DISSERTATION

Titel der Dissertation

Strategic Benchmarking for Hospitals

Verfasser

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Contents

Section 1: Research Outline

Section 2: Papers

Section 3: Annex

Section 1: Research Outline

1. Framework

My cumulative dissertation "strategic benchmarking for hospitals" comprises three research papers published between 2008 and 2010. I started the underlying research as an external doctoral student at the Department of Innovation and Technology Management of the University of Vienna after receiving my master's degree in business administration in 2002. Since 2003, I have additionally been working as a researcher in the field of health economics and health policy at the Institute for Advanced Studies (IHS) in Vienna.

My contribution to the research field consists of three thematically related research papers as required by the University's guidelines for cumulative dissertations. The submitted papers can be subsumed within the overarching research topic "strategic benchmarking for hospitals". A special emphasis is put on the development of the business logic of an internet-based management game, which illustrates the economic and organizational decision-making processes in a hospital by using discrete event simulation. The deployment of this game in teaching, policy, and research can improve policy making at the hospital, regional, and national levels.

2. Selected Papers

The submission encompasses three papers which were published in international peer-reviewed journals:

A1. **Kraus M.,** Rauner M.S., Schwarz S. (2010): Hospital management games: a taxonomy and extensive review. Central European Journal of Operations Research 18:567-591.

A2. Rauner M.S., **Kraus M.**, Schwarz S. (2008): Competition under different reimbursement systems: The concept of an internet-based hospital management game. European Journal of Operational Research 185:948-963.

A3. O'Neill L., Rauner M.S., Heidenberger K., **Kraus M.** (2008): A cross-national comparison and taxonomy of DEA-based hospital efficiency studies. Socio-Economic Planning Sciences 42:158-189.

3. Discussion of Research Results

My interest in the field of health care, and particularly in hospital benchmarking, was prompted by the main challenge faced by the health care systems of many Western countries, namely increasing costs accompanied simultaneously by decreasing revenues. One of the major cost drivers in these countries are advances in technology as well as increases in life expectancy occurring together with a rising number of multi-morbid elderly people. Consequently, the health care sector consumes a major share of the Gross Domestic Product (GDP) of these countries. In 2008, on average, the EU-15 countries spent 9.8 percent of their GDP, that is US-$ 3,336 per capita, on health care, and in the US, 16.0 percent of the GDP or US-$ 7,538 per capita went into this sector (OECD 2010).

In Europe, the US, and other Western economies, the executives' interest in containing health care costs and increasing the sector's efficiency has been high on the political agenda. Careful planning and coordination of resources, processes, and finances is imperative for increasing the efficiency of hospitals, which consume a large share of total health care expenditures. In Europe, more than 36 percent of these costs are attributed to the hospital sector, whereas in the US, hospital costs amount to 25 percent of total health care expenditures (OECD 2010). To reduce this financial burden, national, regional, and local governments search for suitable approaches. A first step towards the evaluation of a health care system and, as a consequence, the efficient distribution of human and economic resources in this sector, is efficiency measurement.

In general, for efficiency measurement in health care, data envelopment analysis (DEA) has proven to be a suitable instrument. This non-parametric approach measures the relative efficiency of decision making units (DMUs) measured by the ratio of the weighted sum of outputs and the weighted sum of inputs. The weights for both inputs and outputs are determined endogenously in the model, such that the efficiency measure of each DMU is maximized subject to the constraint that the efficiency score lies within the bounds of 0 and 1. The scores thus calculated produce the efficiency frontier, on which the Pareto optimal DMUs are located (Charnes et al. 1978 and 1994).

Reviewing the application of efficiency measurements in the hospital sector was therefore the key motivation for the first paper (A3). Its main research task was 1) to provide a cross-national comparison and taxonomy of hospital efficiency studies which used DEA and related techniques for efficiency measurement and 2) to demonstrate the broad applicability of DEA in the hospital sector. In this context, 79 hospital efficiency studies from 1984 to 2004, covering 12 countries were reviewed. The studies were classified into three groups based on their country of origin: Europe, the US, and other countries. The use of statistical tests aimed at identifying significant differences between Europe and the US for various study characteristics: number of DMUs, input categories, output categories, allocative efficiency (Yes/No), multi time periods (Yes/No), average efficiency score, and percentage of efficient DMUs.

The results disclose significant differences between Europe and the US in terms of important study characteristics. The average number of DMUs was significantly larger in US studies than in European ones. Furthermore, US studies tended to use more input categories, but fewer output categories. Also, 52 percent of the European studies incorporated allocative efficiency, compared with 12 percent of the US studies. Furthermore, 60 percent of the European studies were based on panel data, compared with 25 percent of the US studies. Finally, the analysis highlights that both the average efficiency score and the percentage of efficient DMUs were slightly higher for studies of European hospitals.

