and customer value are important, but difficult to measure and thereby difficult to make subject to operations management analysis. Whatever is said about outcomes, there will always be a need for outputs. The focus in this thesis, therefore, is on the production system, the output and the use of resources in operating units.

Efficiency in the production system could be categorized as technical, economic, and allocative (e.g., Eklund 2008) (Figure 5). *Technical efficiency* is the ratio between quality and case-mix-adjusted output, and production resources in terms of personnel working hours and machine hours. *Economic efficiency* includes the costs of resource units and a resource mix. Finally, *allocative efficiency* describes the impact of allocative decisions such as the resource mix, the location, and the effects of (de)centralization on technical and economic efficiency and other performance measures such as service access and waiting times.

The capacity utilization rate (CUR) is also used as an efficiency measure. It illustrates activity, but does not necessarily have a direct relationship to output and intensity of resources. It is of significance in top-down cost accounting (dividing the total cost by the total output), whereas bottom-up accounting such as ABC largely ignores it, assuming full capacity utilization (e.g., Kaplan and Anderson 2004). In summary, CUR is not recommended for use as a primary efficiency measure. Once the allocative decision has been made it can still be used as a planning measure in scheduling. The quality of a production system affects its process yield, which is the ratio between realized and planned output. Speed is also an element in creating output: greater speed enables increased output at constant capacity.

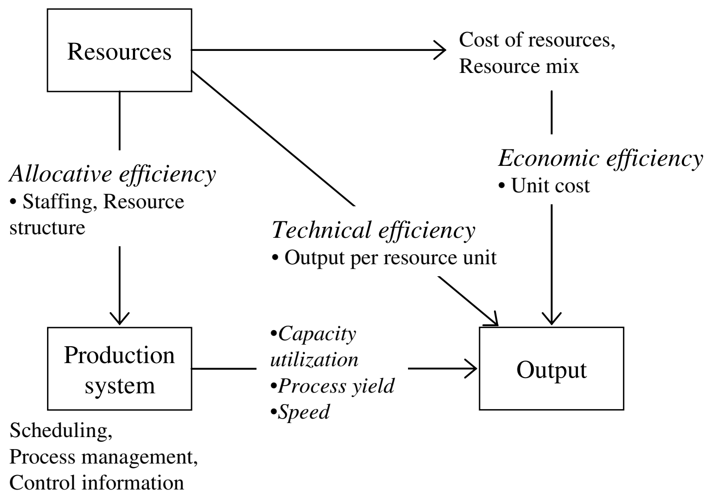

Figure 5. Efficiency in healthcare production (according to Lillrank et al. 2004 and Eklund 2008)

This study concerns technical and economic efficiency in the operating unit. Allocative efficiency, the capacity utilization rate, process yield, and speed are considered factors that enable high technical and economic efficiency.

2.2.2 Evaluating previously used efficiency measures

The literature on current efficiency measures in surgical services was reviewed in order to define how the value chain has been understood historically. A search of the Helsinki University Vertex database was conducted and a structured bibliography of surgical services maintained by Dexter (Dexter 2010) was consulted. The database query resulted in 52 articles in which the terms "*operating room management*" and "*efficiency*" occurred in the title, abstract or text. Efficiency measures were extracted from Vertex articles and those in Dexter's bibliography. If they contained references to other articles relating to defining efficiency, those articles were also included.

The review revealed some variation in the efficiency measures used in surgical services, and almost every research study concerning OR management defined performance measure(s).

The performance-measure taxonomy developed by Li and Benton (1995) was applied in order to divide OR efficiency measures into four efficiency categories, and into external and internal measures (Table 2). The internal measures focus on performance inside the operating unit whereas external measures consider performance from the broader perspective, and include pre- and post-operative parts of the surgical process in other hospital units.

Table 2. Measures used for assessing the efficiency of operating-unit processes

	Production-system quality measures	***Capacity utilization and time measures***	***Technical efficiency measures***	***Economic efficiency measures***
Internal measures	*Late cancellations* (Ferschl et al. 2005; McGowan et al. 2007) *Shifted operations* (Testi et al. 2007) *Start-time tardiness* (Windle et al. 2001; Macario 2006) *Surgery time* (Seymour et al. 2002; Torkki et al. 2006; Pandit et al. 2009)	*OR raw utilization rate* (Marjamaa et al. 2007; Denton et al. 2007) *Non-operative time* (Overdyk et al. 1998; Torkki et al. 2006) *Turnover time* (Marjamaa et al. 2007; Macario 2006; Sokolovic et al. 2002) *First operation start time* (Overdyk et al. 1998; Windle et al. 2001) *Overused OR time* (Dexter & Macario 2002; Testi et al. 2007) *Underused OR time* (Dexter & Macario 2002; Peltokorpi et al. 2007b)	*Standardized surgery time per personnel hours* (Torkki et al. 2006) *Quantitative performance* (Pandit et al. 2009) *Minimum OR blocks needed with constant throughput* (Van Houdenhoven et al. 2007a) *Number of operations per unit of time* (Marjamaa et al. 2007; McGowan et al. 2007; Santibanez et al. 2007; Testi et al. 2007)	*Costs of care episode* (Hall et al. 2006) *Contribution to margin* (McIntosh et al. 2006; Macario 2006) *Anesthesia workload per unit of labor cost* (McIntosh et al. 2006) *Cost per case* (HFMA 2002) *Cost per unit of output* (Peltokorpi et al. 2007b) *Anesthesia cost per unit of surgical time* (Berry et al. 2008)
External measures	*In-hospital waiting time* (Marjamaa et al. 2007) *Total waiting time* (Oudhoff et al. 2007)		*Maximum ward beds needed* (Santibanez et al. 2007) *Opening hours of ward unit* (Testi et al. 2007)	

Most measures used in studies of OR management focus on internal performance, and emphasize the fact that operating units function in isolation from other hospital units. Internal measures also reflect the fact that ORs are bottlenecks in the surgical process (Torkki et al. 2006). Therefore, interest in the whole surgical process is focused on flow and the use of resources inside the operating unit.

Measures of production system quality focus on how exactly production plans are realized. Late cancellations occur when planned operations are cancelled for reasons related to patients, such as when a patient's condition improves or if he or she simply does not appear. Sometimes surgery may not be performed because a patient is deemed not eligible due to another disease or because of insufficient preparation. Late cancellations are typically the result of poor pre-operative processes and deficiencies in information management. Maintaining a buffer of patients to refill empty slots is difficult, and late cancellations usually lead to lost capacity and diminished efficiency.

Shifted surgery refers to scheduled or urgent operations that are delayed for at least one day due to overload or a lack of critical resources (Testi et al. 2007). Although shifting might increase an operating unit's daily efficiency, it incurs extra costs in other units and also typically weakens the patient's condition. Start-time tardiness is a punctuality indictor with regard to starting the operation no earlier and no later than planned (Macario 2006). The significance of tardiness is emphasized in pediatrics when a parent is supporting the patient, in strictly scheduled ambulatory operations, and in operating rooms in which the surgeon changes between operations. Surgery time is also a production system measure. A long surgery time is not problematic if it is forecasted and accounted for in the scheduling. The unforeseeable extension of surgery or OR time may result in overtime costs or shifted operations.

Capacity utilization and time measures are the performance measures most frequently used in studies of OR management. The raw OR utilization rate, which is the proportion of staffed OR hours when there is a patient in the OR, is among the most commonly used measures. Two other common measures include *non-operative time* between consecutive surgeries, and *turnover time* when there is no patient in the OR. The underlying assumption is that staffed OR time is an expensive resource bottleneck in the surgical process, and must therefore be used efficiently.

Underused OR time is idle time during office hours after the last patient has left. Similarly, overused OR time is the amount of time from the end of office hours until the time the last patient leaves. The sum of underused and overused OR time (Dexter and Macario 2002) provides information about the balance of scheduling and resource use. Overused time is typically multiplied by a relative cost factor of between 1.5 and three (Dexter and Macario 2002, Peltokorpi et al. 2007b), which makes it more costly to staff an OR after regular scheduled hours than during office hours. In addition, a penalty of less than 1.0 is applied for underused hours versus utilized hours. This means that some amount of personnel idle time during office hours could be utilized in other value-added tasks outside the operating unit (Peltokorpi et al. 2007b). When there are no more operations scheduled surgeons could carry out tasks such as examining their patients in outpatient clinics and ward units.

One problem with using underused OR time as an efficiency measure is that it penalizes teams that operate quickly. These teams should be rewarded. It is a relevant measure when scheduling patients efficiently (Dexter and Epstein 2005). However, during the day of surgery it is typically included in the sunken personnel costs for regular hours. As a result, using it as part of a measure of overall efficiency may lead to a non-optimized process. Most of the production quality, utilization rate, and time measures do not account for the amount and the cost of used resources. Moreover, it has been noted that the overall influence of surgeons on utilization is small (Faiz et al. 2008). Time and utilization are often used in more complex resource-related or financial measures (Torkki et al. 2006; Testi et al. 2007).

Technical efficiency measures, which consider the relationship between process output and the amount of used resources, are seldom mentioned in the literature. One exception is a study conducted by Torkki et al. (2006), which used standardized surgery time per personnel hour. Each procedure was weighted by its historical average duration. The total standardized surgery time of the period was calculated by summing the weights of operations performed. Pandit et al. (2009) define a quantitative performance measure that takes OR time utilization, speed of surgery, turnover time and over-utilized OR time into account. However, it focuses on the use of OR time rather than the more expensive personnel resources.

Some studies evaluate proposed interventions by estimating their effects on the number of operations performed per unit of time with fixed resources (McGowan et al. 2007). The approach was reversed in Van Houdenhoven et al.'s (2007a) research: the aim was to find the minimum OR blocks needed for constant throughput. Regardless of the details, measures of technical efficiency aim at revealing the effect of interventions on the ratio of process output to used resources.

Measures of economic efficiency are mainly applied in competitive environments (McIntosh et al. 2006). Contribution to margin is used when the aim is straightforwardly to maximize profit in the operating unit. Attracting the fastest and most profit-making surgeons is essential when maximizing contributions to margins. The anesthesia workload per cost hour is used as a measure of economic efficiency when billing is based on the workload, such as time used in value-adding tasks. Hall et al. (2006) examined how surgeons affected the variation in total hospital costs per patient. However, they considered only patient- and surgeon-specific factors, and not decisions that were made in the operating unit planning process.

Measures such as profit and total costs are not widely used in non-competitive operating units. One reason for this could be that increased costs are added to the price in a non-competitive environment. In addition, the price of certain services is not based on unit costs, but is defined on a higher level so as to balance total costs and profits. It would be possible to measure economic efficiency in operating units by dividing the personnel costs by the produced output (Peltokorpi et al. 2007b). This measure could be further developed by incorporating costs incurred by reason of actions in the operating unit but that are burdensome on other units in the hospital.

Only a few studies have identified the bottleneck in the surgical process as being outside the operating unit. Santibanez et al. (2007) aimed to minimize the number of ward beds needed by reengineering the allocation process of OR time blocks to the ward units. The study emphasized the operating unit's role in defining the use of resources everywhere in the hospital.

Some studies use total waiting time as a primary measure of operating unit performance (Oudhoff et al. 2007). This is best suited to operating units mainly serving emergency patients (Torkki et al. 2006). Total waiting time is also widely used in studies in which the aim is to consider the total costs associated with illness, not only the costs attributable to the service provider (Peltokorpi et al. 2006).

Given the relatively high cost intensity of operating units versus other care phases in the surgical care process, technical efficiency and economic measures should both be emphasized in the assessment of their performance. Pure resource utilization measures such as OR utilization rates and turnover times are inadequate because they typically focus more on the use of space than on the use of more costly personnel, and they do not account for output. Technical efficiency has a wide range of implications in other areas. It can be used as a proxy measure of broader performance issues, for example, and at the end of the day it can be measured accurately, which is not the case with many other measures. It fulfills the two major requirements of a good measure: it is *powerful*, i.e. valid and is of considerable significance, and *parsimonious,* i.e. not too complex or ambiguous, and does not involve a lot of measurement and data quality problems (Neely et al. 1997).

Measures of both technical and economic efficiency are applied and developed in the following parts of the present study. The term productivity is also used to describe such measures as they concern the ratio between the inputs and outputs of the operating unit processes.

2.3 Surgical service planning and control

2.3.1 Defining the service strategy and concept

An essential part of strategic planning for an operating unit is to define the term *service concept*. The service concept incorporates a shared understanding of the nature of service. It combines customer needs and customer segments with provider services that fulfill those needs. Johnston (1999) divided service concepts into four different groups, depending on (1) the number of markets served and (2) the range of services. At the two extreme ends of this grouping are the *service-focused concept* involving the delivery of a narrow range of services to many markets, and the *market-focused concept* involving the delivery of a wide range of services to a small number of markets (Johnston and Clark 2005).

This grouping can also be applied to service operations. When it is a question of a *business focus the* markets are split into segments with similar needs, which are serviced by separate operations. Alternatively, with an *operational focus* each business or site provides the same range of services to a range of customers. This leads to high variation in operations, since single markets and customers need individual combinations of operation modules (Johnston and Clark 2005). This is a classic focus dilemma.

In surgical units the operational focus is mainly apparent in regional hospitals, which perform surgical operations on different levels of urgency in several specialist areas. The business focus is adopted in hospitals that provide a narrow range of operations for defined problems. It is essential that patient needs are assessed separately during the early phase of the patient episode, and then to provide focused surgery to meet these needs. Some operational focus is therefore necessary in regional hospitals that accept emergency cases, in spite of the coordination problems that accompany it.

It is essential to know in surgical services when it is optimal to use an operational focus and when it is optimal to use a business focus as a production strategy. At a minimum, quality, efficiency, and accessibility issues should be considered in the organization of surgical service production for any region. In Finland, for example, the biggest healthcare organizations, such as the Helsinki and Uusimaa hospital districts, are moving toward more self-managed and profitable business units that operate hospital-wide. This will enable the centralization of similar functions in one unit. In addition, the increasing power of business units over single hospitals allows the more flexible use of functional resources in the network.

The operational focus has been dominant in surgical services, although the business focus or the factory approach is emerging (Hyer et al. 2009). More information is needed about the optimal production strategies. It is not clear, for example, how the selection of a business or operational focus affects overall performance.

2.3.2 Strategies for capacity management

Capacity management may be (1) short and medium term or (2) long term. Short and medium term relate to managing existing resources, whereas long term refers to developing new capacity. Capacity management is typically a balancing act between service quality, waiting times, and financial results. (Johnston and Clark 2005)

Service capacity is the maximum level of value-added activity in a certain time period that the service process can achieve consistently under normal operating conditions (Slack et al. 2004). In order to manage capacity it must be measurable. However, some factors make its measurement difficult (Johnston and Clark 2005). For example, the service-product mix might be so variable that making calculations is very complex.

There is typically high variation in surgery time and staffing needs in an operating unit. Although certain needs, such as for nurses and anesthesiologists, can be estimated accurately, there may be capacity constraints due to the need for specialized surgeons and equipment. Therefore all surgery subgroups have their own maximum capacities, which cannot be exceeded.

There are three basic strategies for short-term capacity management. A *level capacity* strategy requires the maintenance of scarce and expensive resources at a constant level, the prime objective being to maximize their utilization. A *chase capacity* strategy involves matching supply and demand as far as possible by building flexibility into the system. The prime objectives are service availability and fast response. In the case of *demand management*, the organization influences the demand profile in order to even out the load on its resources (Johnston and Clark 2005).

All three strategies can be identified in surgical services. Operating units producing mainly elective operations typically focus on level capacity: capacity, which is the number of staffed operating rooms during office hours, is almost constant from day to day (Peltokorpi et al. 2007a). Operations are scheduled into free OR block times and peaks in OR demand lead to longer waiting times.

Chase capacity is used as a strategy in many operating units that perform emergency operations outside office hours. These units typically retain core shift teams that operate the base load in the evenings, at night and on weekends. During acute or estimated peak periods, either there is a duty-on-call team or personnel from office-hour teams are invited to work overtime. Another solution is to delegate existing resources (Ronen et al. 2006), in which case some tasks assigned to constrained resources are delegated to more plentiful resources. For example, nurses may carry out some of the surgeons' tasks if surgeons are bottleneck resources.

Extensive demand management is uncommon in hospitals, which are responsible for treating all patients in their regions. Hospitals cannot easily control demand because there are no substitutive providers. However, operating units utilizing level capacity to balance their production between weeks and days might affect demand via waiting times, at least with less serious illnesses - if people know that the waiting time for general practice is long the threshold for contacting the provider rises.

The choice of capacity strategy in an operating unit is extremely important in that different strategies limit the methods available for managing overall cost levels. Level capacity may lead to a reduction in unit costs through an increase in output or a decrease in the use of variable supporting resources whereas in the case of chase capacity the cost level depends on the accuracy of demand forecasts and policies in terms of responding to the variation. Personnel flexibility is the key given the significant contribution of staff costs to total costs, and especially because increased personnel flexibility tends to raise hourly wages.

2.3.3 Managing constraints and bottlenecks

The capacity of a process equals the capacity of the tightest bottleneck. According to this principle in the theory of constraints (TOC; Goldratt 1984), a bottleneck occurs in a process where the maximum throughput is at its lowest point. When aiming to improve efficiency management should focus on improving bottleneck throughput. There are five key steps in the application of TOC to the operational environment: 1) identify the constraint, 2) utilize the constraint to its fullest extent, 3) make sure that non-constraints keep the constraint busy, 4) improve the productivity of the constraint, and 5) repeat the previous steps (Ricketts 2007).

The TOC approach also has applications in healthcare organizations. TOC intervention was found to have a positive impact on most measures in Eyes and ENT departments in an NHS trust (Lubitsh et al. 2005). Motwani et al. (1996) presented an example of a US hospital in which a TOC solution led to the improved utilization of operating rooms. There are also arguments that constraints frequently resemble policies and procedures rather than capacity or equipment (Motwani et al. 1996).

The OR is typically cited as the main bottleneck in surgical processes (Jebali et al. 2006; Torkki et al. 2006). According to reported improvement efforts, however, post-operative care is relatively infrequently identified as a bottleneck (Santibanez et al. 2007).

There are many ways of managing bottlenecks. Sometimes there is sufficient capacity, but its use in the bottleneck phase is weak. When the bottleneck is in the OR the reason for low utilization is typically in the planning phase, especially in case scheduling. For example, the algorithms used in the scheduling may be inaccurate, or the targets for capacity utilization may be too low. Furthermore, setting times between care phases and consecutive operations may lead to long idle times for ORs and personnel. Developing sophisticated algorithms for case scheduling (Van Houdenhoven et al. 2007a) and implementing new practices and communication technologies could improve the OR utilization rate (Mazzei 1994).

It may be possible to increase throughput by splitting a bottleneck phase into several sub-phases and moving some of them away from the scarce bottleneck resource. This approach is widely used in OR processes (Stahl et al. 2007; Torkki et al. 2006; Krupka and Sandberg 2006). For example, separate adjacent induction rooms and exit areas could shorten OR lead time by enabling the parallel processing of consecutive operations. Safety issues are addressed through the use of mobile OR tables in order to minimize patient transfer (Stahl et al. 2007). A large “OR of the Future” project featured ceiling-mounted surgical equipment, and a work area with telephone and information access to allow surgeons and anesthesiologists to dictate and teleconsult. This approach was applied in one study, resulting in improved patient turnover and minimized clutter in the OR (Stahl et al. 2007).

Reducing OR time is worthwhile only if it leads to increased surgical capacity without added resources or reductions in labor costs. Operations can be added only if the reduction in OR time leaves sufficient time to schedule another case during office hours. Labor costs can normally be reduced only by reducing allocated OR time (Dexter and Epstein 2005). However, because allocated OR time blocks are typically fixed (8 hours, no more or less), the only way to reduce it is to delete entire eight-hour blocks and perform the operations in other sessions.

Resources in the bottleneck phase of a process should be increased only if other actions do not increase the flow sufficiently. Even in that case additional resources should be allocated, if possible, from underutilized phases. For example, some of the personnel from the PACU or even outpatient clinics could be reallocated to ORs during busy periods.

Capacity constraints of the surgical process may arise in very different phases. In summary, new technologies, new facilities, resource reallocation and process reengineering should all be tried before deciding to broaden a process bottleneck through the provision of additional resources. The best results are typically achieved when technologies, facilities and resource-management issues are combined to improve service delivery in the bottleneck phase (Krupka and Sandberg 2006).

2.3.4 Capacity allocation and scheduling systems

In surgical services, production capacity is typically defined as staffed OR hours. '*Staffed'* means that sufficient nurses and anesthesiologists are available. Capacity allocation practices in hospitals differ based on local scheduling systems. Two systems are most commonly used in operating units, block scheduling and open scheduling (Denton et al. 2007).

Under the block-scheduling system OR time is first allocated to specialties, wards, surgical groups or individual surgeons (Testi et al. 2007; Van Houdenhoven et al. 2007a). These groups book cases in their assigned slots, subject to the condition that procedures are completed within the allocated time period. If demand is high they need to overbook or negotiate additional OR time, which is released from non-allocated time or other allocated subgroups. Open-scheduling systems aim to accommodate all patients. Surgeons submit cases up until the day of surgery and all cases are scheduled. Individual operations are allocated to ORs to create a schedule prior to the day of surgery (Denton et al. 2007).

Both systems have strengths and weaknesses (Table 3). For example, with block scheduling the responsibility to manage resources is divided efficiently. Specialties and surgeons schedule their own time blocks, and operations planning and control becomes easier from management's point of view. However, the early allocation of resources to subgroups reduces the adjustment of capacity to realized demand inside the subgroups (Van Houdenhoven et al. 2007a). The higher variation in demand inside these subgroups means that some capacity has to be reallocated nearer the day of the operation, otherwise there is a buffer of patients waiting for surgery.

Table 3 Advantages and disadvantages of block- and open-scheduling systems.

	Block-scheduling system	***Open-scheduling system***
Advantages	Daily and weekly throughput can be adjusted. Decreased need for resource flexibility. Timetables of surgeons and OR staff can be planned in advance. Operating rooms can be better equipped for special surgical groups.	Increased patient satisfaction. Shorter wait times. Decrease in patient-in-process leads to diminished administrative tasks and additional examinations. Personnel are better motivated to increase efficiency.
Disadvantages	Resource coordination needed in advance with limited information about actual demand. Susceptible to fixed weekly and monthly allocations without connection to actual demand. Variation in demand within specialties leads to the need for capacity-adjustment systems. Longer wait times.	Resource coordination needed within a limited time frame. Susceptible to mistakes due to short planning periods. Variation in daily demand leads to the need for flexible working hours.

If there are no financial implications block scheduling tends to lead to fixed allocations. Specialty-specific schedules are similar from week to week, and even from year to year. Production planning is comfortable for personnel, but variations in demand lead to longer waiting times and capacity losses (Peltokorpi et al. 2007a).

In open-scheduling systems patients can decide the date of surgery. Given the shorter waiting times there is also less need for additional care, such as new examinations and ward care, or for administrative tasks such as queue management (Kujala et al. 2006). Open scheduling requires high personnel flexibility however, and is typically not possible without high wages.

Predictability and the use of fixed resources are emphasized in block-scheduling systems, whereas customer-orientation and entrepreneurship are emphasized in open scheduling. The essential aims in the latter are to retain and develop surgeons' practices, to enhance market share and reputation, and to fulfill the mission of rapid access to care (Dexter and Macario 2002). Open scheduling is more typical in an environment of free competition, whereas block scheduling is more typical in public healthcare. This study focuses mainly on block scheduling, which is typically used in Finnish hospitals. However, the potential benefits of moving toward an open system are discussed.

The allocation of surgical-service capacity in a block-scheduling system is a three-stage process (Santibanez et al. 2007):

1. The creation of an annual plan for the specialties, and the related OR and equipment needs.
2. The daily, weekly and monthly allocation of staffed OR time blocks to specialties and surgical groups.
3. The daily scheduling of individual cases in the OR.

Allocating surgical capacity is a complex process that must account for a variety of surgical specialties, different priorities, post-surgical capacity, and a mix of elective and emergency procedures (Santibanez et al. 2007). OR blocks cannot typically be allocated to subgroups in a completely centralized and coordinated way. Allocation is a result of many factors. First, equipment availability and the requirements of different specialties mean that certain procedures can be performed only in certain ORs. This limits both the maximum daily amount of OR time allocated to certain subgroups and the likelihood of finding a subgroup able to use an open OR block.

In addition, specialties and surgeons must also examine patients in outpatient clinics (Santibanez et al. 2007). Although personal schedules can be adjusted, surgeons push for blocks that better fit their own schedules. Moreover, patient-specific factors may mean that surgeons prefer certain days. For example, Fridays are not very attractive because surgeons prefer to monitor the first critical days of a patient's recovery during weekday office hours.

Timing is an important issue in capacity allocation. If this is done very near the day of surgery it is possible to estimate true demand accurately based on the queues. This enables efficient allocation and reduces the need for reallocation. On the other hand, early allocation of OR capacity enables advance personnel planning, and patients are not put in queues but rather scheduled immediately after the decision to operate has been made.

Even with block scheduling the total daily and weekly allocated OR time is significantly dependent on factors that are outside the control of operating unit managers. This reality emphasizes the importance of other factors, such as staffing and case scheduling.

2.3.5 Managing emergencies and elective operations

An elective case is one for which patients can wait at least three days for surgery without sustaining additional morbidity (Dexter and O'Neill 2001). Other cases could be defined as non-elective or emergency surgery. Managing emergency surgery differs from managing planned operations in many ways. The planning process before emergency surgery is very short, and achieving a high capacity utilization rate is challenging. Urgent operations are typically managed in a separate hospital or operating unit in metropolitan areas, in which the volume of accidents is high. The decision to separate production strategies for emergency and elective surgery is made during the front-end phase of the production planning process in these hospitals (see Figure 1).

Decisions about emergencies are also made in the capacity-allocation phases and on the day of surgery. Some hospitals allocate separate office-hour ORs for emergency patients (Peltokorpi et al. 2008). The main reason why this approach was adopted in many Finnish hospitals was because waiting times in urgent cases led to diminished quality and extra costs in ward units. Furthermore, there was a discouraging effect on personnel and the flow of elective operations was disturbed. If emergency and elective operations are mixed, surgical case schedules may need to include free OR time (planned slack) (Van Houdenhoven et al. 2007a). Because the proportion of emergencies varies depending on the specialty, planned slack differs among allocated ORs.

In summary, separating OR time blocks facilitates elective surgery scheduling without uncertainty, and the more systematic planning of urgent cases. However, a sufficient volume of emergencies is necessary in order to achieve an adequate OR utilization rate. If there is a low volume of emergencies during office hours there are two challenges. First, during very low-volume days the utilization rate of the OR and its staff is also very low. Second, allocating surgeons to operating rooms for emergencies is challenging in units with low volumes but high surgical variation: getting hold of a competent surgeon for all emergencies may be difficult. Denton et al. (2007) found in their studies that reserving OR capacity to accommodate urgent and emergent cases was an open area of research. More information is needed about many things, such as the critical emergency volume that enables separated processes and how capacity should be reserved for emergencies in a mixed system.