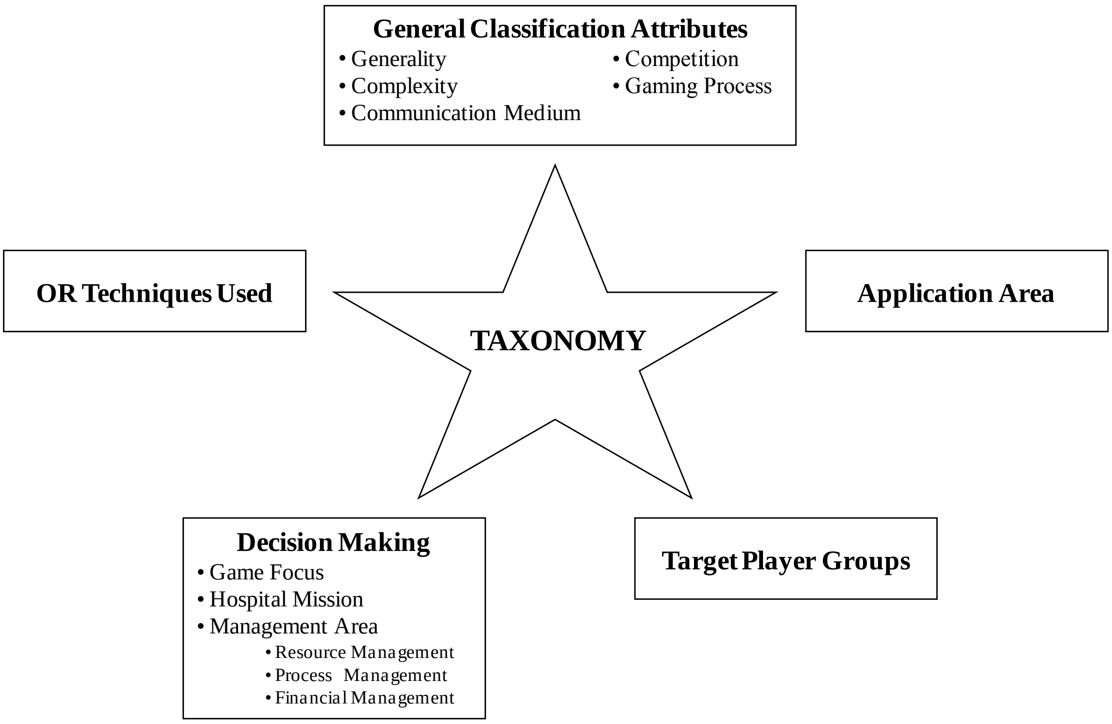
Since the main objective of my dissertation was to develop the business logic of a hospital management game, a particular focus in A3 was put on identifying the most important input and output variables to support the design process of the game. On the one hand, the analysis of the input variables, therefore, served as a basis for identifying key categories in the decision making processes in the hospital game. On the other hand, the analysis of the output variables aimed at identifying key categories for the development of the game's performance measurement system.

Through the analysis of the input variables, three broad categories were derived: capital investment, labor, and other operating expenses. Capital investment is a central input category when measuring the efficiency of hospitals. Accurate data on capital investment, however, is difficult to obtain. Consequently, in many hospital efficiency studies, "number of beds" is used as a standard proxy for capital investment. This proxy variable was then further disaggregated into acute care and long-term care beds. Another proxy used for capital investment is "number of hospital services". The second and most crucial input category for efficiency measurement of hospitals is represented by the variable labor, since about two thirds of hospital operating costs are payroll expenses. Its frequently used proxies are "number of personnel" or "labor expenses". The "number of personnel" variable was either defined as one general labor input variable or subdivided into "number of physicians", "number of nurses", "number of medical/clinical staff", "number of technical staff", and "number of management and administrative staff". While the physician category was further disaggregated, for example, into "number of general medical doctors" and "number of specialized medical doctors", the nursing category also distinguished between "number of registered nurses", "number of licensed practical nurses", and "number of nursing support staff." Labor expenses were variously subdivided into "general staff costs", "nursing staff costs", "medical staff costs", and "other staff costs". Operating expenses is the third main input category in the reviewed hospital efficiency studies. Its most common proxy variable was "operating expenses excluding payroll, capital, and deprecation". "Supply costs" were another frequently used proxy for operating expenses. These costs were variously disaggregated into "equipment costs", "medical supply costs", "food costs", "drug and pharmaceutical costs", and "material costs".

The analysis of the output variables of the reviewed hospital efficiency studies, identified three broad categories: "medical visits, cases, patients, and surgeries", "inpatient days", and "admission, discharges, and services". The most important output variables for measuring the outpatient activities of hospitals were "number of outpatient visits", "number of outpatients", and "number of outpatient surgeries". Most commonly, the outpatient visits were subdivided into "emergency visits" and "non-emergency visits". The output variables for measuring inpatient activities of hospitals highly depend on the hospital reimbursement system. Therefore, hospital efficiency studies opt for "cases" or "adjusted discharges" when hospitals are reimbursed on a case-/DRG-based system, while they tend to use "inpatient days" for hospitals with day-based reimbursement. The inpatient day category was often disaggregated by method of payment, care intensity (e.g., acute, long-term patient days), and hospital division (e.g., surgical, psychiatric, pediatric inpatient days) to capture the case-mix of a hospital.