2.3.6 Scheduling surgery

Scheduling surgery means allocating a particular time block in a particular OR to a particular patient. Scheduling is typically executed so that OR time blocks are allocated to patients waiting for surgery. Patients are typically informed of a surgery date at least two weeks beforehand. If the scheduling is inefficient, finding patients at short notice is challenging and the OR utilization rate may remain low.

The literature on elective case scheduling is abundant. It divides optimal scheduling processes into three phases: (1) estimating the duration of each operation, (2) allotting cases to individual OR blocks, and (3) determining the optimal sequence of operations.

The most essential point in predicting case length is to find a model and factors that explain the variation in required OR time better than surgeons' subjective estimates. Only one study (Wright et al. 1996) found that surgeons provided more accurate time estimates than data-based scheduling algorithms. Dexter et al. (2005) argue that specialties consistently underestimate surgery duration. Many studies have concluded that the combination of procedure, surgical complexity and surgeon explains the remarkable variation in case length (e.g., Shukla et al. 1990; Opit et al. 1991; Strum et al. 2000b; Broka et al. 2003; Lebowitz 2003a).

At the core of the scheduling process, daily operation lists are determined according to the cases planned for a certain OR session. Overbooked lists lead to overused OR time and cancellations (Pandit and Carey 2006). Similarly, loose booking leads to idle time and diminished efficiency. Few studies have examined optimal planned idle times or OR utilization rates. Tyler et al. (2003) suggest that a utilization rate of 85-90 percent is optimal when the last cases end no more than 15 minutes past the scheduled end of the day. The variability in the duration of surgery affects the optimal utilization rate and planned idle time. Van Houdenhoven et al., (2007b) proved that with a fixed risk of overtime, the optimal OR utilization rate ranged between 75 and 91 percent among the specialties. Peltokorpi et al. (2007b) determined the optimal planned idle time for open-heart surgery, which lasts an average of 4.5 hours. Depending on the forecast accuracy and the use of parallel anesthesia induction, the optimal planned overtime ranged between 30 and 70 minutes.

Lowering scheduling barriers by allowing different specialties and surgeons to use the same OR on the same day may increase OR utilization and free block time (Van Houdenhoven et al. 2007a). Dexter and Traub (2002) found that scheduling any add-on case to the OR with the earliest free start time led to the highest efficiency. If one specialty has non-scheduled OR time efficiency can be maximized by releasing non-scheduled OR time to another (Dexter and Epstein 2005). If OR time must be reallocated between specialties it may be best if the one with the most non-scheduled OR time gives its capacity to the one that has problems scheduling all its operations (Dexter and Macario 2004).

The literature shows that there is no absolute optimum for planned idle time in the scheduling of elective cases. How tightly the OR blocks should be scheduled depends on many factors, including the average case length, variation and unpredictability in length, overtime costs, and practices such as parallel processing.

The sequence of operations is not as important from the organizational perspective as resource allocation and case scheduling. Therefore, the literature on case sequencing is largely ignored in this thesis. The prevailing conclusion is that scheduling patients in order of increasing mean duration (Lebowitz 2003b; Testi et al. 2007) or increasing variance in duration (Denton et al. 2007) is best in terms of reducing in-hospital waiting time.

2.3.7 Ensuring efficiency during the day of surgery

The main goal on the day of surgery is to ensure that all operations can be performed safely while minimizing additional costs (Dexter et al. 2004). Urgent cases must be scheduled and sequenced, limited resources and personnel must be prioritized, some cases may need to be moved, and additional staff assigned. Overdyk et al. (1998) suggest that the central aim on surgery day is to minimize OR delays.

Nevertheless, unexpected events such as a high number of emergencies or operations that are more complicated than anticipated may require a compromise between added resources and surgery rescheduling. Dexter et al. (2004) argue that overused OR time or added OR capacity should be always preferred to rescheduling. In practice, elective or emergency operations are sometimes rescheduled to the next day due to overload or unavailable resources. An essential task during the day is to schedule emergencies during staffed OR time. This need often leads to overused OR time and sometimes to the rescheduling of elective surgery.

In practice, decisions on surgery day are typically not based on maximized total efficiency. Instead, OR culture and intangible and tangible rewards for working fast lead to decisions that are based on increased clinical work per unit of time (Dexter et al. 2007). This approach may be disadvantageous for decisions involving multiple ORs. For example, a surgeon might schedule an emergency case in a certain OR even if using another one would be more efficient. Dexter et al. (2007) argue that command displays with recommendations generated from information about the system status may be more effective at changing decisions than education and distributed status displays.

Managing resources and production plans on surgery day is a challenging task. Overreaction to unexpected events may lead to high additional costs, but only minor increases in production. Adding staff within 24 hours of surgery is more expensive than using planned personnel. Difficulties can be minimized with realistic scheduling and staffing, and with clear decision-making criteria for unexpected situations.

2.3.8 Managing performance in a multi-specialty operating unit

According to the theory of service operations management, increased variation in service products and sub-processes increases the challenge of managing service production (Johnston and Clark 2005). Likewise, multi-specialty operating units have special features and challenges. First, a significant challenge arises when OR time is allocated weeks before the scheduling, as there are no accurate demand estimates. This situation typically leads to variation in waiting times between specialties, and those with low demand can operate sooner than those with high demand.

Second, scheduling decisions are decentralized in multi-specialty operating units. In practice the specialties typically have the autonomy to schedule operations as they please. Consistent rules are needed, but any reduction in autonomy is hard to implement. Balancing resources between specialties is also challenging due to a lack of communication. Third, surgeons, and sometimes also nurses, are non-substitutive in multi-specialty operating units. This means that readjusting schedules or resources on surgery day is hard or even impossible. Patients and surgeons may be changed only inside the specialty. This constraint emphasizes the importance of proper planning.

Fourth, in multi-specialty units the surgery volume in most specialties is typically not sufficient to justify reserving separate OR time blocks for emergencies. Elective and urgent cases are performed with shared resources. This situation increases planning challenges. OR time overruns and cases are delayed if the number of emergency operations is underestimated. The need to forecast unplanned events is emphasized in the management of multi-specialty operating units. The managers also need more information about the effects of planning actions on system errors, such as over-utilized OR time and delayed operations.

2.4 A summary of the existing theory

The existing theory and the identified gaps in the context of this dissertation are summarized in Table 4. General frameworks for production planning and control in healthcare organizations are developed in several studies (e.g., Vissers et al. 2001). However, specific needs and features in the context of operating unit processes and surgical services in general are not presented systematically. There is a clear need for the kind of framework that would make it possible to identify all the relevant features affecting operating unit performance.

Table 4 A summary of the existing theory and the identified research gaps

Subjects of this study	Existing literature	Gaps in the literature
A framework for production planning and control in surgical service	Sophisticated and extensive frameworks are constructed for general production planning and control in healthcare organizations	No detailed framework for the production planning and control of surgical services and operating units
Performance measurement in operating units	Several efficiency and quality measures are developed and applied. Most of them focus on resource utilization and simple cost analysis.	Need for a combined productivity measure that enables the daily monitoring and comparison of operating units with different case mixes.
Performance improvement and management in operating units	Plenty of studies on the effect of single practices and features on the selected performance measure. Most of the studies use a modeling approach.	Lack of understanding of the effect of unit size, scope and urgency profile, and the combined effect of different practices and features on performance. Also a lack of empirical studies utilizing data from many hospitals.

Several efficiency measures have been developed and applied in the area of performance measurement in operating units. However, only a few of these have been tested in multi-hospital comparisons (e.g., Berry et al. 2008). There is also a lack of productivity-based measures that focus on standardized output from defined resources rather than resource utilization or production costs. In the best scenario, the measure used should also enable daily performance monitoring. This means that it should provide timely and accurate feedback (Globerson 1985), respond to the activities of the personnel and management, and be mainly immune from non-manageable actions such as day-to-day patient-specific variation (Neely et al. 1997).

The third question of the present study relates to the practices and features of production planning and control that lead to high performance in operating units. The existing literature covers several practices, especially in the areas of case scheduling and parallel processing. Most of those studies investigate the relevant phenomena in a single hospital environment, and there is a lack of understanding of the effect of strategic features such as unit size, scope, and urgency profile. Moreover, the combined effect of different practices is not investigated thoroughly. The use of the modeling approach may be one reason for this narrow scope in previous studies. Instead of investigating performance management in operating units piece by piece, it is suggested that a more holistic approach is needed, and this is more suited to an empirical approach in which the performance phenomena are investigated systematically in several hospitals.

3 Developing a framework for operating unit planning and control

This chapter traces the development of a framework for healthcare production planning and control for an operating unit environment. The aim is to define the relevant variables in the management and planning process that affect performance.

According to earlier models (e.g., Vissers et al. 2001; Smith-Daniels et al. 1988; Rhyne and Jupp 1988; Butler et al. 1992) and the current literature on relevant management practices in operating units, there are four hierarchical levels of production planning and control operating within a system environment in the organization (Figure 6).

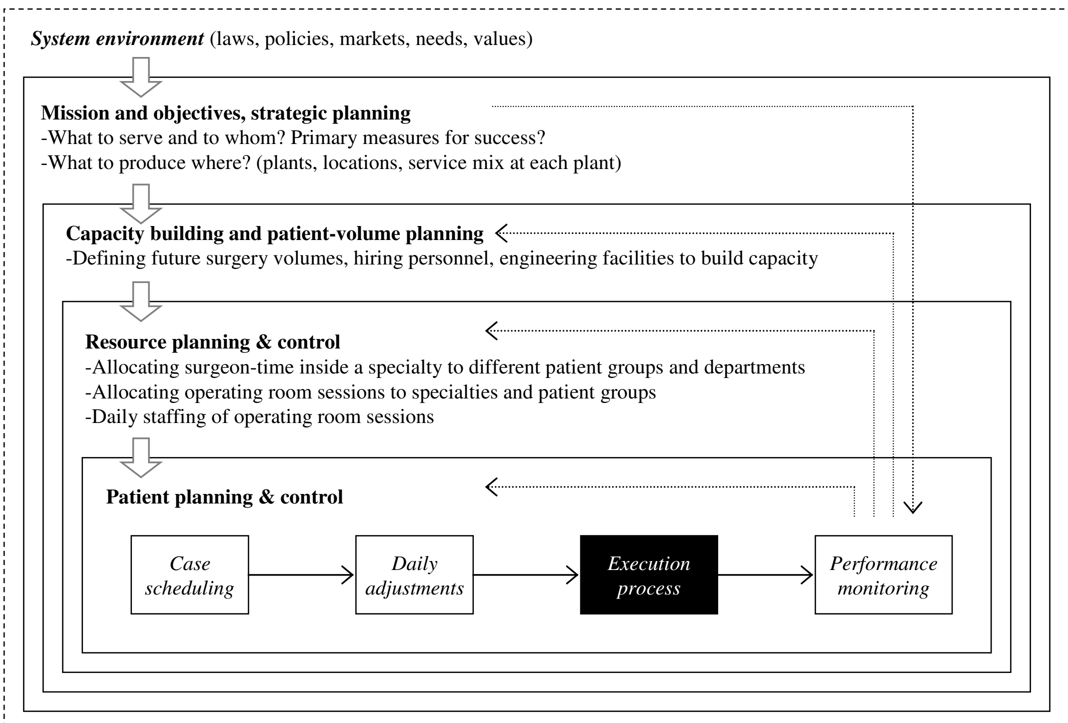

Figure 6 A hierarchy for operating unit production planning and control.

The system environment consists of concepts such as laws, values, markets and needs that are valid in the organization’s area of operation. Labor legislation, the division of work between personnel groups, personnel sizing in ORs and the use of external personnel are examples of the cultural or legal factors that affect the resource side of the production planning. On the demand side of the services, variation in morbidity, established care practices and ethical issues related to certain operations are some of the factors that have to be taken into account in comparisons of organizations with different system environments.

On the highest level of operating unit production planning organizations define the missions, objectives and strategies for producing surgical services. Strategic planning is the process of creating a rough plan of how the organization will fulfill its surgery-production function in upcoming years. Plans covering the number of operating units, service variety in each unit and the surgery output per unit are drawn up. Regional distances and the location of support services such as intensive care and imaging that are shared with other disciplines affect the production strategy. Moreover, the historical evolution of the organization in terms of supporting centralized or decentralized service production in general, for example, might limit the strategic choices.

On the second level of the hierarchy, capacity building and patient-volume planning focus on estimating future demand and building fixed capacity, such as the core personnel and facilities. Decisions about the necessary mixes of personnel skills are made and applied in the recruitment and training. The essential questions concern the number of anesthesiologists required for a given amount of surgery and the necessary skill mix of nurses, and whether there is a need for separate anesthesia and OR nurses, for example. The fixed facilities include ORs and PACU rooms, and the layouts that have to be regularly reengineered to comply with changing demand and service needs. Building a layout that enables the parallel processing of consecutive patients is one of the most common applications of such facility reengineering.

Resource planning and control, on the third level, includes weekly, daily, and even hourly plans covering the use of shared core resources, specialist time and staffed OR sessions. Specialist time is allocated to different patient groups and departments in the hospital. Daily OR sessions are allocated to specialties or directly to individual specialists. ORs are staffed with anesthesiologists, nurses and other professionals in line with the allocations. The seasonality of illnesses and surgeon availability create variation in monthly capacity needs among the specialties. This fluctuation and other demand trends must be accounted for in the allocation of capacity and staffing. Decisions about OR opening hours and the numbers of daily nursing and anesthesiologist personnel are also made on this level.

The fourth level of the hierarchy, patient planning and control, involves the scheduling of individual cases to the OR sessions. This process typically happens a couple of weeks before surgery. The case-scheduling practices affect the balance between allocated and used OR time. Additional cases, such as emergencies, force last-moment adjustments in plans. Intraday flexibility in the use of personnel helps in achieving a balance between service access and resource utilization. Measuring performance is an essential part of the control process. In well-managed organizations the monitored measures are based on organizational objectives, and performance results have implications for future plans.

The developed framework may be useful in creating a research frame within which to identify the most productive strategic decisions and practices. It is used in this study to categorize decisions and practices on each level in the production planning and control that potentially affects performance (Table 5). Strategic decisions about unit focus and size are discussed in the existing literature (Berry et al. 2008), but there is no comprehensive study on their effect on overall productivity. One reason for such a lack could be the fact that in most studies the environment is a single case hospital or operating unit and therefore the variation in strategic decisions is not investigated. The effects of lower-level practices, such as sophisticated case scheduling or process layouts, have been analyzed one by one, but the efficiency measures used are typically incomplete (Saleh et al. 2009). There is also lack of knowledge about combining different decisions and practices, and a need for more understanding concerning the effect of single decisions and practices on efficiency when earlier decisions on the strategic and the system-environment level are taken into account.

Table 5 Decisions and practices on each planning level that potentially affect operating-unit performance

Planning level	*Decisions and practices*
Strategic planning	Service scope (sub-specialties, urgency profile, complexity profile) Unit size
Capacity building	Process and layouts Personnel skill mix
Resource planning and control	Day-to-day staffing flexibility Use of personnel incentives
Patient planning and control	Case-scheduling practices Intraday flexibility in personnel management Performance monitoring

4 Research hypotheses

4.1 The method of hypothesis

Hypothesis has an important role in the development of theory (Emory 1985). Knowledge is increased through the acceptance or rejection of hypotheses that are deduced from the theory (Niiniluoto 1983). Hypotheses are formulated through an inductive or a deductive strategy (Ketokivi 2009). Under an inductive strategy regularities in empirical observations are used as a source in drawing general conclusions, whereas the aim in a deductive strategy is to draw conclusions through logical reasoning (Ghauri et al. 1995). The origin of hypothetico-deductive reasoning is in the philosophy of science (Evans and Kakas 1992). Karl Popper (1959) and Carl Hempel (1965), for example, effected the formulation of the hypothetico-deduction method, the aim of which is to create scientific theories by forming a hypothesis from which results already obtained could have been deduced. The basic idea is that hypotheses cannot be derived from observations, but once formulated can be tested against observation.

There are arguments that claim, however, that the division into hypothetic-inductive and hypothetic-deductive methods is mainly normative and does not describe their practical application (Ketokivi 2009). Therefore the term *method of hypothesis* is proposed when the aim is to understand the application process of the method (Ketokivi 2009). Hempel (1965) also argued that, especially in the social sciences, hypotheses are never generated deductively from the theory but are derived from different social conventions, definitions and semantic rules (e.g., Costner & Leik 1964; Gorski 2004; Ketokivi 2009). In summary, this means that the emphasis in the method of hypothesis should be on empirical testing (Ketokivi 2009). Such an emphasis is especially important in research that aims at high practical relevance. For example, if the size of the operating unit is assumed to drive its productivity, it is more relevant to show if the empirical data supports or refutes the hypothesis than to find a theoretical explanation for the relation.

Given that there are identified gaps in the current theory of OR management, the method of hypothesis is well suited to this research in terms of formulating hypotheses around the identified gaps and testing them on empirical data. Practical relevance is highlighted in this study. Therefore, the focus in applying the method is on the testing part. The empirical and theoretical background of this study is a combination of 1) a coherent theory of general operations management, 2) the wide but not comprehensive literature on OR management, and 3) the researcher's previous scientific and practical work on performance development in several operating units. This background was taken into account in selecting the appropriate method for the hypothesis development.

The hypotheses were developed on the basis of deductive reasoning from the existing theory, combined with the researcher's preliminary understanding about the relations between the phenomena. The use of existing theory in the process entailed taking accepted statements, such as the effect of volume on performance in different production modes, from the general theory of operations management and applying them in the context of operating unit production. If the literature on OR management or the researcher's understanding of the context contradicted the general statement, the assumed relation in the hypothesis was set to be neutral or even contrary, depending on the context.

The study methods and hypothesis testing are discussed further in Chapter Five, which also goes into more detail about the aspects of the researcher's background that affected the hypothesis development.

4.2 Hypothesis development

Hypotheses were formulated and tested on empirical data from operating units in order to enhance understanding of the tools and practices explaining high productivity. A total of 12 hypotheses were formulated, based on the earlier chapters describing the background, the study objectives, the literature on surgical service management, and the framework for operating unit production planning.

> *Hypothesis 1: A productivity measure that considers standardized surgery as output and used personnel hours as input is valid for monitoring daily performance and comparing operating units with a different case mix.*

Hypothesis 1 relates to the second research question concerning valid measures for evaluating and comparing operating unit productivity. According to the healthcare operations management literature, a productivity measure that has some standardization on both the output and input sides of the equation may be appropriate (e.g. Torkki et al. 2006). The testing of Hypothesis 1 will show the appropriateness of a productivity measure for comparing the performance of different operating units and monitoring day-to-day performance. A valid measure is one that responds to the daily planning decisions, gives equal consideration to different cases and is not too complex or ambiguous (Globerson 1985; Neely et al. 1997).

> *Hypothesis 2: Operating units with a narrow service scope have higher productivity than units providing a wide range of services.*

Hypotheses 2-10 relate to the third research question concerning the effect of single decisions and practices in the production planning and control system on operating unit productivity. Hypothesis 2 is based on the theorem that the variation in product range and the customization of services decrease productivity (e.g., Schmenner 2001). Units with a focused scope may benefit best from the learning curve and from systematic processes (e.g., Skinner 1974). In healthcare services, the concept of focus factory has challenged more traditional functional and discipline-driven departments (Lathrop et al. 1991; Wilson 1999; Hyer et al. 2009). Although there are also examples in which focusing led no permanent improvements in costs (Liedtka and Whitten 1998; Hyer et al. 2009) it is proposed that in quite a compact operating unit environment focusing increases generated output per resource unit. In order to test Hypothesis 2, the productivity of units with a focused scope and those hosting a wide range of operations within several sub-specialties will be compared.

> *Hypothesis 3: The size of the operating unit has no effect on its productivity.*

There are no unambiguous conclusions about the optimal operating unit size in the current literature. It is unclear that simply putting the operating rooms next to each other guarantees any synergistic effects (Berry et al. 2008). Although one might suggest that economies of scale (e.g., Stigler 1958) are also applicable in this context, the fact that the production in most ORs is planned and staffed separately implies a cell-based production system in which the productivity is not that dependent on the total volume. It is also suggested that the complexity of coordination between ORs and personnel groups counteract the volume advantages in bigger units.

Hypothesis 4: Operating units with high proportion of acute surgery have higher productivity than units engaged mainly in elective surgery.

Contrary to the general assumption concerning the restricting effect of a rapid response time on production productivity, it is suggested that operating units may benefit from a high proportion of acute (= rapid response) surgery. The underlying assumption is that acute units respond more actively to all unscheduled changes in production, regardless of whether the reason for the change is related to patients, the personnel or anything else. Acute units are also potentially more capable of mitigating the destructive effect of a change of shift on production, and acute surgery could fill idle times in ORs when elective surgery proceeds more quickly than estimated. In other words, operations are hard to manage because of their variable duration, and therefore acute surgery works as an in-house buffer to maximize the use of staffed OR time.

Hypothesis 5: The use of parallel processing increases operating unit productivity.

There are several studies on OR management that attest to the positive effect of the parallel processing of consecutive patients on operating-unit performance (Stahl et al. 2007; Torkki et al. 2006; Krupka and Sandberg 2006). Parallel processing has its roots in concurrent engineering (e.g., Prasad 1996). There is reason to suggest that the practice is also applicable from the productivity perspective. Although the literature also warns about over-resourcing in its implementation (e.g. Torkki et al. 2006), the positive effects of parallel processing are assumed to outweigh the disadvantages.

Hypothesis 6: The utilization of historical case duration and target OR filling rates in case scheduling increase operating unit productivity.

Despite the high random variation in surgery times, the literature on OR management shows clear evidence that historical surgery duration should be utilized in estimating the required process times of future surgery (e.g. Strum et al. 2000b; Broka et al. 2003; Lebowitz 2003a). Hypothesis 6 posits that combining accurate estimations with target OR filling rates leads to the optimal utilization of OR session time and thus to increased productivity. Setting a target OR filling rate is an important step toward countering the harmful effects of OR idle time and overtime.

Hypothesis 7: The use of multi-skilled nurses instead of separate anesthesia and OR nurses increases unit productivity.

There is a great deal of discussion about multi-skilling in lean production: Lean producers employ teams of multi-skilled workers at all levels of the organization (Womack et al. 1990). In the operating unit environment it is suggested that units that focus on recruiting and training multi-skilled nurses have higher productivity than those with separate pools of anesthesia and OR nurses (e.g. Buchanan and Wilson 1996). Multi-skilled nurses can be easily reallocated to new duties during the day to cover for staff absences and additional operations, for example. From the managerial perspective it is essential for at least some of the nurses have the capability to fulfill both functions.

Hypothesis 8: The use of incentive systems increases operating unit productivity.

The effects of personal and team incentives on business performance have been widely studied in different organizations (e.g., Groves 1973). Although there are studies (e.g. Conrad et al. 2002) that found positive effect of financial incentives on personnel productivity, its importance seems to be undervalued in healthcare (Parvinen et al. 2005). It is suggested that bonuses connected to output or other performance measures motivate operating unit personnel to work toward improving overall productivity. It seems that connecting incentives to the compensation of all personnel groups leads to the best performance. However, it is also assumed that partial implementation, in particular bonuses for surgeons, drives the productivity due to the centricity of surgeons in case scheduling.

Hypothesis 9: Personnel flexibility increases operating unit productivity.

There has been a lot of research on investment in and the application of flexible production capacity, especially in manufacturing companies (Mieghem 1998; Bish et al. 2005). Personnel flexibility is assumed to drive high productivity in any case. Annualized hours are proposed to introduce flexibility in operating unit environment (Guinet and Chabaane 2003). Day-to-day flexibility in the number of nurses and anesthesiologists decreases the number of low-productivity days due to the low number of open ORs and in-house surgeons. Intraday flexibility regarding the length of the working day and overlapping OR sessions facilitate the carrying out of all planned operations despite the lengthening of some and the need for additional acute surgery.

Hypothesis 10: Continuous performance monitoring increases operating unit productivity.

The introduction of new forms of competition and improved management have stimulated performance monitoring systems in public health services (Ballantine et al. 1998). It is suggested that continuous performance monitoring and the connection of past performance to future plans is an essential part of the operating unit's production planning system. Monitoring itself, as long as the measures used contribute to overall productivity, is also assumed to be a motivating factor for personnel and teams (Goddard et al. 2004). Without performance monitoring the staff might not have the cognitive means to be flexible or to make micro-improvements if they do not know what works and what does not.

> *Hypothesis 11: Capacity-building, resource-planning and patient-planning practices have a higher impact on operating unit productivity than strategic decisions.*

Although it is suggested that some strategic decisions, especially those related to service scope and the proportion of acute surgery, affect unit productivity, it is assumed that the effects of decisions and practices on lower levels of the planning hierarchy (see Table 5) are more significant. This is based on the theory that it is the operative decisions and practices such as case scheduling and staffing which are managed mainly by sub-specialties and heads of personnel groups (Santibanez et al. 2007), rather than strategic management that drive the floor-level operations in operating units. The dominance of lower-level planning decisions is understandable given the bias in the current literature toward case scheduling and staffing over strategic decisions (Dexter 2010).

> *Hypothesis 12: Operating units with a narrow scope benefit best from case scheduling and parallel processing, whereas units with a large scope benefit best from resource flexibility and multi-skilled personnel.*

Hypothesis 12 is related to the fourth research question concerning the productive operative features of different production strategies. It is assumed that operating units with a different strategy have to implement different capacity-building, resource-planning and patient-planning practices. More specifically, units with a very tight scope will benefit more from parallel processing and case scheduling than those offering a wide range of services. That is because in the latter case not all surgery types cope very well with the patient-transfer requirement of parallel processing (Krupka and Sandberg 2006), and case scheduling is easier to coordinate in units with only a few sub-specialties (Lehtonen et al. 2009). Further, high variation in the necessary patient preparation time may reduce the effectiveness of systematic parallel processing. Given that resource planning is more challenging in units with a large scope, such units are assumed to benefit more from resource flexibility. Moreover, arguments against the use of multi-skilled personnel hold especially in units dealing with very complex patient conditions (Haupt et al. 2003). In order to maintain high quality it may be a better policy to have nurses specialized in either operating room or anesthesia duties in those units. The result of testing hypothesis 12 will be used in defining practical solutions and roadmaps for managers and practitioners to increase productivity in their daily work.

The overall research approach and the methods used for testing the hypotheses and thus answering the research questions are presented in the next chapter.

5 Research methodology

This chapter describes the research methodology adopted in the study. It begins with an introduction to the approaches used in industrial engineering and management, and of the particular approach taken in the present study. After this the research process is described and the data gathering and analysis methods explained.