As the major goal of my dissertation was to develop the business logic of a hospital management game, in A1 special emphasis was placed on assessing the state of the art of existing hospital games, their main characteristics as well as their shortages with respect to, for example, the adaptation to new reimbursement systems. A1 thus derives a taxonomy of hospital management games. This taxonomy provides a unique classification of the precise decision making of players in resource, process, and financial management by describing the applied operations research (OR) techniques. In this context, 13 hospital management games were classified according to general classification attributes, application area, target player groups, decision making, and OR techniques used (cf. Figure 1).

Figure 1: Structure of the taxonomy for health care management games



Source: own compilation.

The analysis of the general classification attributes indicates that the majority of the games exhibit at least one of the following characteristics: they can be classified as general games, in that they focus on the entire or main functions of a hospital, are characterized by a rather complex game situation, are played online, and are played in a setting of indirect competition, where the players' performances are evaluated only in terms of predefined criteria. With regard to the gaming process, the majority of the games allow a game host to vary both internal conditions (e.g., number of beds, number of operating rooms) and external conditions (e.g., reimbursement system), use quarterly rounds, and evaluate the results after each round.

Furthermore, the taxonomy shows that teaching is the main application area of hospital management games. However, they are also used for policy purposes for the illustration of how regulations impact decision making as well as outcomes and for research purpose to investigate different game situations by controlled experiments. Hospital management games target different player groups, such as health care leaders/policy makers, health care practitioners/professionals, hospitals staff, and students. The majority of games reviewed are designed to be played by hospital staff (e.g., doctors, nurses, medical staff, technical staff, administrative and management staff) as well as economic, management, and medical students.

Also, the analysis of decision making yields some interesting findings. Hospital management games have a different game foci regarding decision making resulting from their differing emphasis on resource, process, and/or financial management. Consequently, three game categories for decision making were identified: 1) resource and financial management focused games, 2) resource and process management focused games, and 3) resource, process, and financial management focused games. Games of the first category treat structure quality as a main factor determining the outcome. The hospital processes are modeled as black-boxes using equation-based techniques. All games in this group neglect queuing of patient services and do not account for patient and staff scheduling. The majority of the games reviewed fall into this category. Games of the second category use process quality as an additional contributor to outcome quality. Since process management contains more operational decisions, it requires discrete event simulation for queuing of patients. Such games model the decisions in resource management by allowing for the planning of the availability of personnel and non-human resources, but restrict decisions pertaining to financial management to a minimum. Games of the third category focus on structure and process quality and account for reimbursement, therefore, discrete event simulation for modeling patient flows is needed.

The findings also illustrate that the decision making process of participants forms the core of hospital management games. Participants make decisions with respect to resource, process, and/or financial management in all games reviewed. Resource management decisions in the games intend to simulate the importance of forecasting, developing, and controlling resources. It is the crucial role of resource management to combine capacity planning for human and non-human resources, service planning, and staff and non-staff resource allocation. A shortage of capacities, a lack of service planning, and a misallocation of resources slow down processes, prolong waiting periods for patients, increase staff workload, lower quality of treatment/care, and may therefore also increase costs. A certain amount of resources has to be available for emergency patients and/or unexpected events. The aim of process management decisions is the training for patient and staff scheduling. Patient scheduling issues comprise admission planning, care planning, queuing planning for services, and discharge planning. Scheduling strategies affect the number of patients admitted and discharged as well as the number of laboratory examinations, radiology examinations, and surgeries performed in a given period. Financial management decisions encompass efficient and effective planning with scarce financial resources, which is especially important in times of increasing expenditures and decreasing revenues. Successful financial management is highly dependent on appropriate resource management. For hospital management games, financial management decisions consist of decisions on cash outflows (e.g., equipment, buildings/rooms, financial investments) on the one hand and decisions on cash inflows (e.g., reimbursement, services charges, donations, revenues from financial investments) on the other.

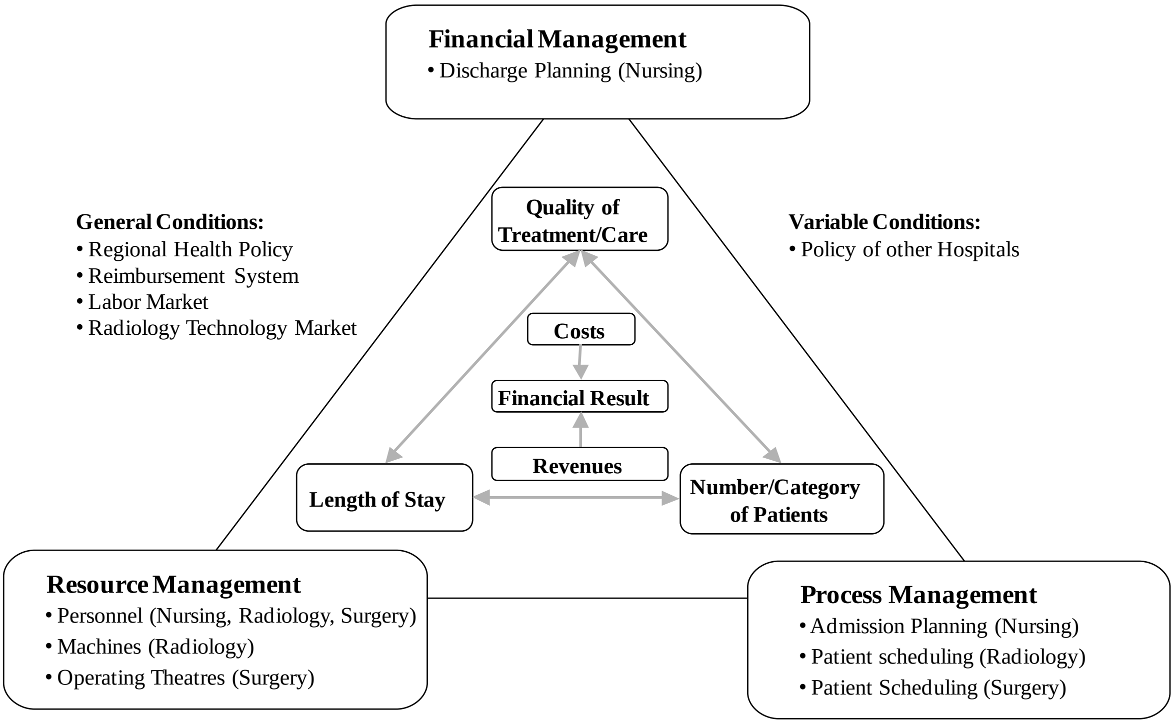
The investigation of the OR techniques highlights that they are used to model both the internal and external environment of hospitals and to facilitate the decision making of the players. In the games reviewed, the following OR techniques were applied: agency/game theory, decision making theory, system dynamics, discrete-event simulation, assignment problem, priority rules, staff scheduling, stock-keeping, forecasting, data envelopment analysis, and technology assessment.

The conclusions of the analysis reveal that hospital management games and OR have gained importance in better planning the use of scarce resources in times of tight budgets, growing health care demand, and increasing technology costs. They enable health care policy makers, health care professionals, hospital staff, and students to study the real-world environment in an artificial game setting. Regarding the game focus, different hospital management games place different emphases on resource, process, and/or financial management.

Based on A1 as well as A3, paper A2 then deals directly with the main aspiration of my dissertation by developing the concept of the business logic of an internet-based hospital management game, which was given the name of *COREmain hospital*. It illustrates the economic and organizational decision making processes in a hospital by using discrete event simulation. *COREmain hospital* simulates a region with up to six hospitals treating patients in different disease categories. Within this region, hospitals compete against each other for inpatients depending on the general and variable conditions of the game. The game host sets up the general conditions by defining the health policy of the region, the inpatient reimbursement system, the labor market situation for medical staff, and the radiology technologies available at the beginning of the game. The hospital player groups then determine the variable conditions by defining the mission of their hospital at the outset of the game and again after six periods. Each hospital has up to 500 beds and consists of four departments: management, nursing, radiology, and surgery. When playing the game, each player is responsible for one department in one hospital.

The defining feature of *COREmain hospital* is to teach players about the interdependencies of resource, process, and financial management in the management, nursing, radiology, and surgery departments. The players manage resources such as personnel in the nursing, radiology, and surgery departments, machines in the radiology department, and operating rooms in the surgery department. They also plan processes like admissions in the management department and patient scheduling in radiology and surgery and control finances by determining the discharge policy of patients. All decisions of the players mutually influence each other and are affected by the general and variable conditions (cf. Figure 2). For example, the more resources that are available, the more patients can be admitted and the shorter the waiting times in radiology and surgery. Also, the better processes are coordinated, the earlier patients can be discharged.

Figure 2: Resource, process, and financial management of the game



Source: Rauner et al. 2008 (A2).

The uniqueness of *COREmain hospital* lies, in addition to the internet-based framework and the combination of resource, process, and financial management, in the fact that different inpatient reimbursement systems are considered. It allows for simulating four different reimbursement systems: 1) inpatient days independent of diagnosis and treatment, 2) Diagnosis-related Groups (DRGs) with unlimited budget, 3) DRGs with limited budget, and 4) global budgets. This feature of the game enables players to learn about the impact of the length of stay on the revenue of a hospital, subject to the type of reimbursement system. A reimbursement system based on inpatient days is dependent on the inpatients' length of stay. In such a system an extended stay is highly compensated. For this reason, there is a tendency in this case to discharge patients with expensive treatments later as compared to patients with cheaper treatments since higher patient costs can only be covered through a more lengthy stay. In contrast, a reimbursement system based on DRGs is generally independent of the inpatients' length of stay because a longer stay is only partly compensated. A reimbursement system based on a global budget completely neglects the inpatient length of stay.