5.1 Research approach

Research in industrial engineering and management is typically positioned within the applied sciences, which aim at providing practical solutions for organizations and businesses (Olkkonen 1994). Niiniluoto (1993) argues that *explanative* and *predictive descriptive science* is a useful approach in that it aims at results that are expressed in terms of technical norms: if you wish to achieve A, and you believe you are in situation B, then you should do X. In applied science, the produced knowledge functions as a tool.

The phenomena studied and the objectives of this study are close to Niiniluoto's (1993) notion of *explanative* and *predictive descriptive science*. High operating unit productivity is set as a target (A), and the tools in the production planning and control (X) for achieving this target are investigated. Since the study sets high productivity as a target objective in operating unit production, it adopts not only a *descriptive* but also a *normative decision-oriented approach* (e.g., Kasanen et al. 1993). This matches well with the traditional emphasis on practical utility in the research conducted at the Department of Industrial Engineering and Management at Helsinki University of Technology (Eloranta 1999).

Given the apparent lack of a comprehensive definition of operating unit productivity in the literature, one objective of this study was to construct a measure that clarifies what productivity means. In that sense it takes a *constructive research approach*, which is defined as a goal-directed managerial problem-solving activity carried out through the construction of models, plans and organizations, for example (Kasanen et al. 1993). However, given that managerial problem solving is not practically considered in defining the measures, this study cannot be categorized as purely constructive. Instead, it is possible to test the hypotheses in *existing* organizations that have already applied the strategies and practices under investigation. In that sense the study does not create a totally new model or theory, but develops the existing theory and models of OR management in enhancing knowledge about the effect of strategies and practices *in use*. It thus aims at normative conclusions that identify strategies and practices already used in some operating units that should be applied in others under certain circumstances.

5.2 Research methods

As discussed in Chapter 4, this study is based strongly on the principles of Karl Popper's hypothetico-deductive method, which demands falsifiable hypotheses, framed in such a manner that the scientific community can prove them false. There is always the possibility that future studies will show that a hypothesis is false. However, if it is rigorously tested and not falsified there is a reasonable basis for assuming it is true – until it is falsified. (Popper 1959)

In order to enhance knowledge, hypotheses are typically tested against empirical analysis (Ghauri et al. 1995). However, it should be remembered that empirical data and analysis will never verify the theory because the data only provides inductive evidence (Ketokivi 2009). Empirical data can be gathered through several means - case studies, experiments, surveys, and analyses of archival information are mentioned as alternatives (Yin 2009).

The data-gathering methods for this study were selected carefully. Given the aim to identify the effect of single variables on productivity when taking into account other variables it was necessary to use control variables, meaning that data should be gathered from organizations in different settings. Theoretically it could have been gathered by conducting experimental studies in one unit, but testing different strategies, for example, would not have been possible. Surveys are used in gathering data about management practices in operating units (Marjamaa 2007), but they do not provide reliable data for performance analysis.

The case study could be defined as a research strategy, an empirical inquiry that investigates a phenomenon within its real-life context (Dul and Hak 2008). Case study research involves both single and multiple cases. It may produce quantitative evidence, it relies on multiple sources of evidence, it and benefits from the prior development of theoretical propositions (Lamnek 2005). Information on the many variables investigated in the present study, such as the use of scheduling methods and personnel flexibility in the unit, was obtained not from archives and registers, but also through structured interviews and observations conducted in the unit. In addition, it was considered reasonable to test the relevant productivity measure in a real-life context through a deep analysis in one case unit before applying it to a wider context. Other hypotheses that relate to the connection between practices and productivity have to be tested on data from several units.

In summary, after constructing a productivity measure for operating unit purposes we tested it in a single case unit. Given that it had an appropriate form for comparing different units, we used a combination of surveys, multiple case studies and analyses of archival information in testing hypotheses 2-12.

5.2.1 Case study research

According to Yin (1981), “the distinguishing characteristic of the case study is that it attempts to examine (a) a contemporary phenomenon in its real-life context, especially when (b) the boundaries between phenomenon and context are not clearly evident.” Another definition is that as a research strategy the case study focuses on understanding the dynamics present within single settings (Eisenhardt 1989). In this study the dynamics examined relate to the combined effect of different planning decisions, and the effect of decisions on the strategic level on the options and optimal decisions on the operative level.

With reference to the above definitions it was suggested that productivity in operating units should be examined in a real-life context. The case study was the most appropriate method for this part of the research because the productivity measure developed here has not been tested in experimental analyses, and thus its behavior in a real-life context is uncertain. The case study approach facilitates assessment of the appropriateness of the measure in the operating unit environment, which is dynamic and productivity therefore has to be understood in single settings before generalizations are possible. Conducting the case study prior to the multi-unit study also allowed application of the developed framework for production planning and control in real settings.

Case studies have their weaknesses. For example, they may incorporate complex theories that try to capture everything (Eisenhardt 1989). This was a risk in this study if the developed measure was too complex or too many variables in the planning process were investigated. Another risk is that either the theory describes an idiosyncratic phenomenon or the theorist cannot generalize it. In the present study the aim of the multi-unit part of the research was to improve the generalization. A third problem with case studies is that new theories may be very modest, such as in the work of Gersick (1988) and Burgelman (1983). The multi-unit study was assumed to reduce the risk in that case, too. It enabled the comparison of organizations with different production strategies, which broadened the study scope and the potential value of the developed theory.

Inductive case study research is a suitable method when the aim is to explore new phenomena in order to build a new theory (Eisenhardt 1989). Theoretical case selection, multiple and opportunistic data-collection methods, and comparison with the literature are characteristic of the process of creating a theory from a case study. The aim in this work was not to build an entirely new theory, but rather to deepen and revise existing theory on productivity measurement, and to consider production planning and control from that perspective in a practical real-life context. The iterative process of building theory from case study research (Eisenhardt 1989) was only adopted in part because the overall aim of this part of the study was to test the developed measure and to provide new insights into its behavior.

5.2.2 Statistical hypothesis testing

Gathering empirical data from multiple operating units and from various implemented production planning and control practices allows the utilization of statistical methods in testing the hypotheses.

A statistical hypothesis test facilitates the making of statistical decisions from experimental data (Fisher 1925). The method is largely attributed to Ronald Fisher (Fisher 1925), Jerzy Neyman and Egon Pearson (Neyman and Pearson 1933). Fisher emphasized the need for a rigorous experimental design and methods to extract a result from a few samples assuming Gaussian distributions. Neyman and Pearson, on the other hand, emphasized mathematical rigor and methods in order to obtain more results from many samples and a wider range of distributions. Statistical tests are used to determine how likely it is that the overall effect would be observed if no real relation as hypothesized existed (Fisher 1925). If that likelihood is sufficiently small (e.g., less than 5%), the existence of a relation may be assumed. Otherwise, any observed effect may just as well be due to pure chance. A p-value of five percent was used as a threshold in the present study, and likelihoods of less than 10 percent were noted.

Statistical hypothesis testing involves the comparison of two hypotheses, called the null hypothesis and the alternative hypothesis. The null hypothesis states that there is no relation between the investigated phenomena, or at least not of the form given by the alternative hypothesis. The alternative hypothesis, as the name suggests, states the opposite - that there is some kind of relation. It takes several forms, depending on the nature of the hypothesized relation; it may be two-sided, meaning that there is some effect although the direction is unknown, or one-sided if the direction of the relation is fixed in advance. (Lehmann et al. 2005)

The hypotheses formulated in this study were primarily of the alternative type and thus express the assumed direction of the effect, such as a positive effect of performance monitoring on productivity. Hypotheses 1, 3 and 12 are exceptions, each in a different way. Hypothesis 1 includes the indefinite term a *suitable* measure, which is nevertheless clarified in the following text (see Chapter 4.2) as meaning several aspects of a good measure. The multidimensionality of Hypothesis 1 was one reason for testing it in a separate single-case research environment. Hypothesis 3 posits that there is no relation between unit size and productivity. If based on the statistical tests the likelihood of a non-relation is small (e.g., less than 5%), the non-existence of the relation may not be assumed. According to Hypothesis 12, the strategic position of the unit matters when explaining and predicting the effect of other practices on productivity. This is an example of an unknown direction in a hypothesis.

5.3 The research process

The study presented in this dissertation has long roots in my and my colleagues' previous work in the HEMA research group. As is typical of research in Industrial Engineering and Management, the need to investigate the phenomenon of operating unit productivity was identified by the practitioners. After that the emphasis was mainly on practical cases and explanatory studies in a couple of Finnish hospitals (Torkki et al. 2006; Peltokorpi et al. 2008b). The next step in the process was to develop better tools for performance measurement, although the studies still focused on applying the measures in single-case settings (Peltokorpi et al. 2008a).

All those pre-studies and other non-scientific practical projects to improve operating unit performance accumulated a database of practices covering surgical operations, used resources and implemented production planning and control in several Finnish hospitals. The practical work and the database provided significant input in drafting the hypotheses concerning the relations between managerial issues and operating unit performance. This combined with the research cooperation with a German and an American hospital provided the basis for conducting a more systematic review of the existing theory of OR management, formulating hypotheses in a scientific form and testing them on empirical data gathered in several hospitals. The large accumulated data set was also a reason to reject modeling-based methods and to focus on empirical analysis.

Figure 7 illustrates the process from hypothesis formation to study results and conclusions. The first step was to construct a productivity measure with a basis in the previous literature and suited to operating units in healthcare systems. The next phase included testing the measure, first in single case settings in order to evaluate its suitability in daily performance monitoring. The third phase extended the testing to a multi-unit environment in which its suitability for comparing different units was assessed. The same multi-unit setting was used to test hypotheses 2-12 concerning the relation between production planning and control practices and productivity. The results are discussed in practical and theoretical contexts, and conclusions are made with regard to both further research and managerial decision-making in surgical services.

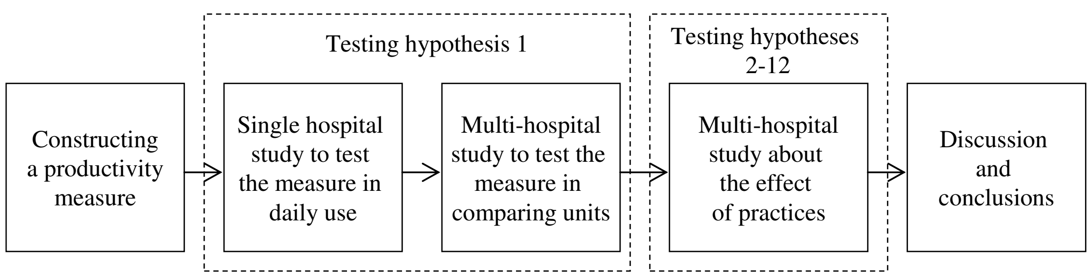

Figure 7 The research process

The following sub-chapters describe the research environment and process, and the data gathering and analysis in a single-hospital and a multi-hospital study.

5.3.1 The single-hospital study

This sub-chapter charts the process of testing the proposed measure in a single-case study. As it was defined in the hypothesis setting, the main objective was to test how the measure responds to the daily planning decisions, gives equal consideration to different cases and is possible to use with current data available. The sub-chapter is divided into four sections: case selection, research environment, data gathering, and data analysis.

Case selection

According to Eisenhardt (1989), case selection should be selective and should focus on theoretically useful cases that are likely to replicate or extend the emergent theory. Jorvi Hospital (Jorvi) from Finland was selected as the single case for the following reasons:

1. Process data about the planning and execution of surgical services are collected widely, thus allowing thorough analysis of the processes and the relations between the planning factors and the performance measures.
2. Jorvi has a multi-specialty operating unit with responsibility for emergencies occurring within its catchment area. Independent specialties and emergency surgery present challenges in terms of managing the daily and weekly variation in demand.
3. Jorvi and the HEMA Institute have a long history of cooperation in developing surgical processes.

The availability of both the planning and execution data about surgeries and resources was the main reason for selecting Jorvi for this part of the study.

Research environment

Jorvi hospital serves 270,000 inhabitants in the Helsinki metropolitan area and is responsible for treating acute cases from the municipalities of Espoo, Kirkkonummi and Kauniainen. It belongs to Helsinki and Uusimaa Hospital District, meaning that it runs elective operations as part of a large network of hospitals. The main operating unit has 11 operating rooms in which 6,500–7,000 operations are performed per year.

The surgical specialties at Jorvi are orthopedics, gastroenterological surgery, vascular surgery, thoracic surgery, plastic surgery, urology, breast surgery, gynecology & obstetrics, and pediatric surgery. Elective operations occur from Monday to Friday from 8.00 am until 3.30 pm. There is one operating room for emergency cases, which is resourced in the evenings, at night and on weekends. Jorvi is a typical Finnish multi-specialty hospital. The severity of its case mix in 2005 was near the median among Finnish hospitals (n=42). In terms of episode productivity of surgical services it ranks in the middle. The average cost per produced surgical patient episode was slightly over the national average in 2005, and between 2001 and 2005 it showed a bigger-than-average increase in productivity (Stakes 2007).

Data gathering

The aim in the data gathering for the Jorvi case was to map the production planning and control system and to obtain relevant data about the planning decisions and executed production. Data gathering process also tested the third criterion for the valid measure: is the developed performance measure possible to apply with current data available.

It is essential in case-study research to utilize multiple data-collection methods (Eisenhardt 1989). This study combined qualitative and quantitative data, and in most cases at least two investigators were used for the interviews and observations. The qualitative data comprised interviews with surgeons, head nurses and anesthesiologists, and observation of surgery in the operating unit, whereas the quantitative data included patient-specific information on hospital processes and documents about production plans. The literature on specific questions complemented the case data and analysis. The outcome was the construction of a practical model of process planning and control that would facilitate high performance in the operating unit.

The production planning and execution process was modeled on the basis of personnel interviews, observation and planning documents received from Jorvi hospital. Interviews with surgeons, head nurses, and anesthesiologists provided insights into the planning and execution, as did observations of surgery and other tasks in the operating unit. Planning documents included information about daily OR allocation, staffing, and case scheduling.

Retrospective analysis was used to identify the effect of the planning parameters on productivity. The actions and performance in the operating unit were considered retrospectively over 89 days between January and May 2007, excluding weekends and holidays. All essential data about daily production plans, resource use, and operations was collected.

The data on daily production planning included total scheduled personnel resources divided among anesthesiologists and nurses, training and education personnel, and allocated OR hours to specialties. Other daily factors were calculated based on the planning data:

1. Planned staff intensity = Total scheduled personnel / Allocated OR time (7.5 hours)
2. Estimated raw OR utilization rate = Output of planned and estimated emergency operations (hours) / Allocated OR time (hours)

Other day-specific data included unexpected personnel absences, standby personnel used, changes to allocated OR time, cancelled operations, and rescheduled elective and emergency operations. The estimate for the daily emergency load was calculated as the daily average amount of OR time used on emergency operations during the period. This load was used in the estimated raw OR utilization rate.

The surgical data included 2,145 operations performed during the period. Daily productivity was calculated according to the developed measure.

Planned daily output was calculated based on the planned elective operations on a given day, and realized daily output was based on operations that were actually performed, meaning that the patient arrived between 7.30 am and 3.00 pm. The difference between the realized and the planned output was calculated as the number of emergency operations performed during office hours minus the sum of lost output due to cancelled and delayed elective surgery.

Planned and realized daily input was calculated by summing the planned and realized working hours for all operating unit personnel. It was assumed that surgeons used half of the slack time between allocated OR time and actual surgical time in value-added tasks outside the operating unit. The working time of surgeons in the OR was calculated as an average of realized operation time and total allocated OR time.

The estimated costs used in the productivity measurement were as follows:

- hourly cost of surgeons and anesthesiologists (c_1 and c_2) = €37.8;
- hourly cost of nurses (c_3) = €18.4;
- hourly cost of overtime (x) = €196;
- cost of delayed elective surgery (y) = €200;
- cost of delayed emergency operations (w) = €400.

The hourly costs of the scheduled personnel, surgeons, anesthesiologists and nurses were calculated based on average wages (Vänskä 2005; Super 2004) and the employer’s share of social-security contributions (Kuntaliitto 2007). The hourly cost of stand-by personnel was estimated at 1.5 times the cost of scheduled nurses. Hourly overtime costs were calculated on the assumption of one anesthesiologist, one surgeon and three nurses per OR, and by multiplying the costs of regular working hours by a factor of 2.0. The cost of delayed elective surgery was estimated on the assumption that cancellations led to additional examinations and an extra half-day stay in a ward unit. Delayed emergency operations led to one additional day in a ward unit, which was the basis for this cost estimate.

Data analysis

Multiple regression models can be used in prediction problems in which the goal is to forecast an outcome based on data that were collected earlier (Cohen et al. 2003). Linear regression analysis and curve estimation were used in this part of the study to analyze the effects of the planned and unplanned variables on daily productivity. The aim was to test the first criterion of the valid measure: how it responds to the daily planning decisions. The Kolmogorov-Smirnov test of normality was used to assess the normality of the variable distributions. If the relationship between a planning variable and a performance measure was not linear, other approaches such as curve transformations were used so that the relationship could be represented as linear.

With regard to daily use, the second criterion for a good measure set in the hypothesis section, was that it is not too sensitive to variation in the daily case mix. It should be such that the average case length or ratio between surgery time and preparation time does not distort the daily monitoring. In the present study it was possible to test this effect by means of linear regression, which was thus used to determine whether the daily variation in productivity could be explained by the daily variation in the estimated ratio of surgery time to OR time.

Eight linear-regression forecasting models were constructed in order to analyze the ability to forecast daily productivity (Table 6). Each one described a particular point before the end of the day under consideration, starting from the moment when only the date was known (Model 1) to the moment the day ended (Model 8), and included all the variables that were known for the period in question. Therefore, each successive model included all the variables of the preceding ones, and of the new ones that occurred.

Table 6 Productivity forecasting models comprising the represented moments and the variables included. All models incorporate new factors and factors from earlier models.

Model No.	*Represented moment*	*New variables in the model*
1.	After definition of date and weekday	Date (running number) Weekday
2.	After OR allocation	Amount of allocated OR time Allocated specialties*
3.	After staffing	Total scheduled personnel Scheduled personnel per allocated OR time Amount of personnel in education
4.	After scheduling	Number of scheduled operations Estimated OR time of scheduled operations Estimated OR utilization rate (all operations)
5.	The day prior to surgery day	Number of emergencies from previous day
6.	The morning of surgery day	Number of personnel absences Number of stand-by personnel Number of cancellations due to patient
7.	The end of the office hours	Changes in allocated OR time Number of new emergency patients Lengthened operations (% of estimated time) Lengthened preparations (% of estimated time) Average OR turnover time Average delay of first patient in the OR
8.	The end of the day	Amount of overused OR time Number of delayed emergencies Number of cancellations due to the system

* Orthopedics, gastroenterological surgery, vascular surgery, thoracic surgery, plastic surgery, urology, breast surgery, gynecology, obstetrics and pediatric surgery

The estimated daily OR utilization rate for all operations was calculated by dividing the estimated required OR time by the allocated OR time. Required OR time was the sum of the estimate of time required for scheduled elective surgery and forecasted emergency operations during office hours. The average weekday volume in 2005 was used to estimate the number of emergency operations. Changes in allocated OR time represented the difference between the used and the allocated time. Used OR time was the maximum number of ORs used simultaneously during office hours. In other words, when a team moved from its allocated OR to another OR, and the allocated OR was not used again, there was no change in allocated OR time because the team was not operating in both ORs simultaneously. The average delay of the first patient in the OR was the average of the difference between the time the patient entered it and the planned start time of the session.

Forecasting models were constructed to reveal how productivity can be forecasted during the planning of service production. However, the models cannot be used to prove causal connections between individual variables and economic efficiency because, in reality, variables may be interrelated. In that case attention might focus on the variables with high beta coefficients, but which are dependent on other variables that do not seem important. In addition, we could not be absolutely sure that there were no variables affecting the independent variables that were not accounted for in our models.

Path analysis was used to illustrate how productivity consists of unplanned factors and decisions in production planning. It is an extension of the regression model (Cohen et al. 2003), and enables consideration of the isolated effects of single variables on one dependent variable, as well as of the interrelated connections in hierarchical systems. In path analysis the theory under consideration is described as a path model. Nodes represent the independent variables, which according to the theory affect a particular dependent variable. Arrows between nodes describe proposed causal effects between variables. Exogenous variables are those with no arrows going to them, and endogenous variables are those with incoming arrows. Regression analysis is carried out separately for each endogenous variable. Independent variables in the regression models are those that, according to the theory, have an impact on an endogenous variable.

SPSS Statistics 17.0 was selected as the program for calculating the statistical analyses on account of its availability to the HEMA research group at Helsinki University of Technology.

5.3.2 The multi-hospital study

The multi-hospital study was conducted in order to test the applicability of the measure in comparing different operating units and analyzing the effect of the production planning and control variables on productivity on the organizational level. This sub-chapter is similarly divided into five sections: case selection, research environment, operationalizion of the variables, data gathering, and data analysis. A separate sub-chapter evaluates the multi-hospital approach used in this dissertation on a general level.

Case selection

International workshops around the future of the operating room management indicate that the operating unit is one of the most standardized and universal parts of the hospital process (Cleary et al. 2005). This means that in this context the choice of cases for empirical research is not based primarily on theoretical selection, e.g., on the country, case mix or hospital status. The country and the healthcare system have an effect, but they do not set constraints on planning and control. In practice, this universality allows the inclusion of all available operating units in the study sample.

Increasing the size of the study sample is typically seen as one way of increasing the accuracy of the statistical estimates (Ketokivi 2009). That was the other reason why I included all the operating units from which I had operative data in my study sample. The multi-hospital study covered 26 operating units in 15 hospitals, most of which were selected on account of their research cooperation with the HEMA group and other groups engaged in practical development projects with HEMA researchers. The effect of a consulting-like relationship on the results was diminished by three methods: First, analyses for practical development work and for this research were totally separated. Secondly, results regarding the productivity and efficiency values of hospitals engaged with practical projects were dealt with several hospitals for benchmarking purposes. Thirdly, even with those hospitals, some practical results will be published in academic journals. In the best situation the sample size would have been larger. However, that was not possible within the given time frame for this dissertation.

Research environment

The selected 26 units represented different types of organization (Table 7). Seven of them (26.9%) were focused on ambulatory surgery. In addition, one unit focused on operations with a short length of stay after surgery (0-2 days). The other units (69.2%) were so-called mixed units operating mainly on in-hospital patients but also on some ambulatory (day-surgery) patients. Seven had a clear academic status, meaning that they were responsible for teaching and research duties in a specific area of surgery.

Table 7 Basic information about the analyzed operating units

Unit no	Status	Country	No of ORs**
1	ambulatory	Finland	4
2	ambulatory	Finland	6
3	ambulatory	Finland	7
4	ambulatory	Finland	4
5	ambulatory	Finland	8
6	ambulatory	Finland	6
7	ambulatory	Finland	3
8	short surgery	Finland	7
9	academic, acute	Finland	4
10	academic, acute	Finland	4
11	academic, acute	Finland	4
12	academic, acute	Finland	3
13	academic	Finland	4
14	central hospital	Finland	11
15	central hospital	Finland	9
16	central hospital	Finland	8
17	central hospital	Finland	12
18	central hospital	Finland	6
19	central hospital	Finland	8
20	academic	Finland	5
21	central hospital	Finland	8
22	regional unit	Finland	5
23	academic, acute	Germany	12
24	central hospital	USA	13
25	regional hospital	Finland	3
26	regional hospital	Finland	3

** number of staffed operating rooms during office hours

More detailed information about the investigated units is to be found in Appendix 2.

Operationalizing the variables

The relations between the theoretical constructs related to production planning and productivity are illustrated in the hypotheses of this dissertation. Operationalization is a method of moving from the theory level to the empirical level (Ketokivi 2009). In the process it is important to consider the rules of correspondence between 1) the theoretical and empirical constructs and 2) the empirical constructs and the measurement results (e.g., Niiniluoto 1981). Problems typically arise in formulating empirical constructs from the theoretical constructs (Ketokivi 2009).

In the present study the operationalization of the theoretical constructs concerned the planning decisions and practices presented in Table 5 and in the study hypotheses. Three case-mix variables, three production-strategy variables, and six planning-and-control variables were identified as potential performance drivers (Table 8). The same variables were also operationalized for the data analysis.

Table 8 The organizational variables and performance measures used in the multi-hospital study

Organizational variables	Operationalization*
Case mix	
Case complexity	Academic and regional status [0, 1, 2]
Case length	Average standardized surgery time
Urgency profile	Share of acute operations
Production strategy	
General focus	Ambulatory unit (0) vs. mixed unit (1)
Unit size	Number of staffed ORs
Specialties	Number of sub-specialties [0, 1, 2]
Planning and control methods	
Parallel processing and layout	[0=not applied; 1=partially applied; 2=fully applied]
Case scheduling practices	[0, 1, 2]
Performance monitoring	[0, 1, 2]
Multi-skilled personnel	[0, 1, 2]
Personnel flexibilities	[0, 1, 2]
Incentives	[0, 1, 2]

Performance measures	Operationalization*
Main measure	
Productivity	Standardized OR time per salary-weighted OR personnel hours
Sub-measures	
Speed of surgery	Mean procedure-specific surgery time compared to average of case hospitals
Utilization rate	OR raw utilization rate
Turnover time	OR turnover time
Time efficiency	Idle OR time per patient
Personnel intensity	Salary-weighted anestesiologist and nurse hours per staffed OR hour

*All measures calculated for office hours

The case-mix variables were included in order to minimize their direct and indirect effects on performance. Case complexity measures the academic and regional status of the unit. The lowest value (0) was set for units focusing on short or ambulatory operations in their region; the next value (1) was given to units performing operations in a larger region (e.g., a hospital district in Finland); and the highest complexity status (2) was given to units with high academic ambitions and responsibility for specific operations in Finland, for example. Case length was used as a measure in order to stabilize the effect of very short or long operations on performance. The proportion of acute operations affects the flexibility required and was therefore also included in the case-mix variables.

Three core measures of strategic decisions were used in the study: 1) unit size operationalized by the number of staffed ORs, 2) number of sub-specialties, and 3) whether the unit worked as an ambulatory or a mixed unit. It was assumed that production strategy variables are strongly correlated with case-mix measures. However, in that study those categories were separated due to the higher degree of freedom in supply-side production strategy measures than in demand-side case-mix variables. Due to different interpretations of the limits between sub-specialties and variation in the surgery volume among sub-specialties, three categories instead of accurate number of sub-specialties were used to operationalize the service range. Integer value 0 was given to the units with only one sub-specialty working regularly in the unit. Value 1 was given to the units with 2-4 sub-specialties and value 2 to units with more than four sub-specialties working regularly in the unit.