The game is able to simulate up to 15 operative (e.g., appendectomy, hysterectomy, hip replacement) and non-operative (e.g., myocardial infarction, stroke) patient categories covering a wide range of medical disciplines in a hospital. All treatment paths are based on real-life-data containing information on the required radiology examinations and durations as well as on operative cases with the kind of surgery and duration needed. In addition, the patient paths include the minimum medically-induced waiting time for radiology examinations and surgeries, the minimal and medically-recommended length of stay as well as the nursing category, which vary with different states of the path.

Furthermore, the game calculates the main costs of the nursing, radiology, and surgery departments. The nursing costs include staff costs as well as variable material costs per day. The radiology costs take account of staff costs, fixed and variable material costs as well as deduction costs for radiology machines. The surgery costs cover staff costs, fixed and variable material costs as well as deduction costs for operating rooms.

The collection of real-life-data for the treatment paths and cost categories was a key prerequesite for developing *COREmain hospital*. The data collection was chiefly supported by *Bundesministerium für Gesundheit*, *Hauptverband der österreichischen Sozialversicherungsträger*, and *Krankenhaus der Barmherzigen Schwestern Vienna*. The *Hauptverband der österreichischen Sozialversicherungsträger* supplied the total number of cases per patient category treated in all Austrian hospitals. These data enabled the identification of the 15 most important operative and non-operative patient categories. The *Bundesministerium für Gesundheit* made reimbursement data for these selected patient categories available. The *Krankenhaus der Barmherzigen Schwestern Vienna* provided individual patient data to derive patient pathways of the selected patient categories. Furthermore, they supplied cost and financial statement data.

The performance of each hospital is evaluated at the end of each period based on the following pre-selected performance measures: quality of medical care, staff satisfaction, patient satisfaction, occupancy rate, length of stay, number of patients discharged, regional market share, severity index, dismissal rate, surplus, costs and – in case of a DRG-based reimbursement system – number of DRG-points, not-discovered DRG-creep, and value per DRG-point . The winner of the game is the hospital player group which performed best both in fulfilling their own hospital mission targets and the regional health policy targets over the 12 month periods.

4. Conclusions

In recent years, the high and growing costs of health care systems owing to technological innovations, ageing patients, and an increasing number of demanding health care consumers have become a vital and pressing issue in Western countries. In the EU-15 countries, between 2000 and 2008, total expenditures on health care (expressed as a share of GDP) rose from 8.7 percent to 9.8 percent, which translates into an increase of 1.1 percentage points within eight years. Amounting to costs of 13.4 percent of GDP in 2000 and 16 percent in 2008, the US health care system is confronted with even higher expenses and yet more drastic growth (OECD 2010). Consequently, strategies both for containing health care costs and increasing this sector's efficiency are the focal points in political discussions in most Western economies.

To increase the efficiency of hospitals, which in Europe are responsible for more than one third of health care expenditures, careful planning and coordination of resource, process, and financial management is imperative. A precondition for effective and efficient hospital management is a detailed understanding of the interdependencies in the hospital decision making processes. This fact brought about the development of hospital management games with the goal of training hospital staff and health care decision makers. The first such game emerged in the late 1970s. Since then, hospital management games have been a proven training tool for decision making in hospitals. They play a key role for educating students, hospital staff, and health care policy makers to best plan the use of scarce resources under consideration of both the internal and external environment.

In general, hospital management games help players better understand the reality by means of a simplified simulation. The players can study the effects of repeating decisions as well as of choosing alternative ones. Unlike in the real world setting, wrong decisions by players bear no real consequences. Ideally, players connect the skills and knowledge developed in a hospital management game and transfer them to real-life situations. For example, a hospital manger can use the newly gained insights to improve the resource, process, and financial management in his/her hospital which could lead to an increase in the hospital's efficiency. Whether or not such changes would then have led to greater efficiency can then once again be determined with the use of DEA-method.

COREmain hospital, for which, within the framework of my dissertation, I was responsible for the development of the business logic, is a promising tool for training more efficient decision making in hospitals. Its uniqueness consists of the internet-based framework, the combination of resource, process, and financial management in a set-up with interchangeable reimbursement systems and environmental conditions. *COREmain hospital* illustrates the economic and organizational decision making processes in a hospital and is designed to be played by students, hospital staff, and health care decision makers. It seeks not only to help students and hospital staff understand decision making in complex situations, but also to illustrate to policy makers how potential changes in regulation impact hospital decision making and outcomes.

My scientific contribution to the field of health care lies in the preparation of the concept of *COREmain hospital*, a new and unique hospital management game.

5. Literature

Charnes A., Cooper W.W., Rhodes E. (1978): Measuring the efficiency of decision making units. European Journal of Operational Research 2:429-444.

Charnes A., Cooper W.W., Lewin A.Y., Seiford L.M. (1994): Data Envelopment Analysis: Theory, Methodology, and Applications. Kluwer Academic Publishers.

OECD (2010): OECD Health Data 2010.

Section 2: Papers

A1

CEJOR (2010) 18:567–591
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ORIGINAL PAPER

Hospital management games: a taxonomy and extensive review

Markus Kraus · Marion S. Rauner · Sigrun Schwarz

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Abstract Hospital management games have gained importance in better planning for scarce resources in times of growing health care demand and increasing technology costs. We classify and investigate the main characteristics of these games from an Operations Research (OR) perspective. Hospital management games model the complex decision making process of internal resource, process, and financial management all influenced by the external hospital environment (e.g., purchasing markets, job markets, legal/political conditions, competition) and simulate situations of the real world. We also highlight the potential of these games for teaching OR in the classroom. Experiencing the advantages of OR may reduce the reservations policy makers have and could make them increasingly open to promoting OR applications in practice. We also disclose potential for new applications.

Keywords Hospital management games · Decision making · Operations research techniques

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1 Introduction

"A game is a set of activities involving one or more players. It has goals, constraints, payoffs, and consequences. A game is rule-guided and artificial in some respects. Finally, a game involves some aspects of competition, even if that competition is with oneself (Dempsey et al. 2002)."

Gaming has a long history. War games were already played in China and India around 3000 BC and 1000 BC, respectively. For example, in the 17th and 18th centuries war chess games (e.g., KING'S GAME, NEW KRIEGSSPIEL, WAR CHESS) became more serious and complex (Lane 1995). In the latter part of the 19th century, the so-called rigid war games employed charts, tables, and calculations to, for instance, simulate troop movements. Random effects were included by using dice. During World War II, war business games gained popularity (e.g., BARBAROSSA, SEA LION, TOTAL WAR IN PASIFIC) (Rohn 1995). At the same time, Operations Research (OR) emerged in the United Kingdom to optimize war-related strategic and logistic problems in air defense, antisubmarine warfare, and bombing (Rau 2005).

Recognizing the potential for management, numerous games for general management, accounting, finance, marketing, as well as production and logistics have been developed since the 1950's (Faria and Wellington 2004; Kibbee et al. 1961; Watson and Blackstone 1981). Early popular games include: (1) TOP MANAGEMENT DECISION SIMULATION, (2) TOP MANAGEMENT DECISION GAME, (3) BUSINESS MANAGEMENT GAME, and (4) THE CARNEGIE TECH MANAGEMENT GAME.

Playing management games offers many advantages (Bochennek et al. 2007; Brandl et al. 2010; Dieleman and Huisingh 2006; Faria and Dickinson 1994) such as that, for example, different management theories and fields can be illustrated. In the artificial setting of a game, players can study the process and effects of choosing among decision making alternatives. Decisions can be repeated and feedback is given immediately. Wrong decisions are not always really crucial. Playing games helps develop a shared view of a problem, facilitates mutual understanding, and also enhances team-building and team-work within a group of participants with different cultural, academic, and social backgrounds. Internet-mediated games were instrumental in enriching interaction and communication across time and over distance and provided an open gateway for entering into a game (Dasgupta 2003).

However, some disadvantages of management games have to be taken into account as well (Lane 1995). Goals and learning effects are often not sufficiently clear to the participants. The determination of the optimal level of complexity and the compression of time are difficult but necessary to simulate a simplified model of reality. Briefing and debriefing are sometimes neglected. Thus, a systematic design process, a validity check by experts and further players, and extensive testing are crucial (Peters et al. 1998).

As health care expenditures consume at least 10% of the gross national product in many industrialized countries, health care games emerged in this area in the late 1960's (Panosch 2008). They are applied in two areas: medical education and health care management.

Medical education games for training and teaching students and/or staff how to best treat a patient emerged during the 1970's (Blakely et al. 2009; Bochennek et al. 2007; Panosch 2008). Such games have high potential for decreasing medical errors, facilitating open exchange in training situations, and improving patient safety. Some of the most well-known games include: (1) GERIATRIX—a role-playing game to illustrate the complexity of geriatric patient care (Hoffman et al. 1985); (2) the LACTATION GAME—a quiz game to provide knowledge about breast feeding (Elder and Gregory 1996); (3) the PAIN GAME—a board game to teach pain assessment and management to nurses (Morton and Tarvin 2001); and (4) the PEDIATRIC BOARD GAME—a board game to transmit paediatric knowledge (Ogershok and Cottrell 2004).

Since the 1980's, human patient simulators have been used as a key teaching tool for medical education (Bradley 2006). Competency in the application of knowledge and technical skills of medical staff can be measured without harming a real patient (Nehring et al. 2001). For example, the ANESTHESIA CRISES RESOURCE MANAGEMENT TOOL uses a patient simulator to train anaesthesiologists interacting in teams and managing crises (Gaba et al. 2001).

The first health care management games appeared during the 1970's. These games gained importance due to rising health care costs resulting from expensive technologies, ageing patients, and an increasing number of demanding patients.

Two games that investigate setting up and running medical practices are noteworthy. Reisman et al. (1977) developed a game for dentists to plan their practice, while Mulcahy et al. (1981) provide a game which enables prospective and practicing physicians to learn decision making for medical practice administration.