Planning and control methods were categorized based on the three lowest levels in the operating unit production planning and control hierarchy (see Figure 6). In terms of patient volumes planning and control includes engineering facilities and hiring personnel, whereas in facility management the use of parallel processing and layout that support simultaneous surgery and preparation of the next patient are among the most widely mentioned practices. With regard to personnel hiring the categorization of nurses into one multi-skilled group or two separated anesthesia and OR groups seems to be the most variable factor according to the interviewees. Case scheduling practices include the use of historical data and target values in the process. Performance monitoring refers to whether the efficiency measures are used in day-to-day management and what implications they have for the planning process. Personnel flexibility includes daily adjustment based on open ORs, different working times of OR teams, and the need for overtime. Performance measures are linked to personnel incentives in some hospitals, whereas in other units there are no incentive systems.

Planning and control methods could also be mentioned as operative practices. Schroeder and Flynn (2001) categorize such practices as hard or soft, and this also applies to the variables used in this study. Sophisticated case scheduling and parallel processing and layout represent hard initiatives that refer to the application of new technologies, and computer-aided systems and facilities. Multi-skilled personnel, personnel flexibility, and incentive systems, on the other hand, are soft-based methods that incorporate features of human resource management and leadership. Performance monitoring could be included in both categories depending on whether it is utilized in incentive systems or case scheduling, for example.

All the methods were operationalized in terms of the integer values 0, 1 and 2 in the multi-hospital study, reflecting the depth in the use of the method. For example, if all patients were prepared in an induction room before moving to an OR, the value 2 was given for the use of parallel processing and layout. This in-depth evaluation of the use of the methods in the units was a result of the understanding the researchers gained from the interviews and observations.

Hospital managers and other personnel could not directly affect the values they received in the evaluation process.

The next phase in the research process was to define the efficiency measures. The development of the productivity measure is presented in more detail in the next chapter. Five time-based sub-measures were used in order to find practical mechanisms between the planning and control variables used and productivity. Standardized surgery times were calculated from the case hospital's database. The weight per working hour was set at 1.0 for nurses and 2.05 for anesthesiologists, reflecting the ratio between the hourly costs used in the Jorvi case (€18.4 and €37.8, respectively). Efficiency measured in terms of average idle time during office hours per case reveals the scheduling accuracy, and the raw OR utilization rate and turnover time are components of that measure.

Data gathering

The data for the multi-hospital study was gathered through structured personnel interviews and observations, and from operative IT systems. Interviews were used to map the planning and execution process of the unit and the use of different planning and control practices. The chief anesthesiologists and chief nurses in the operating unit and the heads of the surgical sub-specialties in each hospital were interviewed during the study period (presented in Appendix 2). I conducted the interviews in 20 of the 26 units, and my co-workers Paulus Torkki and Jussi Tan conducted those in the other six. The interviews were semi-structured in order to allow for different understandings about the theoretical constructs used. The questions are listed in Appendix 3. All the interview material was documented in writing.

Observations were made at least once in each operating unit. The visit included familiarization with the unit facilities and layout, the operating rooms and their logistics and the information systems used. Focused questions were also posed to the chief nurse and the anesthesiologist about the use of personnel resources per OR and the operative practices. I made site visits in 20 of the 26 units. My co-workers Paulus Torkki and Jussi Tan visited the other six units, using the questionnaire I drew up for the interviews and observations.

The operationalized results regarding the next organizational variables were defined for each unit based on the interview and observation material: case complexity, general focus, unit size, number of sub-specialties, use of parallel processing and layout, use of sophisticated case-scheduling practices, use of performance monitoring, use of multi-skilled personnel, personnel flexibility, and use of incentives.

The other organizational variables, in other words case length and proportion of acute surgery, and all the performance measures were calculated based on the operative data gathered from the hospital IT systems. Data for the efficiency analysis was gathered separately in each hospital, and included all surgery in the operating unit over one or two calendar years between 2005 and 2008. The components used in the analysis included date of surgery, main diagnosis (ICD9/10 or OPS-code), procedure type (Nomesco, OPS-code, text form), urgency rate, OR number, and four time stamps for the care process: patient entry into the OR, surgery start time, surgery finish time, and patient leaves the OR. Data on a total of 208,146 operations in 26 units were used in the analysis.

Data analysis

The overall purpose in the multi-case study was to test the validity of the measure in comparing productivity in units with different case mixes, and to identify the decisions and practices that facilitated high productivity. The aim in the data analysis was to test hypotheses 1-12, and several statistical models testing the relationships between the identified factors and efficiency were built for that purpose.

Four statistical-analysis methods were utilized in testing the assumed relations between the decisions and the practice and the productivity (hypotheses 2-10). First (1) all correlations between the investigated variables were analyzed, the variables with very high dependence (>0.90) were combined, and the non-linear correlations were revised in linear form.

The second phase (2) comprised a linear regression analysis conducted in three separate parts (Figure 8). First (A) the connections between the sub-measures and productivity were analyzed in order to reveal the sub-measures that best explained the variability in unit productivity. The effects of the production-strategy variables on efficiency were analyzed in the second part (B). Six regression models were constructed, one for each sub-measure and one for the productivity measure, in order to identify correlations between the strategies used and performance. Thirdly (C), the effects on performance of the operative variables used were analyzed. The aim was to find connections between the applied methods and the different performance measures, and to divide the contribution to productivity among the strategic decisions and other variables as necessary when testing Hypothesis 11.

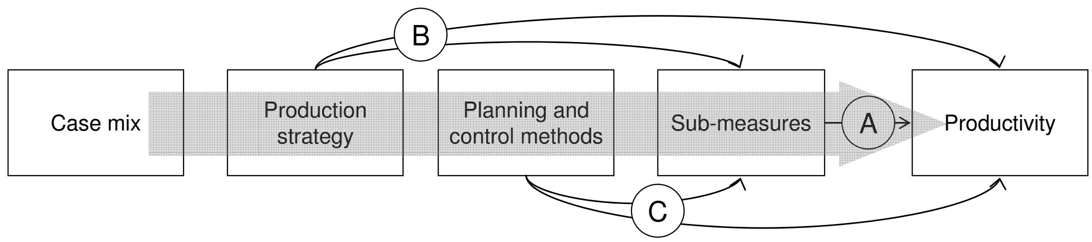

Figure 8 The linear regression analyses

In order to enable regression analysis, variables with ordinal scale, including case mix, number of sub-specialties and all operative variables, were moved to the form of two dummy variables. That transformation made also possible to consider if partial and comprehensive application of practices had diverging results. In order to standardize the effect of the case mix on efficiency the three case-mix variables were included in all the regression analyses. The effect of the operative variables was also controlled by the strategy variables (C). In all cases the variables with the biggest p-value (the worst explanation rate) were eliminated from the model until the R^2 (total explanation rate) was maximized.

The next phase (3) of the study was to conduct an explorative factor analysis in order to reveal the underlying factors behind the variables used. Varimax rotation was utilized to clarify the differences between the identified factors. The objective of the factor analysis was not to estimate the value of single variables or to test the hypotheses but to identify the main routes of the current management in the units and their possible connections with performance. This kind of explorative method was included in order to find connections that were not captured by the theoretical constructs presented in the developed framework.

In the last phase (4) cluster analysis was used to identify current strategic and operative clusters. Hierarchical cluster analysis with range [0, 1] variation was used in the strategic cluster analysis, and the same method without range changes in the operative analysis. In both we calculated the mean values of the excluded variables and their statistical differences between clusters. The cluster analysis enabled the units in question to be classified naturally. This type of analysis resembles factor analysis but is less scientific, and it emphasizes the unit perspective on strategy, the use of practices, and efficiency. The cluster analysis facilitated the testing of Hypothesis 12 concerning the different optimal combinations of strategic decisions and operative practices.

Finally, the results of each sub-analysis were summarized in order to draw conclusions about best operating-unit strategies and management methods in terms of performance.

5.3.3 Evaluating the multi-hospital study

The multi-hospital study was unique on at least three parameters. First, it included 26 units, which is much more than usual in the area of OR management: the most common research frame in previous studies has been to test different scenarios or initiatives by means of modeling or before-and-after analysis. Berry et al. (2008) investigated 87 units in Germany in order to analyze the effect of different characteristics on OR productivity. However, their measure focused on anesthesiology costs, and the output measurement included no “case mix” or “speed of surgery” standardizations. The sample size in this study made it possible to analyze the variation in existing units and management practices. The approach may not be as constructive as in modeling or piloting studies, but it gives managers certain practical insights and tools that have already contributed to enhancing performance in existing hospitals.

Secondly, the data for this study was gathered from many different parts of the production process. Structured interviews aimed at categorizing the strategic features and operative practices used. The operative data was rich and quantitative, and the data on process inputs, such as personnel hours and professions, were gathered systematically. All this provided an all-inclusive view on what was planned, and what was really done and with what resources.

Thirdly, sophisticated methods were used to standardize both the input and output of the units. This is necessary in comparisons of units with different case mixes and system environments. It is not meaningful only to compare units with a similar case mix if the aim is to find correlations between strategies used and performance. The multi-specialty units could be roughly divided into several focused clinics, and therefore inputs and outputs should be benchmarked according to unit type.

6 Results

This chapter presents the results of the study. They are reported in three sections following the structure of the research process (Figure 7): 1) constructing a productivity measure, 2) testing the measure in single hospital settings, and 3) the results of the multi-hospital study. The chapter ends with a summary of the results and their contribution to the research questions and hypothesis testing.

6.1 Constructing a productivity measure

Relevant measures are needed in the management and development of surgical patient processes. Measurement systems must be based on each organization's purpose and the targets emanating from it.

The purpose of an operating unit varies depending on the environment. In healthcare systems funded through private insurance, such as those in North America, ORs typically belong to business units the aim of which is to maximize contribution margins (Dexter et al. 2005). Compensation may be procedure-specific in such systems, which may mean that some operations are more profitable than others (Dexter et al. 2005). In a competitive environment service providers aim for profit over variable costs (i.e. contribution margins) in order to offset large capital and fixed staffing costs. The aim is to increase production volume with profitable operations and specialties (O'Neill and Dexter 2007). In such an environment a hospital can choose specialties to target expanded OR capacity.

Organizations in public-funded healthcare systems are typically responsible for treating patients in a certain geographic area, and the hospital budgets are limited. In the short term operating units aim at minimal waiting times, whereas their long-term goals are to carry out operations at minimal cost and with minimal waiting times (Jacobs and Coddard 2002). It has been proven that long waiting times lead to additional costs, not only for patients and employers but also for service providers (Vohlonen et al. 2002; Peltokorpi et al. 2006). Higher costs occur because of the need for new X-rays and examinations, and the risk of no-shows increases. Short waiting times are especially important in the case of emergency operations. Long wait times typically lead to a decline in the patient's condition and additional costs before and after surgery (Dabke et al. 2005).

In summary, when the aim is for high medical quality and minimized costs there should be minimal waiting times for all operations (Kujala et al. 2006). Operating units could be classified as academic and non-academic units, which partially overlaps with the division between public-funded and private departments. The mission in academic departments is typically more complex in that units have teaching and research responsibilities in addition to providing clinical services (Warner et al. 2007). These responsibilities may limit the implementation of what are, from the perspective of efficiency, optimal policies of planning and execution.

According to the literature presented in Chapter 2, measures of technical and economic efficiency are the most comprehensive in terms of performance measurement in operating units because they cover both the output and input sides of the production system. The next two sub-chapters describe the construction of detailed technical and economic efficiency measures for operating units.

6.1.1 Measures of technical efficiency

There seems to be a contradiction in the goals of operating units in different environments between maximizing contribution and minimizing costs. However, in both it is logical to reason that performance will increase when output per used resource increases: total costs could be reduced if operations were produced with fewer resources, and contribution to the margin would increase if more operations were performed during OR hours or when fewer resources per OR hour were needed. Thus, technical efficiency, defined as the output versus the input of a considered system, is potentially a relevant measure for analyzing operating units on the international level.

It could also be claimed that technical efficiency is not widely applied in studies on operating units due to the assumed complexity of completely defining the output and input of the surgical process. According to Schuster et al. (2005), 64 percent of operating unit costs are personnel-related. Material and pharmaceuticals comprise around 20 percent, whereas equipment, space, and overhead costs represent around 16 percent. Therefore, the input of the technical efficiency measure should be defined in terms of personnel. Personnel resources can be measured by time or wages. Time is unambiguous, but its value differs between professions. Wages describe resources as money, but money has different values in different societies at different times. In addition, the tasks of operating unit professionals vary between countries. In spite of the different time values however, working hours represent an explicit and simple enough measure of input:

$$Input = \sum_{i=1}^{n} H_i \text{, where} \qquad (1)$$

H_i are the working hours of profession i during the considered period. The number of professions is n.

The final output of a healthcare system is a patient who has received care. If he has a chronic illness he can be categorized as partially cared for when a medically valid treatment has been performed. Similarly, medically valid surgery could be called an output of an operating unit.

Some product standardization is needed in measuring the output of surgical services in order to place a value on different operations and patients (Saleh et al. 2009). Operations differ in duration and resource requirements. Some require an additional surgeon or nurse. Personnel needs vary between hospitals, and operations also vary in time requirements, necessary preparations, and post-operative tasks (Peltokorpi et al. 2005). All pre-surgery OR time is not value-added time, merely time spent waiting for the next phase. In addition, the parallel processing of one operation with the preparation of the following patient occurs in many operating units. In such cases the preparations are not on the critical path of the process, and therefore comparing their duration might be misleading.

In summary, it is unclear whether calculating the output of an operating unit should be based on the duration of the surgery or on total OR time. Thus, the best method should be defined case by case. However, when output is defined operations must be categorized or weighted based on duration. This weighting may be based on the historical average total time needed just for the surgery, or for the sum of preparations, surgery and post-operative tasks. It is not recommended to consider PACU time because the resource intensity is much lower than that of OR time.

An operating unit's output is the duration-weighted sum of operations in a given period:

$$Output = \sum_{j=1}^{m} d_j N_j \text{, where} \qquad (2)$$

d_j is the average duration of surgery or OR time for surgery *j*, and N_j is the number of operations of type *j* in the considered period.

Combining formulas 1 and 2, the technical efficiency of an operating unit is:

$$Technical\_efficiency = \frac{Output}{Input} = \frac{\sum_{j=1}^{m} d_j N_j}{\sum_{i=1}^{n} H_i} \qquad (3)$$

6.1.2 Measures of economic efficiency

When the aim is to minimize costs and waiting times, technical efficiency cannot capture all relevant aspects of the objectives. It is valid as a measure in the case of elective and planned operations, but outside office hours the mode of the surgical process is different. If the unit is responsible for emergency operations the main objective outside office hours is not the ratio between output and input, but short waiting times and the high quality of care.

On the other hand, when the aim is high operating unit performance during office hours it is essential to consider the potential disadvantages of high technical efficiency, such as the need for overtime, and cancelled and delayed operations. This total objective could be formulated in terms of a measure of economic efficiency:

$$Economic\_efficiency = \frac{Cost}{Output} = \frac{\sum_{i=1}^{n} c_i H_i + xO + yC + wD}{\sum_{j=1}^{m} d_j N_j}, \text{ where} \qquad (4)$$

c_i is the hourly cost of the work of professional i during office hours, x is the hourly cost of OR overtime, O is the number of overtime hours, y is the cost of shifted elective operations, C is the number of delayed elective operations, w is the cost of delayed emergency operations, and D is the number of delayed emergency operations.

This formula quantifies cost per output, and could be considered a measure of economic efficiency in the operating unit. However, it excludes some costs, such as for materials and space. It can therefore be used, to identify cost margins between periods, but not in relative comparisons. Because personnel costs are the highest in the operating unit the measure could be used to gauge its economic efficiency. It accounts not only for the staffing costs but also for the costs associated with the weak quality of the production system, such as cancelled cases and delayed emergency surgery.

Economic efficiency, including the costs associated with different staffing and shifted operations, is a more extensive measure than technical efficiency, and could therefore be used as a continuously monitored primary measure. Technical efficiency, on the other hand, is more appropriate for comparing efficiency in different hospitals.

6.1.3 Period of measurement

In hospitals, overlapping planning decisions are typically made annually, monthly, weekly, daily, and even from patient to patient. Despite the higher random variation during one day than during a week or a month, daily performance is nonetheless an important measure. Decisions that were previously made in the planning process are tested daily when operating unit managers decide whether to shift operations, to call standby personnel, or to allow overtime hours (Dexter et al. 2004). Daily economic efficiency is also an interesting unit of analysis because rescheduling surgery incurs significant expenses.

Production has to be planned on a daily basis in units that carry out emergency operations in particular. Weekly or monthly performance levels are insufficient in themselves for managing the daily variation in demand. A day in the operating unit is an essential unit of analysis in elective surgery as well. Patients become dissatisfied if operations are rescheduled, but they are not interested in the time of the surgery or in which OR it occurs.

An operating unit's long-term success depends on its daily performance. Therefore, in order to improve overall performance it is necessary to consider the factors that affect its daily economic efficiency.

This daily economic efficiency is a complex sum of multiple factors. Some are easily manageable, but many others are difficult to control. Some are hard to predict, such as the number of new patients requiring urgent treatment and patient no-shows. Therefore, before a measure can be applied in everyday use its behavior and applicability must be tested in a complex real-life context.

The measure developed here differs from those previously in use. Management policies based on previous measures should thus be reassessed from the perspective of more recent ones. There is a need for a greater understanding of the effects of planning decisions and non-planned factors on economic efficiency. On a more general level, information is needed about optimal production planning and control systems in operating units in which the efficiency objective is to maximize economic efficiency as defined in this study.

6.1.4 The limitations of the developed measure

The process under consideration in this study is the short- and medium-term planning process in an operating unit and the patient process incorporated into it. The planning process includes decisions about daily capacity planning, staffing, patient scheduling, and decisions made on the day of surgery. Questions concerning the quality of care and treatment effectiveness were not considered. However, the management methods and process features analyzed were discussed from the perspective of care quality.

6.2 Testing the measure in single hospital settings

Hospitals generally make planning decisions yearly, monthly, weekly, daily, and even patient-by-patient. One day is the minimum time period for operating units to consider. It seems from the interviews, observations, and planning documents examined in Jorvi hospital that daily performance in the unit is the result of decisions in the planning process and of unplanned events (Figure 9).

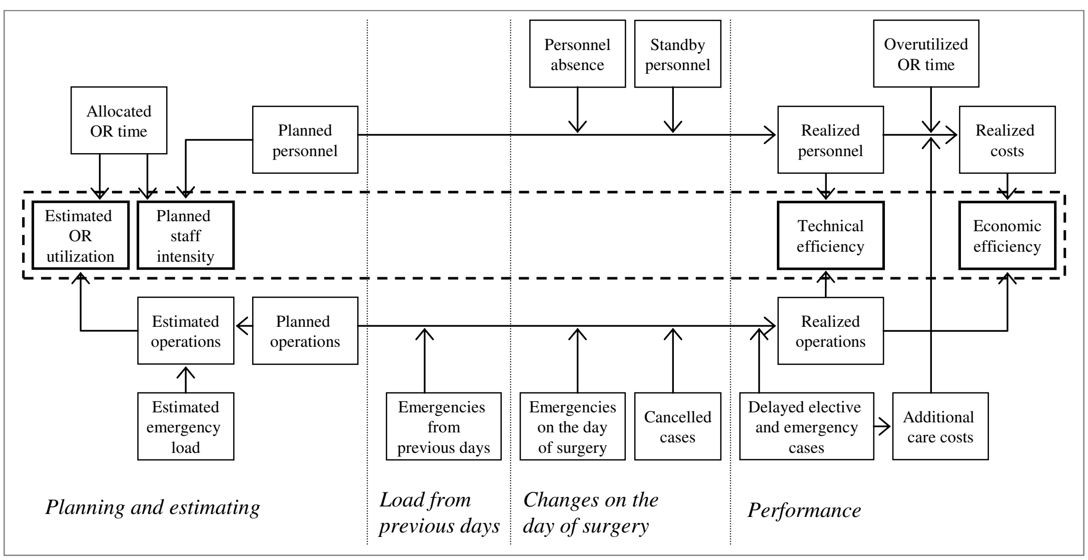

Figure 9 The relationships between planned and unplanned factors, and technical and economic efficiency

Capacity allocation, staffing, and case scheduling provide initial estimates of daily performance in the planning phase. These estimates then can be adjusted in the light of the estimated emergency load. Emergencies remaining from the previous day increase the total emergency load. Next, at the beginning of office hours, cancellations and new emergency operations change the balance between load and resources. These occurrences continue throughout the day. Management's response to an overload might be to call in standby personnel or reschedule one or more operations, which incurs additional personnel and care costs inside and outside the unit.

In Jorvi hospital the operating rooms were allocated to surgical specialties in advance based on historical demand. The allocations were typically similar from week to week, with each specialty using certain ORs on certain days. ORs were open for 7.5 hours on normal weekdays, and 6.5 hours on meeting days (Fridays). Specialties scheduled elective surgery within their allocated OR time blocks, and reserved time for emergency cases. Surgical start times sometimes changed during the day, depending on the load.

The head of anesthesiology was the manager of the operating unit. He was responsible for allocating and coordinating OR time resources and anesthesiologists. The head OR nurse was responsible for the daily allocation and management of nurses.

On surgery day the patients were first moved to the operating unit from the ward. They were received in the entrance hall, moved into the OR, and then transferred to the operating table. Anesthesia induction started when anesthesiology personnel entered the OR. After that, surgical preparations were carried out and instruments were taken into the OR and placed on the tables. The surgeon was called during the surgical preparation time. When the wound was closed and dressed the patient was awoken. If the anesthesia was local he went directly back to bed and to the PACU.

The results of the regression analysis testing different output definitions are illustrated in Table 9. The ratio of surgery time to OR time explained the variation in technical and economic efficiency significantly ($p<0.05$) in three of the four models. The degree of explanation was especially strong in the models in which output was defined as the average historical duration of surgery ($R^2 = 25.5\%$ and 17.0%, respectively).

Table 9 The effect of the ratio of surgery time to OR time on measures of technical and economic efficiency, with different definitions for output based on linear regression analysis (n=89 days)

Definition of output	*Objective function*	R^2	*Validity of model*	*Standardized beta*
Surgery time [historical average]	Technical efficiency	25.5%	p<0.01	.505
Surgery time [historical average]	Economic efficiency	17.0%	p<0.01	-.412
Operating room time [historical average]	Technical efficiency	7.3%	p=0.01	.270
Operating room time [historical average]	Economic efficiency	1.8%	p=0.21	-.135

There was a significant difference between the specialties in the average of the estimated ratio of surgery time and OR time (range: 49.9% in pediatric surgery to 68.5% in plastic surgery). We therefore tested whether or not the daily variation in technical and economic efficiency could be attributed to the estimated ratio when the distribution of operations to the specialties was taken into account. However, the result was that the ratio between surgery time and OR time explained both realized technical efficiency (standardized beta .483; p<0.01) and economic efficiency (-.395; p<0.01) when output was measured based on surgery time.

The regression analyses proved that operating unit output in Jorvi hospital should be calculated based on OR time. If based on surgery time, carrying out operations, which in general have relatively long preparation times, would significantly decrease efficiency (Figure 10). This effect is obviously not desired. Performance measures should be defined so that they are neutral for a mix of surgeries. In all the analyses that follow the measure of economic efficiency, in which the output measure was based on the historical average of OR time, was used as an objective function.

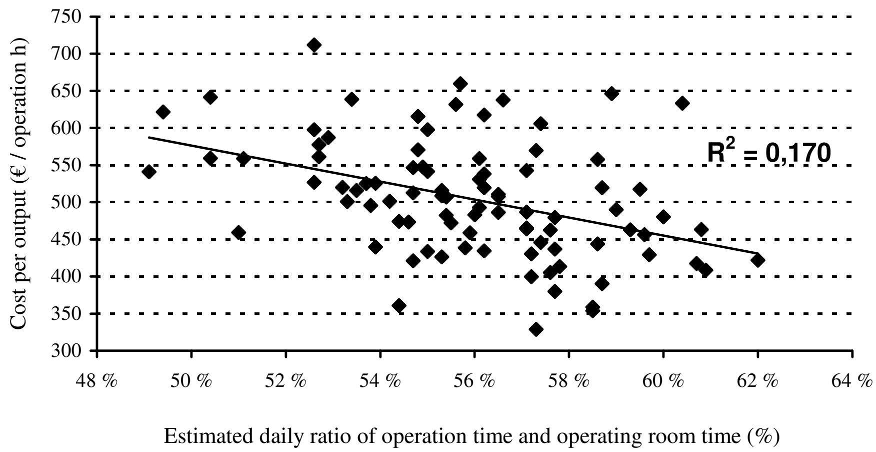

Figure 10 Estimated daily ratio of surgery and OR time and cost per output (n=89 days)

The means, standard deviations, and intercorrelations for all the variables used in the study are shown in Appendix 4. The daily cost per output varied during the study period between €184 and €377 /h (mean 277, s.d. 39.1 €/h) (Figure 11).

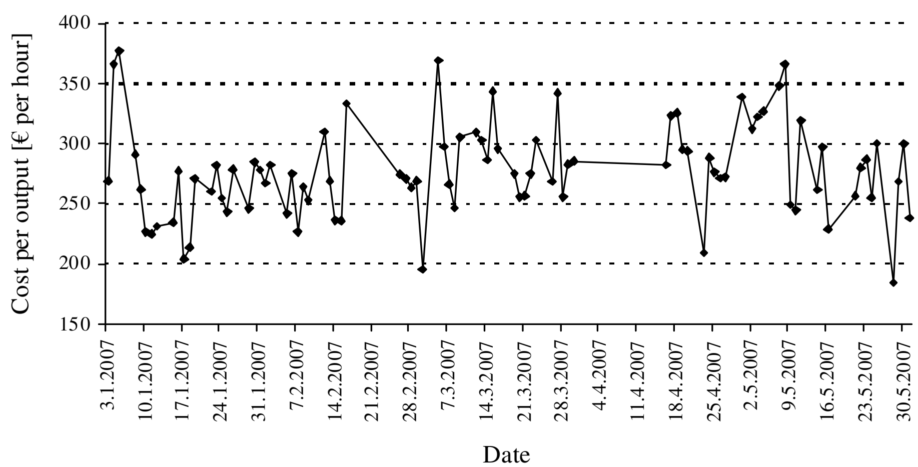

Figure 11 Daily economic efficiency during the study period (n=89 days)

The strongest correlation among the independent variables was between allocated OR time and the number of scheduled personnel (r = 0.813). The absolute value of the correlation coefficient was >0.70 in eight of the relations between the model variables (3.3% of all relations). The high correlations between the variables indicated that there was a need to use path analysis to illustrate the total effect of single variables on the performance measures.

In most cases a straight line was considered suitable for testing whether the relationships between the model variables and efficiency were linear or curved. The relation between the estimated OR utilization rate and realized cost per output was curved rather than linear (Figure 12). Based on curve estimation, the optimal estimated OR utilization rate was 80 percent. For the linear regression analysis the daily-utilization-rate data was transformed to represent the square of the difference between daily value and optimal value. This measure was called the estimated optimality of OR utilization. A pure estimated OR-utilization rate was used in subsequent path analyses in order to identify the effects of low and high utilization rates on other independent variables.