Particularly, hospital games play a key role for educating students, health care staff, health care professionals, and health care policy makers to best plan in the face of scarce resources. This is why we decided to investigate such games in more detail. Players learn to consider both the internal and external environment of a hospital for decision making. The main issues are put forward in Fig. 1.

Purchasing markets, job markets, legal/political conditions, and competition among hospitals form the external environment of a hospital. Within the context of this external framework as well as the internal conditions, players make decisions concerning resource, process, and financial management. Efficient and effective resource and process management in the situation of a particular inpatient reimbursement system impact on the number/category of inpatients as well as their length of stay, quality of treatment, and care provided. This also affects liquidity which consists of cash inflows (e.g., reimbursement, service charges, donations, revenues from financial investments, raising of external financial capital) and cash outflows (e.g., assets, expenditures). In health care, decision makers have to balance economy, efficiency, effectiveness, and equity. In the next section, we discuss and classify in detail the main hospital management games based on this framework for teaching and policy decision making.

2 Taxonomy for hospital management games

For our literature review on hospital management games, we searched the following databases: Blackwell Synergy, EconLit, Jstor, ProQuest, PubMed, ScienceDirect,

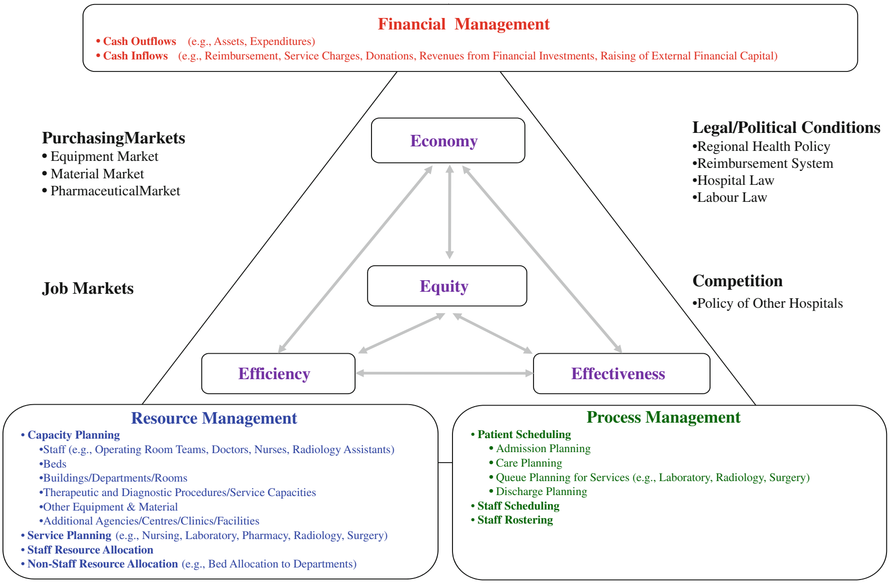

Fig. 1 Decision making in a hospital depending on the external environment

and SSCI. Initial key words include "games," "games AND health care," and "games AND hospitals." We identified 13 hospital management games (Cromwell et al. 1998; Feldstein 1986; Flessa 2001; Hans and Nieberg 2007; Hofweber 1987; Knotts et al. 1982, 1989; Meredith 1978; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001) as well as their follow-up games: (1) KLIMA (Meyer 1982) that was replaced by KLIMA FORTE (Schwandt 1998) and (2) ASTERIKS (Schwarz 1992) that was replaced by PRIMA KLINIK (Warnke 2001) (cf. Table 1). We excluded games described only in technical reports and proceedings due to limited data availability or games developed by commercial organizations.

An early classification of management games includes the distinction of general versus functional games, stochastic versus deterministic games, multi-period versus single-period games, fixed-goal versus individual-goal systems, competing versus non-competing game situation, as well as online and offline games (Koller 1974). Some hospital management games (e.g., Flessa 2001; Meyer 1982; Schwandt 1998; Schwarz 1992) use this classification to describe their own game. Schweinhammer (2008) investigates departments and functions, reimbursement systems, and rough decision categories involved in the decision making in certain hospital management games (Hofweber 1987; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001). Panosch (2008) expands on previous classifications of hospital management games by adding a few more games (e.g., Cromwell et al. 1998; Flessa 2001; Hans and Nieberg 2007; Knotts et al. 1982, 1989), further rough decision categories, and a discussion on the game reports provided to the players.

We extend these classifications found in the literature by providing a unique classification of the precise decisions making of players in resource, process, and