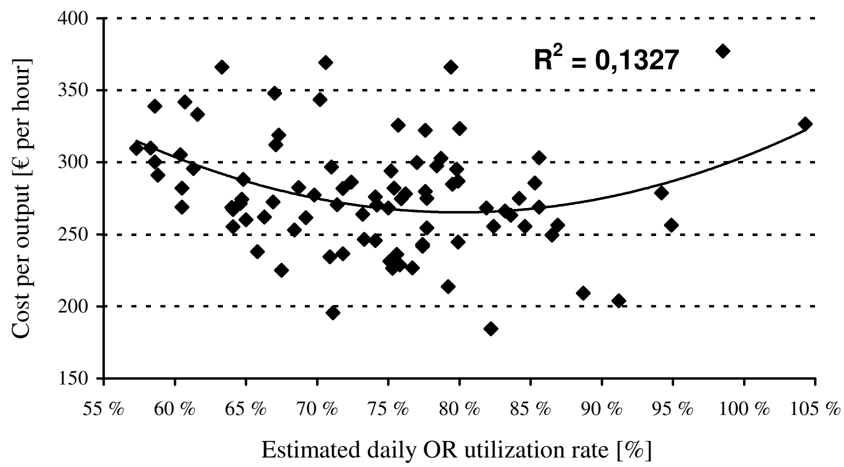

Figure 12 Estimated OR utilization rate and realized cost per output (n=89 days)

The results of the forecasting models are shown in Table 10 and Table 11. All the models, excluding Model 1, were reliable ($p<0.01$). More than one third of the variation in cost per output could be forecasted after OR allocation (Model 2, R^2=35.1%). After staffing and scheduling, the variables used here explained more than half of the variation (Model 5, R^2=54.2%). At the end of the day, all the variables used explained 93.6 percent of the variation in daily efficiency (Model 8).

Table 10 The effects of the independent factors on cost efficiency in models 1-4 (n=89 days)

Independent variables	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Date (running number)	0.16	0.18^{+}	0.12	0.20^{+}
Amount of allocated OR time		-0.69**	-1.08^{+}	-1.13^{+}
Amount of planned total personnel			0.72*	0.97**
Planned personnel per allocated OR time			0.04	-0.28
Number of personnel in education			-0.13	-0.23^{+}
Number of planned operations				0.07
Estimated OR time of planned operations				-0.49^{+}
Estimated optimality of OR utilization rate				0.18
$\mathbf{R^2}$	10.1%	35.1%	43.2%	54.2%
F	1.88	3.79**	4.02**	4.95**

Dummy variables (weekday, specialties) are included in the models, but the beta coefficients are not shown for them. + p<0.10, * p< 0.05, ** p<0.01

Table 11 The effects of the independent factors on cost efficiency in models 5-8 (n=89 days)

Independent variables	*Model 5*	*Model 6*	*Model 7*	*Model 8*
Date (running number)	0.20+	0.19+	0.03	-0.00
Amount of allocated OR time	-1.13+	-0.95	-0.75	-0.35
Total scheduled personnel	0.97**	0.95**	0.60+	0.66**
Scheduled personnel per allocated OR time	-0.28	-0.35	0.24	0.05
Number of personnel in education	-0.23+	-0.18	-0.18	-0.04
Number of scheduled operations	0.07	0.01	0.01	0.01
Estimated OR time of scheduled operations	-0.49+	-0.60**	-0.06	-0.81**
Estimated optimality of OR utilization rate	0.18	0.14	0.17	0.12+
Number of emergencies from previous day	-0.00	0.00	-0.02	-0.24**
Number of personnel absences		0.02	-0.08	-0.09+
Standby personnel exactness		0.17+	0.06	-0.04
Number of cancellations due to patient		0.18+	0.12+	0.24**
Changes in allocated OR time			-0.37**	-0.13+
Number of new emergency patients			0.12	-0.30**
Lengthened operations (% of estimated time)			0.52**	0.23**
Lengthened preparations (% of estimated time)			0.12+	0.11*
Average OR turnover time			0.05	0.02
Average first patient in the OR time			0.18*	0.06
Amount of overused OR time				0.17**
Number of delayed emergency operations				0.54**
Number of cancellations due to the system				0.31**
R^2	54.2%	58.8%	80.8%	93.6%
F	4.61**	4.55**	9.48**	28.3**

Dummy variables (weekday, specialties) are included in the models, but the beta coefficients are not shown for them. + p<0.10, * p< 0.05, ** p<0.01

The dummy variables, weekdays and allocated specialties had no statistically significant effects on cost efficiency apart from slightly positive effects (p<0.05) on Tuesdays and Fridays on costs per output in Model 1.

After staffing and scheduling (Model 4), the largest direct effect on efficiency was due to the number of scheduled personnel and the amount of allocated OR time. The number of allocated personnel was a significant explanatory factor in Models 5-8, whereas allocated OR time no longer had a significant direct effect. The size of the scheduled load and the speed of surgery turned out to explain the variation in efficiency in Models 5-8. Of the variables leading directly to additional costs in the process, delayed emergency operations had the largest effect (standardized beta 0.54 in Model 8).

The most significant increases in predictability happened in OR time allocation (Model 2, increase 25.0%) and during office hours on surgery day (Model 7, 22.0%). Slightly more than half of the variation in efficiency was due to decisions in the planning phase (Models 1-4; Figure 13), and almost all of the rest was due to events and decisions made on surgery day (Models 6-8).

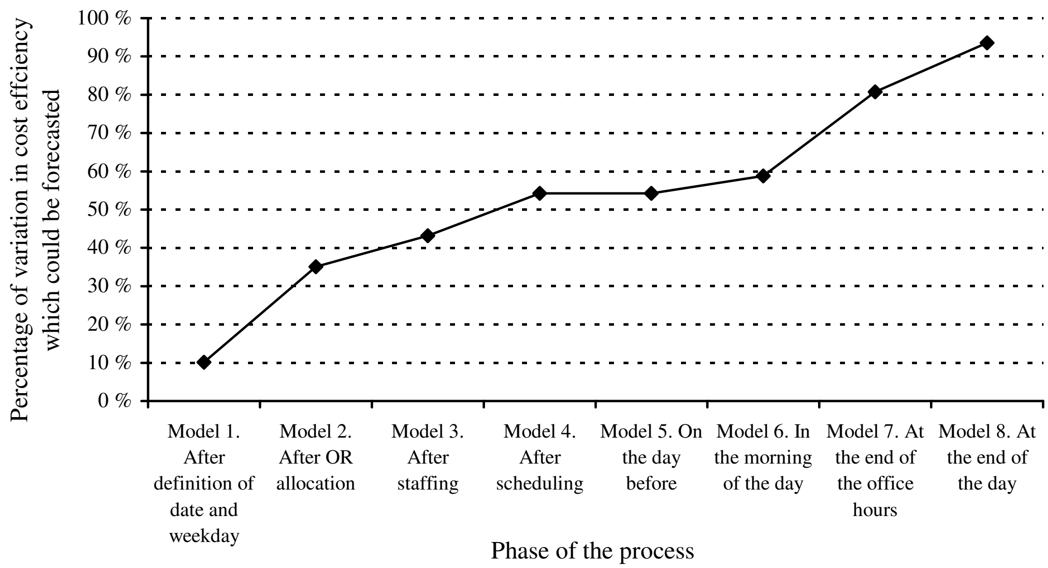

Figure 13 Accuracy in forecasting daily economic efficiency before surgery day (n=89 days)

The most significant factors affecting daily efficiency are illustrated in Figure 14. Variations in the variables examined explained 88.3 percent of the variation in daily economic efficiency, and scheduled personnel per allocated OR time had the largest direct effect (beta coefficient 0.62). One additional person per OR explained an increase of €24.3 in costs per hour of standardized output. However, the scheduled personnel numbers per allocated OR time was strongly affected by allocated OR time (R^2 = 81.3%). In other words, allocated OR time explained economic efficiency indirectly via planned personnel per OR.

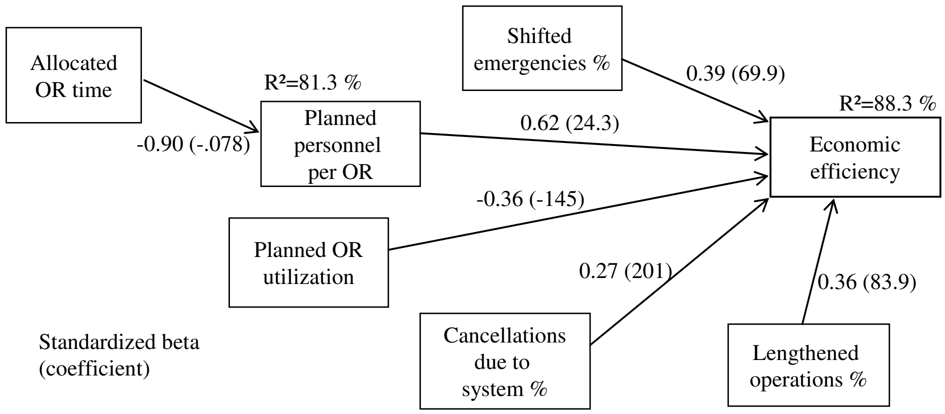

Figure 14 The most significant factors affecting daily economic efficiency (n=89 days)

The detailed results of the path analysis are shown in the table in Appendix 5. Each column in the table represents one regression model with one dependent variable and several independent variables. Models that were statistically insignificant (p>0.05) are excluded from the table. Standardized betas (the first value in the table) describe the relative effect of the independent variables on a dependent variable. For example, variation in scheduled personnel per OR caused variation in economic efficiency of ~62 percent of the whole variation in economic efficiency. The coefficients (second value) describe the correlation in terms of units used. For example, one additional hour of allocated OR time explained a decrease of 0.078 persons in scheduled personnel per allocated OR session.

In order to illustrate the total independent effect of all factors on daily efficiency the direct and indirect effects were summed and the sum was multiplied by the proportion of the variation that could not be explained by other factors in the model (Figure 15). The source of the independent variation in the explained factor could be attributed to random variation, independent decisions, or factors outside the model.

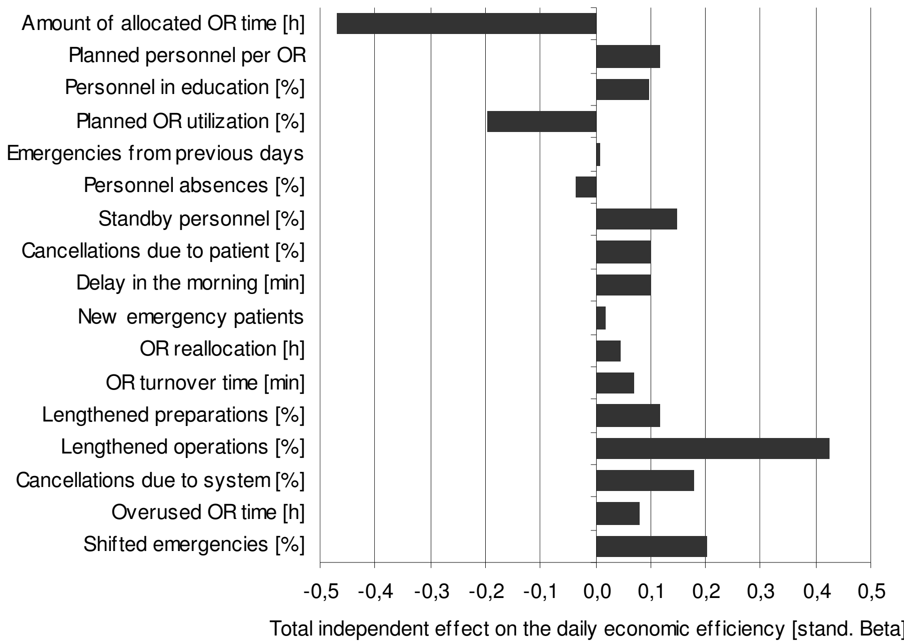

Figure 15 The total independent effect of the factors on daily operating unit economic efficiency (n=89 days)

Lengthened surgery and the amount of OR time allocated to specialties had the largest independent effects on daily economic efficiency (standardized betas 0.43 and -0.42, respectively). Rescheduled emergency operations, the planned OR utilization rate and system-related cancellations had the next largest independent effects. In sum, planning variables explained more than 60 percent of the daily variation in efficiency.

6.3 Revising the efficiency measure

According to the results of the Jorvi case, the economic-efficiency measure is mostly affected by planning and control variables. Non-manageable variables, such as new emergency patients, had a limited effect on total efficiency. This indicates that the proposed measure is appropriate for analyzing day-to-day variation in efficiency in an operating unit. The measure passed the first criteria set up in the hypothesis. Corrections to the planning process could be based on the daily performance level.

The proposed measure also includes economic features, such as wages and costs of ward days. In the Jorvi case, available data made possible to calculate daily economic efficiency.

Therefore the third criterion, that performance measure is possible to apply with current data available, was passed. In an international context, however, the technical form of the measure is recommended because money has different values in different economies and societies. That technical form considers used personnel hours as input and standardized surgery as output. Relative wage differentials could be used in valuing the working hours in different professions.

Based on the findings, an operation is the suggested output measure, defined in terms of standardized time used in surgical preparations and the surgery itself. Inside a hospital, that form of the measure was possible to eliminate the effect of different daily case mixes on the performance. The result supports that the measure passes the second criterion about equal consideration to different cases. However, how this method of output measurement works in comparing units with different average surgery lengths remains to be tested in a multi-case study.

6.4 The results of the multi-hospital study

The effects of the production strategies and planning and control methods on the technical efficiency (productivity) measure were analyzed in a multi-hospital study including 26 operating units. The findings are reported in this section.

6.4.1 Basic figures and correlations

Table 12 gives the means and standard deviations of the variables and performance measures. The average case length varied between 0:33 and 1:52 hours and the proportion of acute operations between 0.0 and 72.6 percent. Personnel flexibility and performance monitoring were the most frequently applied forms of planning and control, and only three units used incentives to some extent. Differences in speed of surgery varied between -27.9 and +19.2 percent of the average speed. There may be some distortion in these results in two units (German and American) due to problems in combining OPS codes and text forms with the Nomesco codes for surgery type. The highest OR utilization rate was 85.3 percent and the lowest was 52.7 percent. Productivity varied between 5.83 and 9.63.

Table 12 The means and standard deviations of the variables used

Variable	n	Mean	Std. deviation
Case mix			
Case complexity [0, 1, 2]	26	.692	.618
Case length	25	1:05	0:25
Share of acute operations [%]	25	16.6%	19.7%
Strategic variables			
Ambulatory (0) vs. mixed unit (1)	26	.692	,471
Number of staffed ORs	26	6.42	3.04
Number of sub-specialties [0, 1, 2]	26	1.35	.892
Operative methods			
Parallel processing and layout [0, 1, 2]	26	.308	.618
Case-scheduling practices [0, 1, 2]	26	.346	.485
Performance monitoring [0, 1, 2]	24	.708	.464
Multi-skilled personnel [0, 1, 2]	23	.565	.590
Personnel flexibility [0, 1, 2]	23	.957	.562
Incentives [0, 1, 2]	26	.115	.326
Sum of operative methods used	23	3.09	1.56
Performance			
Speed of surgery [%]	26	-0.5%	11.3%
Idle time per operation	25	0:56	0:15
OR raw utilization rate [%]	26	66.0%	7.8%
OR turnover time [min]	24	32.5	8.5
Personnel intensity [personnel hour per OR hour]	26	4.85	.44
Productivity [stand. surgery hour per 100 personnel hours]	26	7.72	1.13
Standardized productivity	26	7.72	0.93

Appendix 6 gives the correlations between the variables. All the case-mix variables correlated statistically significantly. Case length and case complexity had the strongest correlation of the all analyzed pairs. Unit type correlated strongly with the case-mix variables; the ambulatory units carried out significantly shorter, less complex and less acute operations. Moreover, a high number of sub-specialties was connected with shorter operations.

There was a positive correlation between the sum of operative methods applied, and within this the use of case-scheduling practices, with longer operations and a negative correlation with the number of sub-specialties. Of the operative methods used, case scheduling was associated with parallel processing and performance monitoring. Performance monitoring, on the other hand, was associated with fewer multi-skilled personnel.

The raw OR utilization rate was positively correlated with all the case-mix variables and with four of the six operative methods. Other efficiency measures were less statistically significantly connected: a high surgery speed was associated only with multi-skilled personnel, and low idle time per operation with ambulatory units. Short turnover times correlated with short and simple operations and ambulatory units. Personnel intensity increased in tandem with complex and long surgery, with a lower number of sub-specialties, and unexpectedly with the use of case-scheduling practices and performance monitoring. High productivity was associated with long operations and the use of operative methods. Productivity was also driven by personnel flexibility and the use of incentives. Raw utilization was the only sub-measure for efficiency that had a statistically significant correlation with productivity.

Given the high correlation between average case length and productivity (Figure 16) a standardized productivity measure was constructed. Personnel intensity was first standardized by case complexity so that units with complex operations did not suffer from their higher personnel level. Each gradual shift from a lower to a higher complexity level seemed to increase the number of personnel per OR by approximately 0.42 employees (adjusted, see Figure 17). The standardized personnel intensity measure took account of the difference to that trend line.

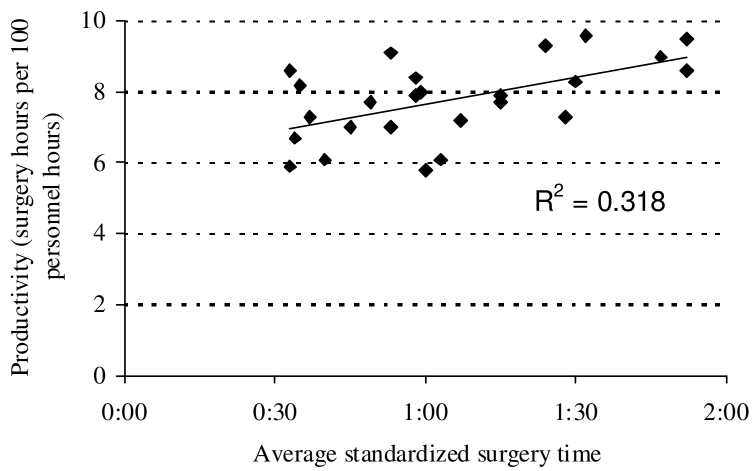

Figure 16 Correlation between the average standardized surgery time and productivity

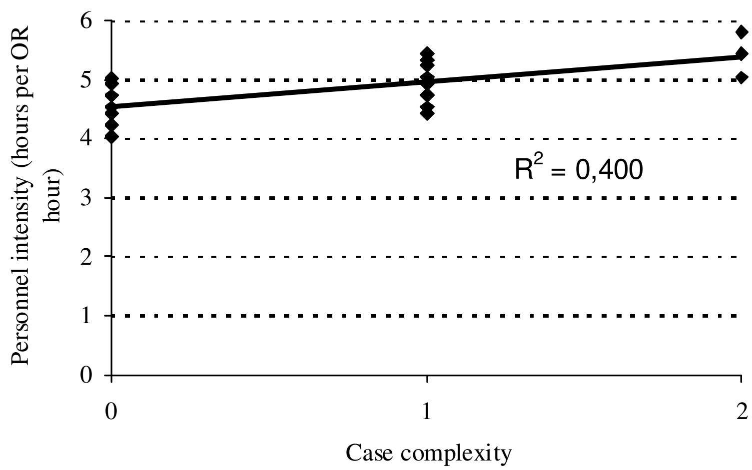

Figure 17 Correlation between case complexity and personnel intensity

On the output side, value-adding time included not only standardized surgery time but also standardized preparation time in the OR and 20 minutes of setting time per operation. In addition, surgery time was standardized in terms of case complexity (Figure 18) in order to account for the fact that units with academic status perform more complex operations per surgery type. Furthermore, a non-standardized productivity measure was also used because the case length was also associated with other measures such as the use of operative methods. The standardized productivity measure was significantly associated only with low idle time per operation.

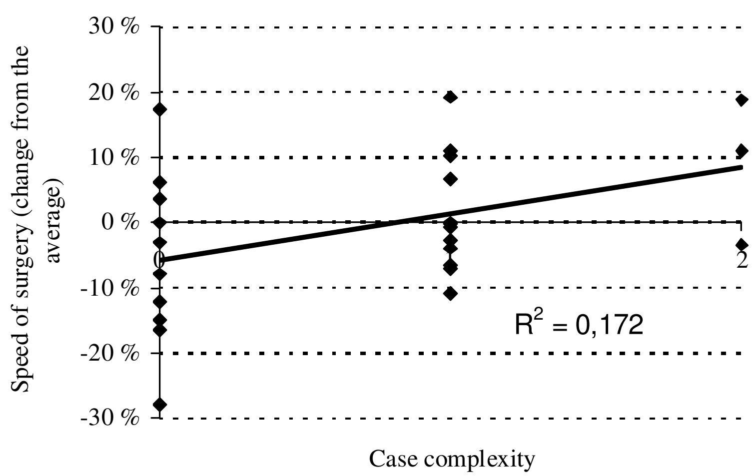

Figure 18 Correlation between case complexity and the speed of surgery

Two exceptions were found when the linearity of the connections between the variables was tested. Idle OR time per operation showed polynomial correlations with case length (Figure 19) and the share of acute operations (Figure 20). Idle time was minimized when the cases on average were very short or long, and when the unit focused on either acute or elective surgery. Models with both linear and polynomial correlations were constructed in the regression analyses, and the one with a better explanation rate was selected for the final results.

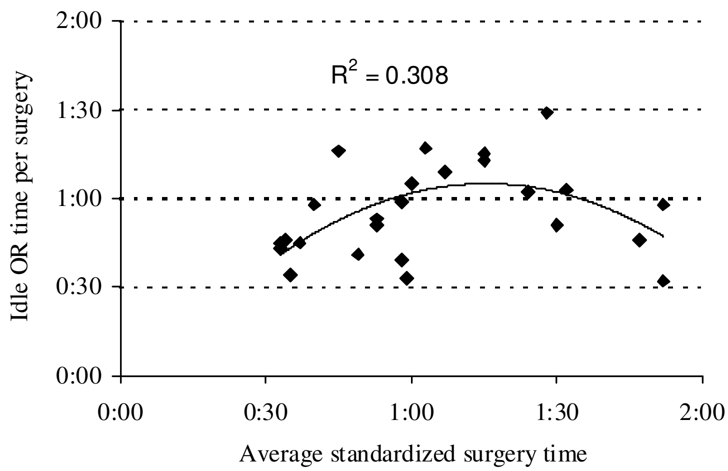

Figure 19 Correlation between average standardized surgery time and idle time per operation

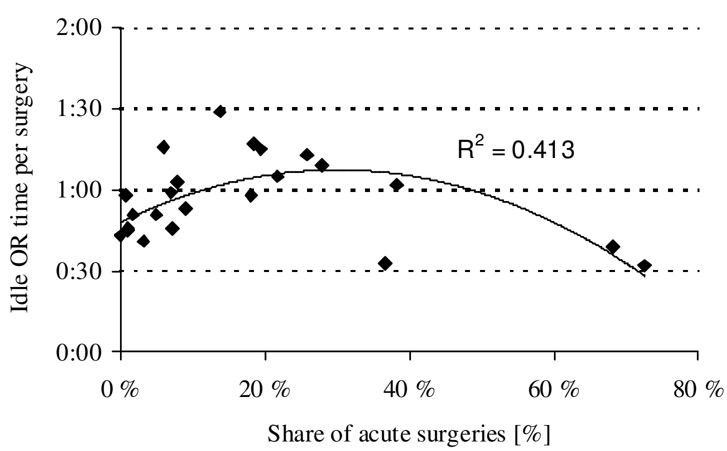

Figure 20 Correlation between share of acute surgery and idle time per operation

6.4.2 Regression analyses

The first regression analysis concerned the effect of the sub-measures on productivity. The average case length had a statistically significant effect on both productivity measures (Table 13), and idle time per operation and personnel intensity had the most significant effects on standardized productivity. Without the other variables these measures explained 56.1 percent of the variation.

Table 13 The effects of the sub-measures for efficiency on unit productivity

Case-mix variables and sub-measures for efficiency	*With case-mix variables*		*Without case-mix variables*	
	Productivity	*Standardized productivity*	*Productivity*	*Standardized productivity*
Case complexity				
Case length	1.18**	.68*		
Share of acute operations				
Speed of surgery	-.31**	-.29** (1)	-.41**	-.35** (1)
Idle time per operation	-.58**	-.90**	-.20	-.64**
Raw OR utilization rate		-.32	1.00**	.31*
OR turnover time			.42*	.25
Personnel intensity	-.67**	-.59** (1)	-.56**	-.56** (1)
R^2	90.3 %	85.1 %	74.0 %	81.0 %
F	44.7**	21.8**	10.2**	15.4**

+ p<0.10, * p< 0.05, ** p<0.01, (1) case complexity -standardized measure

Table 14 shows the regression models concerning the effects of the strategic variables on performance. The case-mix and strategic variables explained the most variation in raw OR utilization (79.8%) and the least in standardized productivity (21.8%). Ambulatory units tended to show a shorter idle time per operation but an increase in personnel intensity. Having a high number of staffed ORs was associated with higher personnel intensity, too. High number of sub-specialties was associated with increased OR turnover time but also with lower

OR utilization rate and personnel intensity. No strategic variable had a statistically significant effect on surgery speed or the productivity measures.

Table 14 The effects of the strategic variables on unit performance

Strategic variables	*Surgery speed of (1)*	*Idle time per operation*	*Raw OR utilization rate*	*OR turnover time*	*Personnel intensity (1)*	*Productivity*	*Standardized productivity*
Case complexity [=1]			.56+	-.69*			
Case complexity [=2]			.41				
Standardized surgery time			.39+	.61*		.83**	.48
Share of acute operations [%]		-.45*	.28+			.11	.24
Ambulatory vs. mixed unit [0, 1]		.69**	-.47*	.80*	-.57**		
No of staffed ORs			.20	-.23	.63**	-.28	-.42
No of sub-specialties [=1]	-.23			.28	-.47*	.41+	.28
No of sub-specialties [=2]		.34+	-.43**	1.09**	-.85**	.43	.54
R^2	11.0 %	46.9 %	79.8 %	69.5 %	47.2 %	48.7 %	21.8 %
F	1.36	6.18**	11.8**	6.46**	4.69**	3.61*	1.06

+ p<0.10, * p< 0.05, ** p<0.01, (1) case complexity -standardized measure

In summary, mixed units with several specialties but only a few ORs tended to have the lowest personnel intensity. On the other hand, these units and also their bigger counterparts had the highest idle time per operation. Increasing the number of sub-specialties was associated with impairments in all the time-based efficiency measures.

The effects of both the strategic and operative variables on performance are illustrated in Table 15. The use of personnel incentives was the only operative variable that tended to have a statistically significant (p<0.05) impact on standardized productivity. Personnel flexibility had positive effects at a significance level of p<0.10. The results indicate that from the hypotheses 2-10 considering the effects of single variables on productivity, only numbers 3 and 8 are confirmed by the empirics.

Table 15 The effects of the strategic and operative variables on unit performance

Strategic & operative variables	*Surgery speed (1)*	*Idle time per operation*	*Raw OR utilization rate*	*OR turnover time*	*Personnel intensity (1)*	*Productivity*	*Standardized productivity*
Case complexity [=1]		-1.58*	1.15**	-2.27**			
Case complexity [=2]		-1.64**	1.11**	-1.17**		.58**	
Standardized surgery time	-.49	.58+		.56*	.32		
Share of acute operations [%]		-.24	.25**		-.35+	.40*	.46+
Ambulatory vs. mixed unit [0, 1]		1.63**	-.87**	1.91**	-.45*	.17	
No of staffed ORs	.73+	.64*			.21	-.46*	-.67+
No of sub-specialties [=1]	-.42	-.52+	.21*	-.43*	-.39*	.64**	.44
No of sub-specialties [=2]	-1.77*	-.43	-.36**	.90**		.96**	.82+
Case scheduling practices [=1]	-.76+	-.27	-.11	.32*	1.09**		
Parallel processing and layout [=1]		-.28	.14*	-.26*	-.18		
Parallel processing and layout [=2]	.32	-.69**	.42**	-.52**	.23		
Personnel flexibility [=1]	.51+		.27**		-.48*	.33*	.31
Personnel flexibility [=2]	.70+	-.36+	.37**		-.33+	.35+	.44+
Performance monitoring [=1]	-.78*			.19+	-.37+	.58*	.42
Incentives [=1]				-.19+	-.62**	.73*	.51*
Multi-skilled personnel [=1]	-.60*	.18	-.07	.45**		.27+	
Multi-skilled personnel [=2]	-.99*	-.28	.14	-.24+		.34+	
R^2	63.6 %	93.6 %	98.3 %	97.2 %	87.3 %	90.4 %	54.9 %
F	1.75	8.37**	38.9**	21.1**	5.72**	7.87**	2.44+

+ p<0.10, * p< 0.05, ** p<0.01, (1) case complexity -standardized measure

Personnel flexibility and the use of parallel processing and layout were associated with a lower idle time per operation and a high OR utilization rate, and the latter shortened OR turnover times. Sophisticated scheduling practices were statistically significantly associated with higher personnel intensity. Performance monitoring and multi-skilled personnel had a positive effect on surgery speed. When the sum of the use of soft-based operative practices (personnel flexibility, performance monitoring, incentives and multi-skilled personnel) was used as a combined variable the combined measure was associated with lower personnel intensity (p<0.05).

The effects of the different variables on the variation in performance measures are summarized in Figure 21. For example, the value "18.5 %" in the raw OR utilization rate means that when the operative variables are added to the regression model the explanation rate increases by 18.5 percent. The variables used were most effective in explaining the variation in the raw OR utilization rate (98.3%) and OR turnover time (97.2%). However, the case-mix variables had high impact on both of these measures. The effect of the strategic and operative variables was strongest on personnel intensity, and idle time per operation. These measures, together with speed of surgery and standardized productivity, were the least case-mix sensitive among the seven measures and therefore the most useful in comparing units with different case mixes.

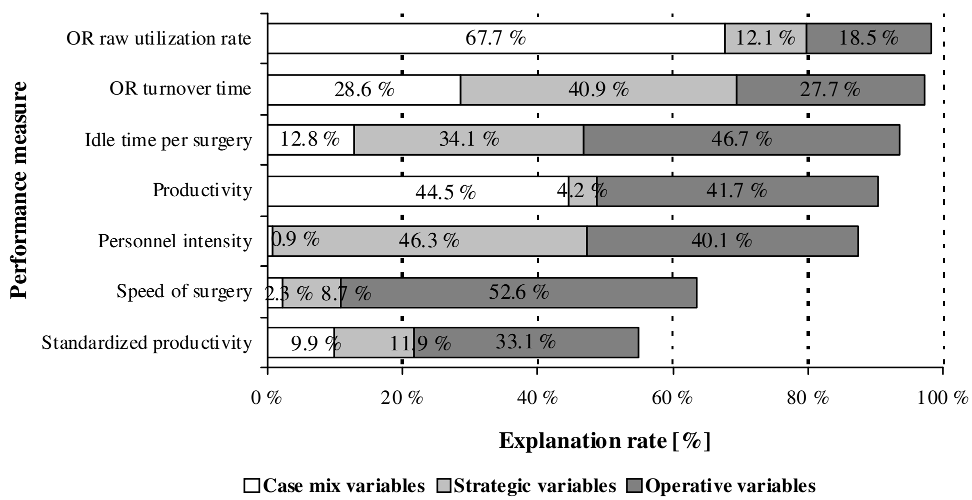

Figure 21 The explanation rates of the variables for different performance measures: personnel intensity and speed of surgery are case-mix standardized

The figure also shows that standardized productivity works better than non-standardized productivity in comparing performance between units with different case mixes. The use of operative practices explained 33.1 percent of the variation in standardized productivity. However, over 40 percent of the variation remained unexplained. The result supports the hypothesis 11 that claims that operative practices have a higher impact on operating unit productivity than strategic decisions.

6.4.3 Identifying the factors behind the variables

All the variables used, and the performance measures, were included in the factor analysis. Six statistically significant components were found with an eigenvalue of over 1.00 (Table 16). In total these components explained 81.1 percent of the variation in the variables.

Table 16 The components and their eigenvalues in the factor analysis

Component	***Initial Eigenvalues***		
	Total	% of Variance	Cumulative %
1	5.380	28.32	28.32
2	3.315	17.45	45.76
3	2.504	13.18	58.94
4	1.808	9.514	68.46
5	1.347	7.092	75.55
6	1.054	5.550	81.10
7	.919	4.837	85.94

Table 17 lists the components and their correlations with the variables. Correlations with an absolute value of more than 0.3 are shown.

Table 17 The components and their correlations with the variables

Variable	Component					
	1	2	3	4	5	6
Case complexity [0, 1, 2]	.804	.179	.375	-.007	-.126	-.160
Standardized surgery time	.872	.277	.169	-.039	.195	-.175
Share of acute operations [%]	.640	-.064	.237	-.100	-.320	.301
Ambulatory vs. mixed unit [0, 1]	.586	.450	.472	-.078	.174	.185
No of staffed ORs	.049	.097	.234	.916	.036	.184
No of sub-specialties [0, 1, 2]	-.625	.265	-.022	.606	-.137	.273
Case-scheduling practices [0, 1, 2]	.718	-.451	-.143	.067	.195	-.184
Parallel processing and layout [0, 1, 2]	.414	-.231	-.065	.131	.530	.545
Personnel flexibility [0, 1, 2]	.447	.376	-.163	.043	-.146	.130
Performance monitoring [0, 1, 2]	.566	-.344	.064	.429	-.269	-.200
Incentives [0, 1, 2]	.124	.055	-.559	.279	.525	-.112
Multi-skilled personnel [0, 1, 2]	-.141	.599	-.235	-.314	.453	-.019
Speed of surgery	.067	-.421	.461	-.291	.092	.417
Idle time per operation	-.282	.542	.655	.145	.271	-.143
Raw OR utilization rate	.939	-.164	.005	-.109	-.037	.071
OR turnover time	.119	.743	.427	.069	-.020	-.233
Personnel intensity	.229	-.738	.075	.264	.232	-.306
Productivity	.620	.502	-.563	.069	-.008	-.045
Standardized productivity	.411	.444	-.656	.054	-.333	.125

Component (1) correlates highly with most of variables, especially with complex and long operations and high OR utilization. The term *profiling* fits that factor well. *This profiling* factor focuses on a narrow range of complex patients. The focus in management practices is on hard-based methods such as the utilization of quantitative data in planning and monitoring and developing new process layouts. Personnel flexibility is also somewhat emphasized. Profiling is connected to better-than-average productivity.

Component (2) is associated with higher productivity based on both standardized and non-standardized measurement. It correlates highly with multi-skilled personnel and personnel flexibility. The term *lean* could be seen as a connecting factor. *The lean* factor is strongly associated with high productivity, which in practice is achieved via faster-than-average surgery times and significantly lower personnel intensity. It is interesting that OR turnover is longer than average, which could nevertheless be attributable to team transitions between ORs or longer lunch breaks due to a lack of circulating nurses, for example.

The most distinctive characteristics of the third (3) component are a long idle time per operation and long OR turnover time. The term *lack of control* fits these variables. *Lack of control* thus implies quite low profiling and a low application level of operative practices, especially incentive systems. The operations are a little more complex and there is no strategic orientation with regard to ambulatory surgery. The abundance of idle time also has a negative effect on unit productivity. The implication is that neither the personnel nor the management is very dynamic in terms of making the unit more efficient.

Component (4) is associated with a large scale in both the number of staffed ORs and the number of sub-specialties. Behind the *volume* factor might be a historical development promoting this kind of centralization (e.g., central hospitals). However, there is no correlation with the performance measures, implying that high performance is achieved by adopting other factors and variables. Separate personnel groups with less multi-skilling and the use of performance measures are slightly emphasized in this factor.

Components (5) and (6) have strong connections with the use of parallel processing, and dispersed correlations with some other variables. However, it is not easy to name the connecting factors behind the variables.

In summary, the factor analysis identified the following three factors (in order of importance) that drive productivity: 1) the lean and flexible use of personnel resources, 2) control over the use of staffed OR time, and 3) a clear case-mix profile.

6.4.4 Clustering the operating units

Finally, cluster analysis was applied to both the strategic and the operative variables. In order to produce enough diversity but at the same time to ensure statistical significance, the number three was set as a target in the different clusters.

The results of the strategic cluster analysis are given in Table 18. Cluster (1) consists of units carrying out complex and long operations, with a high proportion of acute surgery and only one or two sub-specialties. Almost the opposite is cluster (3), which includes ambulatory units, short and simple operations and a low proportion of emergencies. Cluster (2) consists of units with a high number of ORs and sub-specialties.

Table 18 The average values of the variables in the three strategic clusters

Variable	Strategic cluster			
	1 “Focused units”	2 “Central hospitals”	3 “Ambulatory units & regional hospitals”	Total
N	6	8	10	24
Clustering variables:				
Case complexity [0, 1, 2]	1.5**	1.0+	0.2**	0.8
Standardized surgery time	1:30*	1:15	0:44**	1:06
Share of acute operations [%]	32.2 %*	23.6 %	3.1 %**	17.2 %
Ambulatory vs. mixed unit [0, 1]	1.0+	1.0*	0.4**	0.8
No of staffed ORs	4.0*	10.1**	5.2*	6.5
No of sub-specialties [0, 1, 2]	0.0**	2.0*	1.7	1.4
Dependent variables:				
Case-scheduling practices [0, 1, 2]	0.83**	0.25	0.10*	0.33
Parallel processing and layout [0, 1, 2]	0.50	0.38	0.10	0.29
Personnel flexibility [0, 1, 2]	1.00	1.14	0.78	0.95
Performance monitoring [0, 1, 2]	1.00+	0.71	0.44	0.68
Incentives [0, 1, 2]	0.17	0.13	0.10	0.13
Multi-skilled personnel [0, 1, 2]	0.33	0.57	0.67	0.55
Sum of operative practices	3.83	3.29	2.22	3.00
Standardized speed of surgery	3.6 %	-2.1 %	-1.6 %	-0.5 %
Idle time per operation	0:48	1:08*	0:52	0:56
Raw OR utilization rate	76.0 %**	65.9 %	60.2 %**	66.0 %
OR turnover time [min]	30.8	37.8*	29.2+	32.5
Standardized personnel intensity	4.98	4.81	4.82	4.85
Productivity	8.19	7.89	7.38	7.72
Standardized productivity	7.90	7.67	7.67	7.72

+ $p<0.10$, * $p< 0.05$, ** $p<0.01$, p-values for independent samples t-test

There are several operative variables and performance measures that characterize the clusters. Focused units are strongly associated with the use of case-scheduling practices, and high OR utilization. These are very near the features that were connected to the *profiling* factor in the factor analysis. Idle time per operation and OR turnover were longer than average in the central hospitals, which indicates some association with the factors *volume* and *lack of control*. Cluster 3, ambulatory units and regional hospitals, was associated with lower OR-utilization rates and low adoption of case-scheduling practices. In summary, it seems that the strategic cluster of the unit does not have a significant impact on the productivity level.

The results of the operative cluster analysis are given in Table 19. All units are included in one of the three clusters. However, the smallest cluster consists of only five units, and the others of 10 and 11. Cluster (1) is differentiated from the others in its higher total sum of practices used, and especially in the use of sophisticated case scheduling, and parallel processing and layout. It could be called "*Full - Hard*", meaning that operative practices are widely implemented and that there is an emphasis on hard-based practices. In terms of strategic variables and performance measures the cluster stands out only with its higher OR utilization rate. On the other hand, the small sample size (n=5) makes it hard to find statistical significance.

Table 19 The average values of the variables in the three operative clusters

Variable	Operative cluster			
	1 Full - Hard	2 Selective - Soft	3 Careful - Soft	Total
N	5	10	11	26
Clustering variables:				
Case scheduling practices [0, 1, 2]	0.80**	0.50	0.00**	0.35
Parallel processing and layout [0, 1, 2]	1.40**	0.00*	0.09	0.31
Personnel flexibility [0, 1, 2]	1.00	1.22+	0.67*	0.96
Performance monitoring [0, 1, 2]	1.00	1.00**	0.22**	0.71
Incentives [0, 1, 2]	0.20	0.10	0.09	0.12
Multi-skilled personnel [0, 1, 2]	0.60	0.33	0.78	0.57
Sum of operative practices	5.00**	3.22	1.89**	3.09
Dependent variables:				
Case complexity [0, 1, 2]	1.00	0.90	0.45+	0.73
Standardized surgery time	1:28	1:07	0:54*	1:04
Share of acute operations [%]	28.9 %	19.0 %	9.1 %+	16.6 %
Ambulatory vs. mixed unit [0, 1]	0.80	0.70	0.64	0.69
No of staffed ORs	7.40	6.10	6.27	6.42
No of sub-specialties [0, 1, 2]	0.80	1.10	1.82*	1.35
Standardized speed of surgery	1.8 %	-1.5 %	-0.7 %	-0.5 %
Idle time per operation	0:46	0:52	1:02+	0:55
Raw OR utilization rate	74.4 %*	68.2 %	60.2 %**	66.0 %
OR turnover time [min]	29.0	32.3	33.8	32.5
Standardized personnel intensity	5.04	4.82	4.79	4.85
Productivity	8.15	8.11	7.18*	7.72
Standardized productivity	7.83	8.12+	7.31+	7.72

+ p<0.10, * p< 0.05, ** p<0.01, p-values for independent samples t-test

The second cluster (2) includes 10 units that could be characterized by the extensive utilization of personnel flexibility and performance monitoring but no use of parallel processing and layout. The term *"Selective - Soft"* fits the cluster well. In terms of strategic variables and most performance measures the units are near the overall average, but standardized productivity is somewhat higher than in those with different operative policies.

The third cluster (3) consists of 11 operating units that had adopted operative practices very sparingly. None of them used sophisticated case scheduling, and performance was monitored only partially and in pairs. Implementation levels are highest in multi-skilled personnel and personnel flexibility. On this basis the cluster could be called *"Careful - Soft"*. The units carry out shorter and less complex operations than the others, and typically also cover several sub-specialties. The raw OR utilization rate and both productivity measures are lower than those in a combined group of units from other clusters.

Table 20 gives a summary of the cluster analysis, illustrating the productivity levels in the different clusters. All the focused units, but only 50 percent of the central hospitals and 42 percent of the ambulatory units and regional hospitals, are in the two most productive operative clusters. This might indicate that focused units are more willing or capable than other units to adopt sophisticated planning and control practices. On the other hand, there is slight evidence that the central hospitals and ambulatory units, and the regional hospitals maximized productivity by adopting a *selective - soft* approach. Their most significant shared difference from the focused units is the larger number of sub-specialties. It could therefore be argued that the *full - hard* approach works well in a focused unit environment, but in units with several sub-specialties working together a more personnel-oriented soft-based management approach leads to maximized performance.

Table 20 Standardized productivity in the different strategic and operative clusters

Strategic cluster	Operative cluster			Total
	Full – Hard	Selective - Soft	Careful - Soft	
Focused unit	n=2 8.21 ± 0.82	n=4 7.74 ± 1.14	n=0	n=8 7.90 ± 0.99
Central hospital	n=2 7.94 ± 0.62	n=2 8.71 ± 0.00	n=4 7.00 ± 0.65	n=8 7.67 ± 0.91
Ambulatory unit & regional hospital	n=1 6.83	n=4 8.19 ± 0.73	n=7 7.49 ± 1.07	n=12 7.67 ± 0.98
Total	n=5 7.83 ± 0.77	n=8 8.12 ± 0.87	n=11 7.31 ± 0.93	n=26 7.72 ± 0.92

6.4.5 A summary of the results

The methods of statistical analysis used allowed consideration of performance from different perspectives. However, the results of the different analyses are fairly coherent and could be summarized in a few general remarks.

Linear regression analysis revealed that the best measures for eliminating the effect of different case mixes on performance are *idle time per operation*, *speed of surgery,* and *standardized productivity*. Therefore, the results of those measures, especially with regard to standardized productivity, should be emphasized when the final conclusions are formulated. Strategic and operative variables explained, in total, 47.4 percent of the variation in standardized productivity between the units. The use of personnel incentives was the only statistically significant ($p<0.05$) driver of high productivity. With a p-value of less than 0.10, high productivity was also associated with personnel flexibility and a high proportion of acute surgery.

Analysis of the underlying reasons for high performance in the three most productive units also revealed the factors that had the most effect on productivity: The most productive unit had an incentive system according to which physicians were paid per unit of output. It also had very lean personnel-per-staffed OR, and very high surgery speed. Personnel per OR was also very lean in the second-best unit, and was used flexibly during the day. The third unit was a focused unit with a high application level in both hard- and soft-based operative methods. The raw OR utilization rate was also significantly higher than in any other unit.

The results of the factor and cluster analyses can be combined. The strategic and operative clusters and their most productive combinations are presented in Figure 22. Dashed lines indicate the different factors behind the study variables. Productivity was highest in a) high-profiled and focused units that had adopted hard-based operative practices and b) central hospitals, ambulatory units and regional hospitals that focused on lean and flexible personnel management. The result supports the hypothesis 12 that claims that operating units with a narrow scope benefit best from case scheduling and parallel processing, whereas units with a large scope benefit best from resource flexibility and multi-skilled personnel.

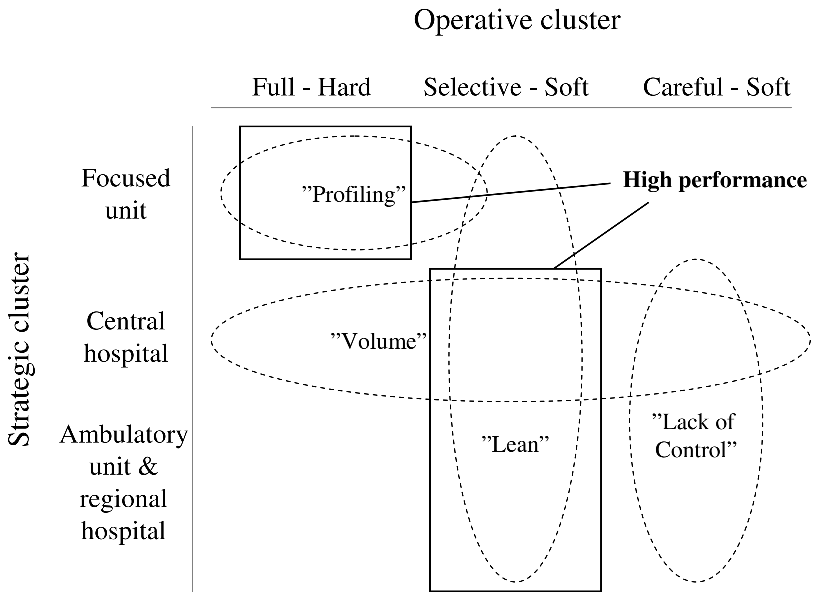

Figure 22 A summary of the factors and clusters from the perspective of unit performance

Table 21 summarizes the answers to research questions 2-4 and the results of the hypothesis testing. The p-value 0.05 was set as a threshold to confirm or reject the hypotheses. A total of five of the 12 hypotheses were confirmed based on the empirical analysis.

Table 21 The outcomes of the hypothesis testing

Research question	Hypothesis	True/False	Comments
II. What are valid measures for evaluating and comparing the productivity of an operating unit?	1. A productivity measure that considers standardized surgery as output and used personnel hours as input is valid for monitoring daily performance and comparing operating units with a different case mix.	TRUE	The developed measure is mainly immune to non-manageable events and different case mixes.
III. What is the effect of the identified features of the production planning and control system on operating unit productivity?	2. Operating units with a narrow service scope have higher productivity than units providing a wide range of services.	FALSE	Productivity was highest in the focused units but not statistically significantly.
	3. The size of the operating unit has no effect on its productivity.	TRUE	Productivity was higher in the small units but not statistically significantly.
	4. Operating units with a high proportion of acute surgery have higher productivity than units engaged mainly in elective surgery.	FALSE	Productivity was higher in units engaged in acute surgery but not statistically significantly.
	5. Parallel processing increases operating-unit productivity.	FALSE	The practice was associated with shorter turnover time but not with

			higher productivity.
	6. The utilization of historical case duration and target OR filling rates in case scheduling increases operating-unit productivity.	FALSE	The practice was associated with higher OR utilization but also with higher personnel intensity and not with higher productivity
	7. The use of multi-skilled nurses instead of separate anesthesia and OR nurses increases unit productivity.	FALSE	The practice was associated with speeder surgery but not with high productivity.
	8. The use of incentive systems increases operating-unit productivity.	TRUE	p-value <0.05
	9. Personnel flexibility increases operating-unit productivity.	FALSE	Productivity was higher in units with high flexibility but not statistically significantly.
	10. Continuous performance monitoring increases operating unit productivity.	FALSE	The practice was associated with speeder surgery but not with high productivity.
	11. Capacity-building, resource-planning and patient-planning practices have a higher impact on operating unit productivity than strategic decisions.	TRUE	There was a triple impact difference.
IV. What are the productive operational features of the different production strategies?	12. Operating units with a narrow scope benefit best from case scheduling and parallel processing, whereas units with a large scope benefit best from resource flexibility and multi-skilled personnel.	TRUE	The number of units with a narrow scope limited the statistical significance.

7 Discussion and conclusions

This chapter considers the study results in the light of the previous literature and understanding of OR management. Conclusions are drawn about relevant performance-measurement and strategic and operative practices. Issues of validity and reliability are discussed in the last section.

7.1 Operating unit production planning and control

A framework system for operating unit production planning and control was developed in the study. Previous frameworks have focused on the hospital level (e.g., Vissers et al. 2001) or on smaller parts of operating unit management, such as capacity and case scheduling (e.g., Santibanez et al. 2007). Berry et al. (2008) investigated somewhat similar strategic and operative variables in their multi-hospital study. However, they did not use a systematic approach in identifying the different variables, but applied an old classification of the basic functions of management (Davis 1951).

The framework developed in this study consists of four hierarchical planning levels: strategy, capacity, resources and patients. On the organizational level the framework could be used in developing management tools and instructions, and dividing management responsibility within the organization. It also shows how decisions affecting operating unit performance are made on several organizational levels: high productivity is typically attributable to a combination of actions carried out among top management, sub-specialty managers, operating unit managers and heads of different professions and personnel groups.

7.2 Operating unit performance measurement

The study broadens understanding of performance measurement in hospital ORs. It introduces a productivity measure in which duration-weighted surgery is the output and cost-weighted personnel hours the input. The first version of the measure was relatively sensitive to case complexity, which therefore has to be included or used as a control in analyzing the effect of the strategic and operative variables on unit performance. In summary, it is recommended that operating unit output should be measured in terms of case-complexity and surgery-type standardized process times, including both surgery time and the necessary preparation time.

The two measures in the existing literature that are closest to the measure developed in this study are OR productivity, introduced by Torkki et al. (2006), and a quantitative measure that considers several performance aspects such as resource utilization and speed of surgery (Pandit et al. 2009). The definition of unit output used was further developed from Torkki et al.'s version (2006). The most notable difference from the quantitative measure (Pandit et al. 2009) is that resource costs and personnel intensity per OR are also taken into account.

It could be concluded from the study findings that the two most interpretative sub-measures of OR productivity are 1) idle time per operation during office hours and 2) allocated personnel per staffed OR. These could be used in everyday production planning in order to facilitate high productivity. Idle time per operation could be utilized in the scheduling of cases on a daily OR list. The best hospitals investigated in this study achieved 30-35 minutes idle time per operation. Personnel intensity as a sub-measure underlines the importance of staffing and personnel management in high-performance production. The OR team in hospitals with the leanest personnel consisted of just three nurses and 0.5 anesthesiologists.

It was interesting that two frequently mentioned and utilized measures, the raw OR utilization rate (e.g., Denton et al. 2007) and OR turnover (Macario 2006; Sokolovic et al. 2002), did not drive high productivity as effectively. There are several problems connected with using these measures. First, neither has any connection to personnel intensity, and both measure the use of room resources rather than more expensive personnel. Secondly, the OR utilization rate is very sensitive to the average case length, and therefore is not suitable for comparing units with different case mixes. OR turnover, on the other hand, measures a very small part of the total process, and does not consider idle time in the mornings and afternoons.

The fifth most commonly used sub-measure, average speed of surgery, also contributed to high productivity. It is effective in explaining differences in productivity between units, but in daily use it is not sufficiently manageable and is vulnerable to random variation. It is therefore recommended for use on the monthly or annual level, and mainly as reference data for surgeons.

7.3 Drivers of OR productivity

The most interesting and practically useful results of the study relate to the drivers of high performance. First, the case mix and the strategic and operative variables together explained

57.3 percent of the variation in standardized productivity between the units. A significant part of it remained unexplained. At least some human-related factors, such as personnel experience and local resource availability, might account for some of the unexplained variation.

Operative practices explained 38.9 percent of the variation in productivity, whereas strategic variables explained only 8.5 percent. It could therefore be argued that proper operative practices are more important than correct strategic decisions in terms of improving OR performance. Benchmarking current operative practices rather than current strategic policies in other hospitals offers higher learning potential. This also offers a good opportunity for operating units in that implementing new operative practices is typically easier than changing strategic orientation (Peltokorpi et al. 2008).

There was an unexpected weak link between unit strategy and productivity, and a couple of remarks on the reasons for this are warranted. Strategic decisions tend to have a significant effect on process sub-measures such as the OR utilization rate, turnover time and idle time per operation: the focused units had the best records in the process measures whereas the ambulatory units had the weakest. However, heavier resourcing and slower operations in the focused units compensated for the effect on productivity. The best units are those that, regardless of their strategic positioning, can combine short idle times in the process and a relatively lean personnel pool.

It appears from the results of study that the use of personnel incentive systems is the strongest single driver of high productivity. The effect of such systems is not directed via some specific variable or sub-measure, however. Instead, there is a slightly positive effect on all process-time and utilization measures and speed of surgery. Although some of the incentive systems used in the case hospitals were constructed around the surgeon's performance rather than the output of all personnel, no signals of sub-optimization were found. This indicates that the production planning process in operating units is strongly coordinated and affected by surgeons, whereas nurses and anesthesiologists usually have less control over planning issues. Extending the incentive system to cover nurses and anesthesiologists gives additional value only if these professions can affect either the case scheduling or the daily staffing.

Personnel flexibility was the other factor that, according to the regression analysis, had an independent positive effect on productivity. In more concrete terms, high personnel flexibility, such as daily staffing based strictly on the number of open ORs, different OR-team working hours and a flexible overtime policy, means significantly less idle time per operation and high OR utilization. Having different team working hours, so that one team works between 10 am and 6 pm instead of only during office hours, enables full OR sessions while still avoiding overtime. Daily staffing based on open ORs, on the other hand, decreases the fluctuation in daily productivity. This policy was the result of the systematic use of stand-by personnel and employment contracts allowing unsalaried days off.

When the effects of both the strategic and the operative variables were analyzed in the same regression model three strategic variables were found to affect productivity ($p<0.10$). First, increasing the proportion of acute surgery tended to increase productivity. This is against the general assumption that shorter response times decrease productivity due to the higher variation in volume. However, it seems that, in practice, units performing both acute and elective surgery can fill the open slots in their daily schedules with emergency operations and therefore improve productivity. Units with a heavy emergency load also typically have more OR teams working after office hours, which makes it possible to schedule more elective OR sessions and still avoid overtime among personnel working during office hours. On the other hand, the study did not include units offering only acute or elective surgery. It could be argued that emergent operations increase productivity up to a certain point, but after that there may be the reverse effect, if almost all operations are acute. It should also be remembered that an unexpected daily peak in acute operations in a single unit might reduce overall efficiency due to the additional costs related to altered schedules and shifted surgery.

Secondly, at the given application level of operative practices, small units tended to be more productive than big ones, and units with several sub-specialties more productive than those focusing on one specialty. However, simply favoring small units with several sub-specialties (mainly ambulatory units or regional hospitals) may be the wrong conclusion, because on average these units are no more productive than others. Instead, the study shows that small units with several sub-specialties are less likely to apply the operative practices, but something related to their small size and wide service range seems to compensate this flaw.

The results provided evidence that small units have less idle time per operation and lower personnel intensity, which indicates that economies of scale (e.g., Stigler 1958) work in the reverse direction in hospital operating units. This is somewhat against the dominant trend, especially on the political level with its emphasis on large organizations and units. Operating units or rooms are not factories, but are more like manufacturing cells in which consecutive steps are taken in small areas (e.g., Hyer and Wemmerlöv 2001). Cellular manufacturing may be a realistic approach in other healthcare services too, and a challenge to traditional volume thinking.

The wide service range was associated with a higher surgery speed. According to the interviews in the case hospitals, however, ambulatory units and regional hospitals may have more senior surgeons and fewer assistant physicians, and this is assumed to correlate with surgery speed. High operating unit performance in small and rural hospitals is conditional on having experienced senior surgeons. Without experienced core personnel hospitals cannot maintain a wide service range and high productivity. Therefore, no unambiguous conclusions can be made about the correlation between productivity and the number of specialties.

Drivers and anti-drivers of productivity can also be identified in the factors affecting the most important sub-measures - personnel intensity, idle time per operation and speed of surgery. Sophisticated case-scheduling practices were significantly associated with high personnel intensity. In other words, only units that had a relative abundance of nurses per OR tended to utilize historical surgery-duration data and target-filling factors in case scheduling. This relationship was so strong that, in practice, it eliminated the positive effect of scheduling practices on the OR utilization rate. Instead, with a given personnel intensity, implementing case-scheduling practices tended to increase the productivity of the unit.

The use of parallel processing and layout was strongly associated with less idle time in the OR process. However, the connection with productivity was not as obvious as argued in previous studies (e.g., Torkki et al. 2006). The reason for this might lie in the thoroughness of the implementation: the productivity in four operating units that had implemented parallel processing in only a few of their many ORs was 3.0 percent lower than in units without parallel processing, whereas those in which the practice was used in all ORs it was 3.6 percent higher. Although the differences were not statistically significant, the results suggest that even if parallel processing typically improves performance, partial implementation may have the opposite effect.

The use of multi-skilled personnel and performance monitoring boosted surgery speed. However, these measures correlated negatively, meaning that the units seemed to choose either of these policies. Multi-skilled personnel could speed up the process because anesthesia and OR nurses can help each other and delegate tasks to unoccupied personnel. The positive effect of monitoring is referred to in the use of the balanced scorecard (Kaplan and Norton 1996), for example. In the OR context, however, the prime objective is to minimize idle time in the process, and not necessarily to speed up the surgery, which could then be associated with a deterioration in quality.

The effects of the variables on productivity are illustrated in Table 22. Incentives and personnel flexibility had the most unambiguously positive effect.

Table 22 A summary of the effects of the strategic and operative variables on OR productivity

Variable	Effect	Mechanism	Remarks
Proportion of acute surgery	+	Emergencies increase OR utilization rate	Might cause additional costs in ward units
Ambulatory unit (AU)	no effect		AUs were associated with a lower idle time per operation but also with higher personnel intensity
No of staffed ORs	-	Small units had less idle time and leaner staffing	
No of sub-specialties	no effect		Focused units have higher OR utilization, but high personnel intensity and slow operations
Case-scheduling practices	+	Increase OR utilization rate	Problems in applying with low personnel intensity
Parallel processing and layout	+	Decrease idle time between operations	Higher productivity might not be achieved when applied only in a few ORs
Personnel flexibility	+ +	Decrease idle time and increase OR utilization	Different ways of adapting: day-to-day staffing, team working hours, overtime policy
Performance monitoring	+	Speed up surgery and turnover	Important to focus on the right measures: output, productivity, idle time
Incentives	+ +	Affect all sub-measures slightly positively	Cost of incentives and their effect on demand should be considered
Multi-skilled personnel	+	Speed up surgery, leaner personnel intensity	Lack of personnel could also be a driver of multi-skilling

As mentioned in earlier chapters, high OR productivity is a combination of low idle time per operation, lean personnel intensity, and high-speed surgery. Single operative practices contribute to productivity in very different ways (Figure 23). Hard-based practices decrease idle time in the process, but they are also associated with higher personnel intensity. Multi-skilled personnel, on the other hand, are associated with low personnel intensity and high-speed surgery. Incentives and personnel flexibility are not clearly associated with any sub-measure, but have a direct effect on productivity.

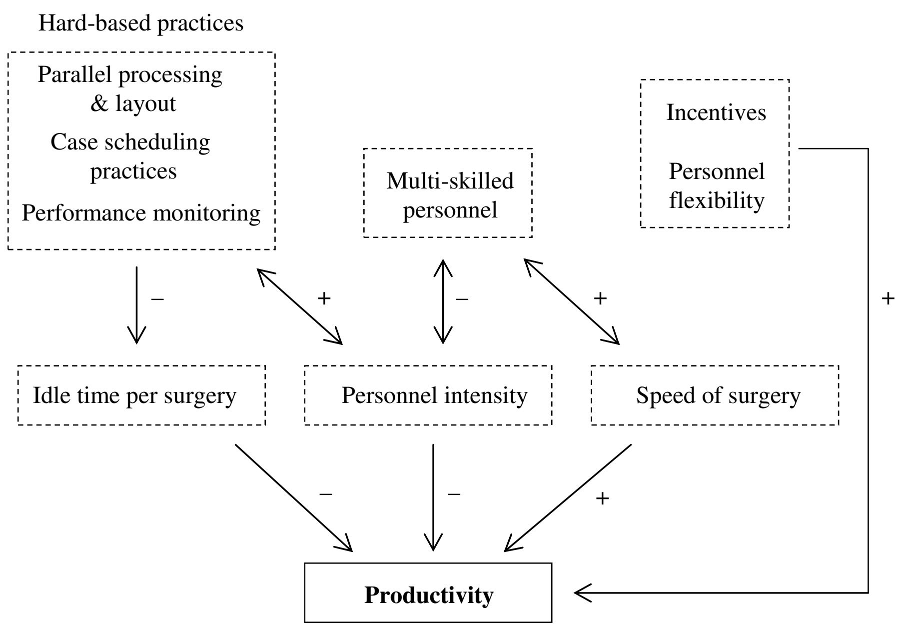

Figure 23 The effects of operative practices on productivity

The factor and cluster analyses gave descriptive insights into the strategic and operative positioning of the hospitals, and into the connections between these positions and productivity (Figure 24). The figure reveals that strategic positioning - whether in a focused unit, a central hospital or an ambulatory or regional hospital - does not preclude high performance. The crucial decision relates to the unit's operative positioning and the underlying factors. The mainstream trend, however, seems to be toward a less productive outcome in each of the three strategic clusters: Focused units tend to choose flexibility instead of profiling, and other units lean toward a lack of control instead of more productive flexibility. In sum, there is a general need for upgrading the operative practices in each strategic group.

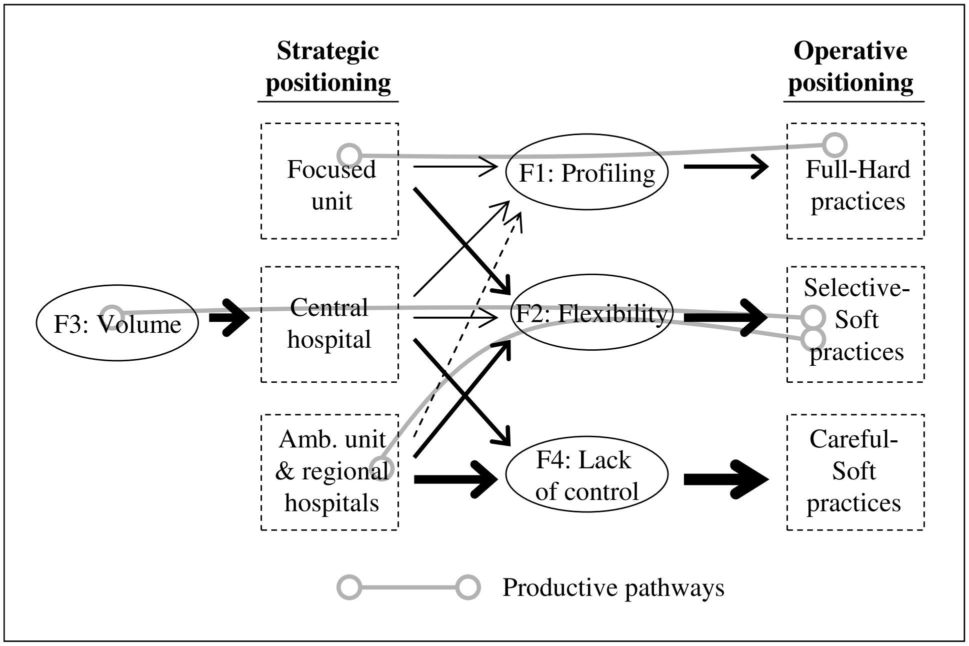

Figure 24 Reconstructed managerial pathways between factors (F1-F4), strategic decisions, and operative decision in the operating units under investigation

7.4 Contribution and directions for future research

The results of the study contribute to the literature on OR management in several ways.

The findings highlight the role of staffing issues in improving operating unit efficiency. Most previous studies focus on maximizing output with given resources (e.g., Testi et al. 2007; Denton et al. 2007). However, the indications in this study are that attention should be diverted to variation in personnel management and staffing levels. Economic principles are not very widely understood in OR personnel management (Bozic et al. 2003; Saleh et al. 2009). It seems that many managers feel successful when they can increase their resources. However, according to the findings of this study productivity could be significantly increased in all kinds of units if more attention was paid to staffing. Ambulatory units and those engaged in less time-consuming surgery could manage with fewer personnel than conventional units. Central-hospital units should improve the coordination between planned surgery and daily staffing. Focused units also tend to have excess personnel resources. The implementation of productivity measurement would make it more difficult to hide poor staffing practices by showing high resource utilization and non-value added activities on surgery days.

The second notable contribution of the study relates to the choice of appropriate strategic and operative pathways. Whereas there have been problems of generalizability in previous studies due to the particular case environment (e.g., Overdyk et al. 1998; Peltokorpi et al. 2007b; Sanjay et al. 2007), this one revealed some diversity in optimal policies. It seems obvious that different units should focus on different practices, but illustrating what the appropriate policy might be in a certain environment is of significant value to practitioners. The finding that focused units should apply hard-based practices whereas a soft-based approach fits non-focused units best enhances understanding of OR performance with regard to the practices used in manufacturing industry (Schroeder and Flynn 2001).

The study also increases understanding of the reasons for the fact that surgical units typically operate below optimal efficiency (HFMA 2005). Findings of the study indicate that operating units systematically tend to underutilize operative tools and practices suitable for their strategic position. Incentive systems and personnel flexibilities, for example, are not implemented in their full potential. In central hospital operating units, inefficiency might be also a consequence of adopting scheduling practices and layouts that are suitable for focused units but not as workable in a wide service range environment.

As previous studies have done (Dexter and Epstein 2005; Dexter et al. 2004), this one emphasizes the importance of daily resource flexibility for scheduled and urgent surgery and in maximizing efficiency. It is more profitable to pay 100 percent extra for overtime than to avoid it and delay cases. Allocated OR sessions must also be scheduled so as to produce appropriate utilization rates (Tyler et al. 2003; Van Houdenhoven et al. 2007b). The optimal planned OR utilization rate is up to 90 percent.

Contrary to other studies, the findings of this one suggest that efficiency is not especially sensitive to first surgery start times (Overdyk et al. 1998), OR turnover times (Marjamaa et al. 2007; Macario 2006) or overused OR times (Dexter and Macario 2002; Testi et al. 2007). Although these measures do affect efficiency, additional improvements can be achieved by focusing on others. Idle times in the morning and long turnover times are obvious problems. Staffing issues are more sensitive, and changes are more difficult to implement, despite the significant contribution to overall performance.

It was also found that, contrary to the results of a previous study (Brenn et al. 2003), personnel intensity is typically no lower in short operations than in long ones. OR staffing in terms of the number of nurses and anesthesiologists is almost the same in all kinds of operations. The implication is that many ambulatory and short-surgery units could potentially make savings by moving toward the norm in outpatient services with regard to personnel intensity. Further, the study results give no support to the economy-of-scale argument mentioned in the literature (e.g., Berry et al. 2008). The bigger units seemed to have particular problems in terms of coordination and planning, which counteract any positive effects of a larger size. On the other hand, there were no large focused units in the study sample. Whether tighter service scope enables higher performance in large units is therefore somewhat unclear.

The study enhances understanding of efficiency as a whole and of the challenges involved in improving it in operating units. Operating unit efficiency is strongly dependent on variation in demand and process times, both of which can be affected by management. Variable process times complicate the measurement of output reliability and efficiency. Basically, it is not easy to reduce the natural variation in surgery times, but the use of information about surgery types, surgeons and surgical complexity may produce more accurate estimates of process times (Shukla et al. 1990; Opit et al. 1991; Strum et al. 2000b; Broka et al. 2003; Lebowitz 2003a). Improved estimates are beneficial in two ways: they reduce variation in both process times (realized vs. estimated time) and daily output.

Table 23 summarizes the contribution of this study to the theory of operating unit production planning and control. Knowledge from previous studies includes previously used and proposed solutions to managerial decisions at different levels of the production planning system. Questions for further studies are based on gaps identified in this one or mentioned in the literature.

Table 23 The contribution of the study to OR management

Level of management	Knowledge from previous studies	New knowledge from this study	Questions for further research
Performance measurement	Rapid access to care, cancellations, OR utilization rate, idle times, overtime, number of operations, contribution to margin.	Productivity (output per input) is a valid measure for comparing units with different case mixes.	How can output measurement be modified toward outcome measurement that incorporates quality issues?
Production strategy	Units can be divided into a) focused units, b) multi-specialty central hospital units, and c) ambulatory and short-surgery units. No findings concerning the connection between strategy and performance.	Focused units tend to have slightly higher efficiency than other units. However, the differences are not statistically significant. Production strategy has less impact on productivity than used operative practices.	What is the optimal production strategy in a regional healthcare system? What is the optimal strategy in different surgical specialties?
Operative practices	Several practices contribute to efficiency at least in certain environments: parallel processing, computer-aided case scheduling, daily personnel flexibility	Incentive systems and personnel flexibility are the least questionable drivers of high performance. Managers should be selective when implementing operative tools: Focused units should apply hard-based practices whereas other units benefit from soft-based initiatives.	What is the best way of promoting the implementation of the best operative practices in different units? What kind of incentive systems improve OR productivity the most?

The next step in performance measurement should be to develop the productivity measure in a quality-adjusted direction to replace output with an outcome measure. A cost-outcome measure would fit the overall aim to maximize the amount of produced health per dollar (e.g., Berwick 2005). In terms of production strategy, more research is needed to define optimal strategies from the perspective of both the regional system and the sub-specialties. It is assumed that regional distances and total demand at least affect the optimal production strategy in a regional organization. There may also be differences between the specialties in the optimal arrangement of services.

The essential question for further research on the use of operative practices is how to encourage units, their managers and personnel to implement practices that improve productivity. According to the results of this study, focused units are better at implementation than other units. However, there may be some general features such as incentive systems, which are not related to the unit's strategy, that promote the diffusion of best practices in OR management.

7.5 The validity and reliability of the research

The validity of case-study research can be assessed in terms of construct validity, external validity, and internal validity (Yin 2009). Construct validity concerns the correctness of the operational measures used in reflecting the investigated constructs. Operating unit productivity was a central construct in the present study. It was operationalized through the process of first analyzing the value chain of healthcare operations, then focusing on the input side on the most expensive personnel resources and on the output-side considering resource use in standardized surgery. Finally, the operational measure was tested in both a single- and multi-case environment. It is possible to expand the measure by including surgeon and other-than-personnel resources in the input side, but that would compromise its suitability for comparing units with different surgeon policies or case mixes. It would also be possible to consider revenue as output, but then the measure would be disturbed by different price levels and pricing issues.

A major limitation of this study is related to output measurability. The calculation of output for each surgery type was based on average surgery times plus standardized preparation time in the OR and 20 minutes of setting time per operation. Although the measure eliminates the effect of average surgery length on productivity relatively well, there were problems in combining surgery types from among the Finnish Nomesco-classification, German OPS-codes and the text form used in the American case hospital. A couple of surgery types could not be classified congruently, and therefore there may be some inaccuracy especially in the speed-of-surgery measure.

Construct validity also has to be considered in the operationalization of production planning and control variables. In this study the existing frameworks, the features of general systems of production planning and control, the literature on OR management, and the researcher's practical understanding of the planning processes in operating units were all utilized in defining and operationalizing the relevant constructs. It should be borne in mind that the model was still a simplification and it did not include features such as surgeon or personnel experience, which would have been used as a control measure when considering unit productivity. The use of a tripartite interval scale simplifies the operationalization of the adopted practices of capacity and resource planning, but still retains some separating capability.

External validity refers to the ability to generalize the results of a study to other settings. There are some limitations in this study that restrict such generalization. First, the study was conducted mainly in the Finnish context. Although hospitals in Germany and the USA were included, the special characteristics of the Finnish healthcare system are presumably reflected in the results. Divergence in the selected strategies and adopted planning practices would presumably be wider if more units from different countries were investigated. Divergence attributable to different system environments was perceived even in this study, however: anesthesiology resources per OR, for example, were significantly higher in Germany due to local regulations, and day-to-day personnel flexibility was highest in the unit from the USA on account of the local labor market. However, since the primary aim of the study was to reveal the effect of practices of production planning and control on productivity, the system environment behind those decisions was a secondary issue. At the same time, it should be remembered that operating units in general are among the most internationally comparable parts of hospitals.

Secondly, according to Eisenhardt (1989), case selection should be selective and focus on theoretically useful cases that are likely to replicate or extend the emergent theory. In this case the study sample included 26 operating units that were not theoretically selected, not even in Finland. This means that there might be a bias toward a certain type of unit, and the ones investigated might be more willing to develop their production planning and control than the average. On the other hand, the units in question covered about 35 percent of the operations performed in Finland, and many of the ones that were selected on basis of the consulting project had had problems with production planning and control. The study sample was fairly diversified in the Finnish context, meaning that the results should be quite similar in other settings. A larger sample size would have increased the statistical power of the study (Cohen 1988; Ketokivi 2009).

Internal validity concerns the causality of the observed relations between phenomena. For example, if there is a correlation between the use of incentives and perceived productivity, does it mean that incentives increase productivity? In order to increase internal validity it is essential to verify that there are no external disturbing factors behind the relation. Case-mix measures such as average case length and case complexity were therefore used as control measures in order to exclude their disturbing effect. Moreover, the statistical methods used, such as multivariate regression analysis, decreased the disturbing effect. The hospital data was gathered retrospectively, meaning that the testing had no effect on the performance. However, it was not possible to eliminate all the disturbing effects, and that should be considered in drawing conclusions from the results.

Research reliability is typically perceived in terms of stability and equivalence (Emory 1985). Research is stable if it can be repeated by the same person and with the same instruments without changes in the results. Given that the practices of production planning and control in operating units change over time, the results obtained in a new situation may differ from those reported in this study. If the research had been repeated almost immediately, thereby eliminating the time effect, the stability problem would have been limited to the interview and observation part of the data gathering: it could not have been totally precluded that repeated semi-structured interviews and observations would have revealed some new aspects that could have affected the researcher’s estimate of the planning practices used in the unit, for example.

Equivalence reliability means the equivalence of a measuring device to another measuring device: both should give the same results when applied to the same object. Semi-structured interviews were used in the study in order to facilitate situational flexibility and to minimize the effect of shortages, with regard to language for example. However, the interview questions were not tested in advance nor were they compared with optional questions, and this decreases the equivalence reliability of the research. Moreover, three different people were involved in the interviews and observations, and this could have affected the results if a person is considered a measuring device.

In summary, the results of this research are limited, largely on account of the regional bias in the sample, the sample size, and limitations in the operationalization of the constructs.

8 Managerial implications

The results of this study lead to several implications and recommendations in terms of introducing optimal production strategies and operative practices in surgical services. It seems that high productivity is more dependent on the choice of pathway than on individual decisions and procedures, and thus the managerial implications focus on finding and following the best pathways.

8.1 A regional production strategy

Healthcare organizations are typically responsible for taking care of insured patients in a certain region. Although the study did not consider regional surgical service networks, some principles for developing a regional production strategy emerge from the results.

The first implication is that economies of scale do not apply to operating unit size: given the operative practices in question, small units tend to surpass large ones. Therefore, compact units with between four and eight ORs should take precedence over large units in the production strategy. Taking the appropriate operative approach would ensure high performance in a compact unit. If the unit has a narrow focus on services it would be appropriate to adopt sophisticated case scheduling, performance monitoring and parallel processing, whereas with a wider range of services effort should be put into the flexible use of personnel resources. Incentive systems drive productivity in any event.

Units with more than eight ORs achieve high productivity only through very strong investment in strict case scheduling and the flexible use of personnel. Berlin hospital invested in short turnover times and full OR sessions for example, and San Francisco hospital in flexible day-to-day staffing and personnel circulation. Those two units are more market-oriented than the large Finnish units investigated in the study. Achieving high performance in a large unit tends to require market-oriented incentives and a strict contract policy between the specialties and the operating unit.

Developing focused units in a regional healthcare system imposes requirements on the region in terms of size and volume. There is a trend in university hospitals in particular to build operating units around sub-specialties such as orthopedics, eye surgery and gynecology. The results of this study imply, however, that this policy does not necessarily ensure high productivity. The problems relate to different urgency rates and personnel-intensity requirements within a sub-specialty. Operating units should therefore be narrower in scope, focusing on trauma surgery, ambulatory orthopedics or hip and joint replacements, for example. Most Finnish hospital districts are currently too small to build focused units. The building of focused surgical units that will serve university districts or even larger regions is therefore recommended.

8.2 Toward more compact and focused units

The study results show that moving toward more focused operating unit is a potentially productive investment given the slight, although not statistically significant, evidence that promoting such units over those with a wide service range leads to increased overall productivity. In any case, such a strategy would offer the opportunity to apply operative practices that drive high OR productivity.

The transition from one wide-ranging operating unit to more compact and focused units happens in various ways. The focus in this section is on these unit types, and on the development of propositions related to increasing their productivity.

The first traditional group includes units with high academic status and complex and project-type surgery among limited sub-specialties, such as trauma and neurosurgery. Although these units seem to have higher-than-average productivity, historically the developmental emphasis has been mainly on quality rather than staffing and productivity. The weighting of quality over other issues may be one reason for the typically significantly higher level of personnel intensity in those units. Thus more effort should be made to optimize staffing levels in units with a strong academic focus. The use of scheduling practices and monitoring should also be encouraged, and false assumptions about the unfitness of sophisticated planning methods in a complex environment should be corrected. Given the specific characteristics of these units, international comparisons are useful in providing valid benchmarking data about practices that drive high productivity.

The second group consists of ambulatory units. However, these units do not appear to differ from central hospital units in terms of productivity. Their problems usually lie in their low OR utilization rate, and idle time occurs especially toward the end of the day. Ambulatory units, like units with a high academic focus, were not founded on the basis of OR productivity: a short stay is the main driver, and in many units same-day discharge is secured by means of loose scheduling in the afternoons. Ambulatory units should increase their OR utilization rate by introducing more strict scheduling and ensuring early discharge in other ways, such as extending PACU opening hours or cooperating with other units that are open in the evenings. Other reasons for the low utilization rate resemble those in central hospital units: the high number of sub-specialties means that some are not very interested in maintaining high productivity and prefer their own daily schedules. This phenomenon supports the move toward more focused units in which the head of the sub-specialty has more responsibility for OR productivity. Another option is to increase flexibility in staffing and then plan nursing shifts based on the sub-specialties' specific needs and surgeons' working hours.

So-called focused factories that concentrate on routine elective surgery with limited specialties comprise the third type of compact and focused unit. Joint replacement and orthopedic ambulatory units are two examples. Given the low number of focused factories in the study, little can be said about their productivity. However, the two units investigated were the top two in the sum of operative practices used. This suggests that focusing gives significant support in the implementation of new management practices. A narrow service range also means less complexity in stakeholder management. However, over-resourcing is a potential threat in focused factories in that when non-routine surgery becomes routine, new challenges might be sought in complex cases. Although this is a desirable development in the main, process planning and resourcing might be altered for complex cases even though most surgery is routine.

There are also other but not such clear types of compact and focused operating units. The division of surgery or surgical sub-specialties within a hospital between elective and acute units is one strategic trend identified in the study. Such a policy tended to increase overall productivity. The reason for the improved performance once again lies in the ability to customize practices of production planning and control to suit the unit's profile: flexible staffing works in units focused on acute surgery whereas incentives and sophisticated case scheduling raise productivity in elective surgery. Extra idle time and decreased productivity due to the provision for random acute operations in every OR are typical phenomena in units that do not have an urgency-based focusing policy. It should be noted that this diversification is based purely on differences in urgency, and the units might still carry out operations in many sub-specialties.

Policies promoting focused units and their critical success factors are illustrated in Table 24. It should be pointed out that the results of this study do not support the formation of units focusing on a certain sub-specialty, such as orthopedics or gynecology. As mentioned in earlier chapters, surgery in such units tended to be too wide-ranging in terms of both urgency rates and resource intensity:, simplicity in stakeholder management does not typically fully compensate the problems in inner planning and control in units formed around a certain medical sub-specialty.

Table 24 Policies promoting more compact and focused operating units

Unit type	Specific characteristics enabling high OR performance	Critical success factors
Academically focused unit	Few stakeholders; high personnel commitment	The unit is not too focused to apply planning practices and monitoring; unjustifiable over-resourcing is avoided
Ambulatory surgery unit	(Homogeneity in urgency profile)	OR sessions are scheduled so as to fully utilize afternoons; coordination between sub-specialties
Focused factory	Few stakeholders; routine surgery; homogeneity in urgency profile	Sophisticated scheduling methods are fully applied; staffing is adjusted to routine surgery
Acute surgery unit	Homogeneity in urgency profile	Flexibility in shift working and overtime policy; coordination between sub-specialties
Elective surgery unit	Homogeneity in urgency profile	Sophisticated scheduling methods and monitoring are fully applied; coordination between sub-specialties

Historically, focused units seem to have been founded mainly with regard to quality issues, and staffing and productivity have been less emphasized. Weighting quality over other issues may be one reason for the typically higher personnel intensity. More attention should be directed toward developing focused units in order to achieve high productivity. This would mean more flexible daily, intraday and inter-professional personnel management and more comprehensive incentive policies.

8.3 Selecting and implementing operative practices

The focus in this section is on selecting and implementing optimal operative practices with a given strategy and case mix. In general it could be said that the units have significant potential to improve their efficiency through the more active implementation of best operative practices. Given that implementation is always hard work and that the results of the study indicate that the feasibility of a practice may depend on the unit's strategy and history, more specific recommendations about best practices are given to suit different situations.

The implementation of incentive systems, for both individuals and surgical subgroups, is strongly recommended in all operating units. Only 10-20 percent of the units in this study sample had implemented policies that directly motivated employees to increase their output. In practice, the incentives in those hospitals took the form of bonus payments. The first phase in an implementation process should cover incentives to surgeons to use their OR time more accurately, They could be extended in the next phase to cover anesthesiologists and nurses with a view to keeping the ratio of personnel per staffed OR time to a minimum and still maintaining a high quality. Special attention should also be given to bonus equality for personnel in different hospital units, and to incentives for carrying out non-operative tasks such as teaching and training. There are also alternatives to money as a reward for high performance. Experience has shown that, given the need to consider the relation between standardized output and used personnel resources in the incentive system, a simple information system is required within which the necessary personnel and operative data can be easily and systematically gathered.

Increasing personnel flexibility in operating units is also highly recommended, given the study results. Flexibility takes many forms, however, and it is essential to find a form that suits the organization. Personnel flexibility falls roughly into three categories. The first of these relates to daily staffing levels among nurses and anesthesiologists. The number of personnel assigned to the unit should be planned strictly according to the number of open ORs. If some of them are closed, because the surgeon is not available or operations are cancelled for reasons to do with the patients for example, the equivalent number of nurses and anesthesiologists should be reduced from the daily roster. Some hospitals, such as the San Francisco hospital, incorporate this flexibility into the work contract. Another way is to reduce the number of salaried employees and to use contract personnel during demand peaks and high-volume days. This policy would also encourage specialties and surgeons to schedule their OR sessions early enough.

The second form of personnel flexibility concerns intraday shift schedules and overtime policy. Some hospitals have successfully introduced overlapping working shifts, so that one OR team is ready to work one or two hours later than the others. The later team could take over operations that would have entailed prolonged overtime. This type of policy would make it possible to schedule OR sessions more tightly and still avoid most non-planned overtime and cancellations. The particulars of current demand and case mix have to be considered when this policy is adopted in an operating unit.

Thirdly, there could be flexibility in the intraday transfer of nurses and anesthesiologists within the unit. The aim of this very practical and widely used policy is to maintain production during breaks, and to respond to unexpected phenomena such as cancellations, new emergency patients and personnel absences. It is not unproblematic, however: if the flexibility is ensured by reserving extra personnel in advance, the consequence might be lower rather than higher productivity. There should also be careful assessment of whether it is possible to forecast or even prevent some of the unexpected events. Acting to reduce case cancellations, prolonged surgery and personnel requirements is usually more efficient than reacting to those phenomena after their occurrence.

Performance monitoring is the third operative practice that is recommended regardless of the organizational context. Nevertheless, it is essential to be aware of what is being measured and how the measurement is utilized in the planning and management process. None of the units investigated in this study measured OR productivity systematically. Most of the ones that used any measures monitored time, such as OR utilization, turnover, and under- and over-utilization. The problem with such measures is that they focus too little on personnel costs and preparation and surgery speed. The management emphasis is too often on the utilization of fixed space resources rather than on the daily ratio of standardized output and personnel resources. Time measures can be quite easily connected to case-scheduling targets. Productivity measurement, on the other hand, should drive both case-scheduling and optimal staffing decisions.

Sophisticated case-scheduling practices include the utilization of historical data on case length and target OR utilization rates. None of the units in the study applied both of those practices properly: either the historical data was out of date and was suitable only for rough categorization or the target optimal utilization rate was set too low. It is recommended that the average length of the last ten cases per surgeon and surgery type is used as an estimation of case length, and that the target OR utilization level is set so that the last case finishes about 20 minutes before the end of the working shift. At the same time, consideration should be given to the appropriate staffing level. The study revealed that ambulatory units in particular, which reported the use of sophisticated scheduling practices, tended to be higher in personnel intensity than their counterparts without such practices.

The parallel processing of surgery and the surgical preparation of the next patient is recommended in order to increase daily output per OR session. If this practice is not combined with increased output, however, additional resources only result in increased costs and lower total productivity. The number of personnel allocated to an anesthesia induction room or a similar process phase has to be defined carefully so that, as a result, output will increase more than input. It seems from the results of this study that there are too many units that find it difficult either to increase output or to size personnel resources in parallel preparation. Sharing resources among two or more ORs is recommended. The benefits of parallel processing are highest in units with a homogenous case mix. Large multi-specialty units applying it only in some of their ORs seem to have problems in both systematic planning and staffing: personnel absences are compensated first in anesthesia induction and preparation work. Therefore, large or multi-specialty units must plan the implementation of parallel processing very carefully in order to establish the practice and achieve cost savings.

Multi-skilled nurses who can perform both anesthesia and instrument-related tasks are utilized mainly to compensate lean staffing levels in regional and ambulatory units. Moreover, some highly focused units and units with experienced personnel share tasks among the nurse pools. Although there was a connection between multi-skilled personnel and faster surgery and leaner staffing, nurses' job descriptions should be expanded primarily on account of personnel competence and not purely to increase efficiency in all circumstances. In many cases the surgeons and nurses argued that inexperienced personnel were one of the main sources of problems in the production process. Therefore multi-skilled personnel are of most benefit to regional hospitals and units with less complex cases, in which the practice relates to motivation and compensation for low output per OR.

8.4 A summary of the managerial implications

The managerial implications are summarized in Table 25. It is recommended that focused units be built mainly in large regions with a sufficiently large population base. In addition, there is a need for regional units for minor acute cases and ambulatory surgery in order to maintain adequate time and distance access to services. Medium-sized focused units should be promoted over very small or large units that provide a wide range of services. Incentive systems and practices to increase personnel flexibility are highly recommended for all operating units. Parallel processing and sophisticated scheduling practices, on the other hand, should be more carefully evaluated before implementation.

Table 25 Managerial implications

Area of managerial decisions	Recommendations
Regional structure	Focused units built around specific surgery types, catchment area circa 1.0 million Fewer focused regional units built around acute and ambulatory surgery, catchment area 0.1-0.3 million
Unit scale and scope	Optimal unit size 4-8 operating rooms, in larger units sophisticated incentive systems for sub-specialties and individuals required Narrow scope recommended: specific elective surgery, ambulatory surgery, acute surgery
Personnel-management practices	Incentive systems: for sub-specialties and individuals to maximize output per paid personnel hour Personnel flexibility: 1) day-to-day flexibility in staffing levels, 2) different working hours for OR teams, 3) flexibility in overtime policy
Technological-management practices	Parallel processing: recommended in focused units when it can be used systematically Scheduling: the use of historical duration and target OR-utilization rates is recommended. Most suitable for focused units.

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Appendixes

1. HEMA Institute research projects, 2003-2007

Patient in Process

07/2003-08/2004

The focus in the Patient in process project was on the length of time a single patient spends in the healthcare system, and the different phases involved. The underlying objective was to improve the functioning of the system by reducing "waste time" through the application of time-based methods from industrial engineering. The research was conducted in two Finnish hospital districts.

Partners: Päijät-Häme Hospital District, Turku University Hospital

Surgery Process Re-Engineering - Anesthesia Induction outside the Operating Room

10/2003-04/2004

This study addressed the following questions: Is anesthesia induction outside the operating room worthwhile from the industrial management point of view? How can performance and efficiency be measured in trauma units? How are cost effectiveness, lead times and throughput times measured?

Partners: HUS Töölö Hospital, Instrumentarium

PMHC - Process Management in Health Care

02/2004-04/2005

The objectives of this project were to increase cost efficiency and transparency in acute coronary syndrome care processes. The BIT research center was a subcontractor in the project, focusing on process modeling and analysis, process simulation and optimization, stakeholder analysis, and governance modes and practices.

Partners: Kuopio University Hospital

Improving Operating Room Efficiency through Process Analysis

09/2004 - 03/2005

The overall aim of this study was to analyze the current state of OR management in Päijät-Häme Central Hospital, to effect an immediate process change, and to define more extensive change proposals for further development projects. The scientific aim was to create general methods and philosophies for hospital operating-unit management, process control, resource allocation for specialties and operation types, and demand control.

Partners: Päijät-Häme Hospital District

Healthcare processes and logistics

05/2004-10/2005

The research environment was mainly specialized healthcare focusing on rationalizing patient processes in emergency and elective operations. The aim was to develop new patient-oriented operational models and tools for managing specialized healthcare. The research was conducted in collaboration with the Research Institute for Health Care Facilities (SOTERA).

Partners: Helsinki and Uusimaa Hospital District, GE Medical Systems, Tamro Medlab, Medix Laboratories, the Finnish Funding Agency for Technology and Innovation

Healthcare processes and logistics II

11/2005-3/2007

The research environment was mainly specialized healthcare focusing on rationalizing patient processes in emergency and elective surgery. The aim was to develop new patient-oriented operational models and tools for managing specialized healthcare. The research was conducted in collaboration with the Research Institute for Health Care Facilities (SOTERA).

Regional Healthcare Service Systems (TAPPO)

3/2007-5/2009

The aim of the TAPPO project was to develop tools and models for the planning and control of regional healthcare systems. Three aspects were investigated in parallel: 1) processes in healthcare networks, 2) regional service structures and 3) cost accounting and performance measurement.

Partners: Helsinki and Uusimaa Hospital District, Keski-Suomi Hospital District, Kymenlaakso Hospital District, Lappi Hospital District, Kainuu Region, Coronaria, Orton, Tieto, the Finnish Funding Agency for Technology and Innovation

Healthcare Operations Management (T3)

8/2009 - 7/2011

The goal of T3 is to develop feasible applications of the latest research on industrial engineering and management for the healthcare sector. The project is organized around four themes: 1) demand-based production control systems, 2) service-production-system planning and optimization, 3) ICT technologies in healthcare, and 4) resource allocation and planning.

Partners: Helsinki and Uusimaa Hospital District, Keski-Suomi Hospital District, Kymenlaakso Hospital District, Ilmarinen Mutual Pension Insurance Company, Logica Ltd., Evalua Ltd., Mylab Ltd, the Finnish Funding Agency for Technology and Innovation

2. *The research environment in a multi-hospital study*

Operating unit	Study period	Interviewed personnel	Interviewers
HUS Herttoniemi, ambulatory unit	2008	Head nurse	Antti Peltokorpi
HUS, Töölö OLS	2008	Chief Physician Head nurse	Antti Peltokorpi
HUS, Töölö, Neuro	2008	Head Nurse Chief Specialist	Antti Peltokorpi
HUS, Töölö, Plastics	2008	Head nurse	Antti Peltokorpi
HUS, Töölö, BLS	2008	Chief Physician	Antti Peltokorpi
HUS, Jorvi, ambulatory unit	2007-2008	Chief Specialist	Antti Peltokorpi
HUS, Jorvi, central unit	2005-2008	Chief Physician	Antti Peltokorpi
HUS, Peijas, ambulatory unit	2007-2008	Chief Physician	Antti Peltokorpi
HUS, Peijas, central unit	2007-2008	Chief Physician	Antti Peltokorpi
Keski-Suomi, ambulatory unit	2008	Chief Physician Head nurse	Paulus Torkki
Keski-Suomi, acute unit	2008	Chief Physician Head nurse	Paulus Torkki
Keski-Suomi, central unit	2008	Chief Physician Head nurse	Paulus Torkki
Päijät-Häme, ambulatory unit	2008	Head nurse	Antti Peltokorpi
Päijät-Häme, central unit	2004-2008	Chief Physician Head nurse	Antti Peltokorpi
Kanta-Häme, ambulatory unit	2007-2008	Chief Physician Head nurse	Antti Peltokorpi
Kanta-Häme, central unit	2007-2008	Chief Physician Head nurse	Antti Peltokorpi
Kanta-Häme, Riihimäki	2007-2008	Chief Physician Head nurse	Jussi Tan
Forssa	2007-2008	Chief Physician Head nurse	Antti Peltokorpi
Kymenlaakso, Kuusankoski	2007-2008	Chief Physician Head nurse	Paulus Torkki
Kymenlaakso, Kotka central unit	2005-2008	Chief Physician Head nurse	Antti Peltokorpi

Kymenlaakso, Kotka ambulatory unit	2007-2008	Chief Physician Head nurse	Paulus Torkki
Coxa, hospital for joint replacements	2006-2008	Chief Physician Head nurse	Antti Peltokorpi
Berlin hospital	2005-2008	Chief Physician Head nurse	Antti Peltokorpi
San Francisco hospital	2006-2007	Head nurse	Antti Peltokorpi
Pohjois-Pohjanmaa, gynecology	2005-2006	Chief Physician Head nurse	Antti Peltokorpi
Pohjois-Pohjanmaa, short surgery	2005-2006	Chief Physician Head nurse	Antti Peltokorpi

3. The semi-structured questions used in the interviews with operating unit personnel

1. Case mix and facilities
    a. Specialties
    b. Patient groups
    c. Acute patient groups
    d. No of ORs
    e. OR allocations to surgical groups
    f. Patient preparation rooms and facilities
    g. Preparation of equipments
    h. No of PACU beds
2. Personnel
    a. Nurse groups
    b. Number of personnel per shift
    c. OR team members
    d. PACU personnel per shift
    e. Use of circulating personnel
    f. No of anesthesiologists
    g. Allocation of ORs to anesthesiologists
    h. Other personnel
    i. Overtime policy
    j. Use of stand-by personnel
3. Production planning
    a. Case-scheduling process
        i. Use of historical data

ii. Target utilization rates

iii. Who decides and when

b. Management of acute operations

c. Rescheduling policies

d. Response to cancelled operations

4. Production process

a. Pre-operative process

b. Target times for first patient into the room

c. Patient call practices

d. Patient reception

e. Preparations, rooms and personnel

f. Surgeon call practices

g. Post-operative tasks in the OR

h. Typical PACU processes

i. Personnel meal and break times

5. Production control

a. Used performance measures

b. Personnel incentive systems

c. The most significant problems in the production and the reasons behind them

4. The means, standard deviations, and correlations of the variables used in the Jorvi case

Variables	Mean	s.d.	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1. Allocated OR time [h]	63.0	11.5	.813**	-.902**	-.013	.756**	.808**	-.209*	-.087	-.005	-.108	.139	-.365**	-.008	-.172	-.085	.115	-.298**	.042	.149	-.105	.409**	-.475**
2. Number of planned total personnel [h]	363	50.9		-.556**	.209*	.689**	.732**	-.086	-.042	.053	-.076	.083	-.142	-.080	-.016	-.061	.058	-.266*	.090	.120	-.102	.072	-.202
3. Planned personnel per allocated OR time	6.06	0.99			.153	-.660**	-.701**	.257*	.120	.076	.099	-.150	.348**	-.003	.133	.103	-.149	.167	-.086	-.135	.144	-.522**	.530**
4. Number of personnel in education [%]	7.7	3.9				-.068	-.024	-.024	-.028	-.226*	.007	-.137	.042	-.003	-.040	-.003	.045	-.134	-.150	-.135	-.024	-.211*	.077
5. Number of planned operations	17.6	4.13					.904**	.284**	-.120	-.137	-.047	.260*	-.121	.014	-.246*	-.257*	-.087	-.346**	-.008	.181	-.044	.510**	-.511**
6. Estimated OR time of planned operations [h]	40.2	9.56						.371**	-.124	-.129	-.037	.227*	-.105	-.016	-.266*	-.181	-.001	-.325**	.108	.202	.027	.595**	-.553**
7. Estimated OR utilization rate all operations [%]	74.1	9.6							.005	-.108	.019	.108	.319**	-.040	-.215*	-.105	-.179	-.136	.095	.153	.283**	.369**	-.168
8. Number of emergencies from previous day	1.46	1.69								.231*	-.114	-.172	.062	-.120	.114	.155	.070	-.127	.132	.425**	-.084	.059	.062
9. Number of personnel absences [%]	9.2	4.7									-.265*	-.079	-.315**	.139	-.071	.012	.168	.011	-.045	.217*	.141	-.160	.120
10. Number of stand-by personnel [%]	7.7	3.2										.187	.054	-.042	-.028	-.079	-.143	-.028	-.018	-.246*	-.178	-.202	.084
11. Amount of cancellations due to patient [%]	1.0	2.6											-.077	.026	.010	-.093	-.027	-.005	.003	.103	-.181	-.019	.072
12. Changes in allocated OR time [h]	4.28	6.64												.103	.250*	.304**	.151	.097	.105	-.085	-.096	.071	.064
13. Number of new emergency patients	7.00	2.53													-.044	.058	.258*	.109	.059	.257*	.079	.198	.056
14. Lengthened operations [% of estimated time]	114.5	16.9														.237*	.057	.184	.475**	.076	.094	-.474**	.641**
15. Lengthened preparations [% of estimated time]	108.4	7.99															.110	.035	.135	-.020	-.054	-.150	.233*
16. Average OR turnover time [min]	40.5	7.96																-.016	.173	.101	.058	.073	.012
17. Average delay in the morning [min]	34.6	24.2																	.243*	.074	.006	-.240*	.355**
18. Amount of overused OR time [h]	2.36	1.71																		.162	.039	.037	.276**
19. Number of delayed emergencies [%]	22.7	21.9																			.040	.176	.192
20. Number of cancellations due to system [%]	2.40	5.18																				-.119	.265*
21. Realized productivity [index]	11.5	1.64																					-.830**
22. Cost per output [€/h]	277	39.1																					

* Correlation is significant at the 0.05 level 2-tailed. ** Correlation is significant at the 0.01 level 2-tailed.

5. The results of the Jorvi path analysis: standardized betas and coefficients

Dependent variable / Independent variables	Planned personnel per allocated OR	Personnel in education [%]	Estimated OR utilization rate [%]	Standby personnel [%]	Delay in the morning [min]	Speed of surgery [% of estimate]	Changes in allocated OR time [h]	Overused OR time [h]	Delayed emergencies [%]	Cancellation due to system [%]	Cost per output [€/h]
Amount of allocated OR time [h]	-.90 -.078**	.67 .002**			-.76 -1.80**			.23 .034*	.24 .005**		
Planned personnel / allocated OR		.76 .030**	.26 .025*				.28 1.87**				.62 24.3**
Personnel in education [%]											.11 113*
Estimated OR utilization rate [%]						-.24 -.416*	.32 22.4**	.40 7.02**	.33 .76**	.51 .28**	-.36 -145**
Emergencies from previous days									.51 .066**		-.19 -4.5**
Personnel absences [%]				-.27 -.18*			-.35 -49**				
Standby personnel [%]											.16 194**
Cancellation due to patient [%]										-.25 -.51*	.17 259**
Delay in the morning [min]								.29 .018**	.21 .002*		
OR turnover time [min]							.25 .207**	.23 .050*		.21 .001*	
Speed of surgery [% of estimate]							.19 7.54*	.55 5.59**		.30 .091**	.36 83.9**
Speed of prepar. [% of estimate]							.24 19.6**				.14 68.5**
New emergency patients [no.]									.33 .028**		-.11 -1.63*
Changes in allocated OR time [h]									-.21 -.007*	-.42 -.003**	
Overused OR time [h]											.14 3.2*
Delayed emergencies [%]											.39 69.9**
Cancellation due to system [%]											.27 201**
R^2	81.3%	10.7%	6.6%	7.0%	19.2%	11.5%	47.6%	44.1%	48.4%	32.7%	88.3%
F	3.79 **	5.17**	6.13*	6.58*	4.98**	2.73*	10.52**	6.15**	8.22**	4.86**	36.8**

** p < .01, * p < .05

6. The means, standard deviations, and correlations of the variables used in the multi-unit study

	Case complexity	Case length	Share of acute operations	Ambulatoryvs. mixed unit	Number of staffed ORs	Number of sub-specialties	Parallel processing and layout	Case scheduling practices	Performance monitoring	Multi-skilled personnel	Personnel flexibilities	Incentives	Sum of used methods	Speed of surgery [%]	Idle time per surgery	OR raw utilization rate	OR turnover time	Personnel intensity	Productivity	Standardized productivity
Case complexity [0, 1, 2]	1,000	,858**	,653**	,762**	,179	-,307	,153	,370	,294	-,200	,227	-,015	,259	,337	,163	,692**	,463*	,656**	,386	,259
Case length	,858**	1,000	,428*	,691**	,133	-,499*	,303	,467*	,353	,056	,401	,192	,618**	,330	,206	,742**	,471*	,599**	,562**	,212
Share of acute operations [%]	,653**	,428*	1,000	,492*	,051	-,279	,207	,381	,268	-,247	,158	-,220	,186	,325	-,199	,614**	,092	,347	,288	,269
Ambulatory (0) vs. mixed unit (1)	,762**	,691**	,492*	1,000	,179	-,213	,201	,135	-,008	,067	,313	-,020	,228	,307	,443*	,448*	,450*	,247	,355	,159
Number of staffed ORs	,179	,133	,051	,179	1,000	,594**	,120	-,049	,302	-,217	,135	,070	,131	-,079	,340	-,043	,198	,174	,018	-,072
Number of sub-specialties [0, 1, 2]	-,307	-,499*	-,279	-,213	,594**	1,000	-,274	-,658**	-,305	-,033	-,065	-,005	-,429*	-,367	,251	-,625**	,164	-,420*	-,154	-,002
Parallel processing and layout [0, 1, 2]	,153	,303	,207	,201	,120	-,274	1,000	,431*	,196	,057	-,081	,214	,642**	,225	-,218	,428*	-,232	,262	,167	,021
Case scheduling practices [0, 1, 2]	,370	,467*	,381	,135	-,049	-,658**	,431*	1,000	,497*	-,168	,225	,243	,711**	,185	-,376	,658**	-,285	,659**	,229	,061
Performance monitoring [0, 1, 2]	,294	,353	,268	-,008	,302	-,305	,196	,497*	1,000	-,499*	,120	-,035	,408	,118	-,242	,490*	-,137	,474*	,158	,095
Multi-skilled personnel [0, 1, 2]	-,200	,056	-,247	,067	-,217	-,033	,057	-,168	-,499*	1,000	,215	,068	,289	-,426*	,250	-,138	,267	-,391	,236	,063
Personnel flexibilities [0, 1, 2]	,227	,401	,158	,313	,135	-,065	-,081	,225	,120	,215	1,000	,031	,521*	,073	-,057	,439*	,156	,023	,527**	,365
Incentives [0, 1, 2]	-,015	,192	-,220	-,020	,070	-,005	,214	,243	-,035	,068	,031	1,000	,400	-,173	-,112	,006	-,158	,015	,450*	,325
Sum of used operative methods	,259	,618**	,186	,228	,131	-,429*	,642**	,711**	,408	,289	,521*	,400	1,000	,019	-,247	,627**	-,090	,336	,548**	,249
Speed of surgery [%]	,337	,330	,325	,307	-,079	-,367	,225	,185	,118	-,426*	,073	-,173	,019	1,000	,064	,421*	,003	,395*	-,215	-,309
Standardized speed of surgery [%]	,002	-,016	,104	,000	-,140	-,233	,196	,068	-,008	-,362	-,013	-,175	-,063	1,000	,012	,136	-,180	,186	-,413*	-,457*
Idle time per surgery	,163	,206	-,199	,443*	,340	,251	-,218	-,376	-,242	,250	-,057	-,112	-,247	,064	1,000	-,386	,649**	-,117	-,277	-,484*
OR raw utilization rate [%]	,692**	,742**	,614**	,448*	-,043	-,625**	,428*	,658**	,490*	-,138	,439*	,006	,627**	,421*	-,386	1,000	-,073	,666**	,496*	,325
OR turnover time [min]	,463*	,471*	,092	,450*	,198	,164	-,232	-,285	-,137	,267	,156	-,158	-,090	,003	,649**	-,073	1,000	,020	,201	,048
Personnel intensity [pers. per OR hour]	,656**	,599**	,347	,247	,174	-,420*	,262	,659**	,474*	-,391	,023	,015	,336	,395*	-,117	,666**	,020	1,000	-,028	-,186
Standardized personnel intensity	,001	,092	-,009	-,292	,128	-,236	,249	,606**	,365	-,305	-,138	,048	,281	,186	-,272	,274	-,318	1,000	-,354	-,449*
Productivity	,386	,562**	,288	,355	,018	-,154	,167	,229	,158	,236	,527**	,450*	,548**	-,215	-,277	,496*	,201	-,028	1,000	,872**
Standardized productivity	,259	,212	,269	,159	-,072	-,002	,021	,061	,095	,063	,365	,325	,249	-,309	-,484*	,325	,048	-,186	,872**	1,000

** $p < .01$, * $p < .05$