Table 1 Summary of the 13 hospital management games reviewed

Reference	Name of the game	Authors	Year	Country
Cromwell et al. (1998)	DRAGON	Cromwell et al.	1998	Australia
Feldstein (1986)	STRATEGIC PLANNING GAME	Feldstein	1986	USA
Flessa (2001)	MOSHI	Flessa	2001	Germany/Tansania
Hans and Nieberg (2007)	OPERATING ROOM MANAGER GAME	Hans and Nieberg	2007	Netherlands
Hofweber (1987)	ARKTIS	Hofweber	1987	Germany
Knotts et al. (1982)	HOSPSIM	Knotts et al.	1982	USA
Knotts et al. (1989)	CHESS	Knotts et al.	1989	USA
Meredith (1978)	THE HOSPITAL GAME	Meredith	1978	USA
Meyer (1982)	KLIMA	Meyer	1982	Germany
Rauner et al. (2008)	COREMAIN HOSPITAL	Rauner et al.	2008	Austria
Schwandt (1998)	KLIMA FORTE	Schwandt	1998	Germany
Schwarz (1992)	ASTERIKS	Schwarz	1992	Germany
Warnke (2001)	PRIMA KLINIK	Warnke	2001	Germany

financial management by describing the OR techniques used. We classify hospital games according to the following criteria: (1) general classification attributes (sub-section 2.1), (2) application area (sub-section 2.2), (3) target player groups (sub-section 2.3), (4) decision making (sub-section 2.4), and (5) OR techniques used (sub-section 2.5).

2.1 General classification attributes

First, we discuss general attributes of hospital management games: (1) generality, (2) complexity, (3) communication medium, (4) competition, and (5) gaming process.

Regarding generality, hospital management games can be either general or functional. General games focus on playing the entire or main functions of a hospital (Cromwell et al. 1998; Feldstein 1986; Flessa 2001; Knotts et al. 1982, 1989; Meredith 1978; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992), whereas functional games are applied to special hospital departments or functions (Hans and Nieberg 2007; Hofweber 1987). PRIMA KLINIK (Warnke 2001) can be both played as a general or a functional game; in the latter players are only responsible for running either the department of nursing, radiology, or surgery. As examples for functional games, OPERATING ROOM MANAGER GAME (Hans and Nieberg 2007) illustrates operating room management, while ARKTIS (Hofweber 1987) models drug supply in a pharmacy department of a hospital.

In a non-complex game situation, only a very limited number of decisions are available and effects of decisions made can be determined well. Typical for management games is that the interdependencies of various actions cannot be easily foreseen. Various random events and stochastic effects may influence the results as well. Thus, players experience random game situations and learn which of their decisions are most critical for pursuing health policy objectives. All games reviewed are characterized by such a, rather complex, game situation. One of the highest complexities is shown by COREMAIN HOSPITAL (Rauner et al. 2008).

In early times, games were sometimes played offline and an operator entered the data on the decisions made by the participants into a computer at the end of each round (Feldstein 1986; Knotts et al. 1982, 1989; Meredith 1978). Today, participants normally enter their data online (Cromwell et al. 1998; Flessa 2001; Hans and Nieberg 2007; Hofweber 1987; Meyer 1982; Schwandt 1998; Schwarz 1992; Warnke 2001). The only internet-based hospital game, COREMAIN HOSPITAL (Rauner et al. 2008), can be played either centralized in one room (e.g., PC laboratory) or decentralized in different locations to overcome locational and temporal restrictions in which the players cannot communicate face to face (e.g., different PC laboratories, PCs at work or home).

In hospital management games, the players representing one hospital compete either directly (Knotts et al. 1982, 1989; Meredith 1978; Rauner et al. 2008) or indirectly (Cromwell et al. 1998; Feldstein 1986; Flessa 2001; Hans and Nieberg 2007; Hofweber 1987; Meyer 1982; Schwandt 1998; Schwarz 1992; Warnke 2001) with the players representing other hospitals. In the case of indirect competition, players are only evaluated by their performance regarding predefined criteria, while in the situation of direct competition players' decisions affect performance of other hospitals as in a real-world environment. For example in HOSPSIM (Knotts et al. 1982) and CHESS (Knotts et al. 1989), the participants compete for physicians who are attracted to working in hospitals with higher quality of care. In COREMAIN HOSPITAL (Rauner et al. 2008), the hospital players compete both for budget and patients within a reimbursement system of limited regional budgets.

The gaming process involves the considerations of a game host, the decision making of the players, and the evaluation of results after each period/round. Several games (e.g., Rauner et al. 2008; Schwarz 1992) have a game host who can vary both internal conditions (e.g., number of beds, number of operating rooms, number and type of radiology machines) and external conditions (e.g., reimbursement system, purchasing markets, job markets).

For a number of multiple periods/rounds, players can make decisions on different levels (e.g., strategic, tactical, operational) and in different areas pertaining to resource, process, and financial management. The length of a period varies from years (Hans and Nieberg 2007; Meredith 1978), quarters (Cromwell et al. 1998; Flessa 2001; Knotts et al. 1982, 1989; Meyer 1982; Schwandt 1998), months (Hofweber 1987; Rauner et al. 2008), 2 weeks (Schwarz 1992), 1 week (Hans and Nieberg 2007), to 1 day (Hans and Nieberg 2007; Warnke 2001). The more operational a hospital game is, the shorter the length of the periods. For example, week-oriented games, such as ASTERIKS (Schwarz 1992), focus on operational staff and patient scheduling issues. In the OPERATING ROOM MANAGER GAME (Hans and Nieberg 2007), three management rounds are played using different periods of one year, one week and one day. Each round represents a managerial level from the top (strategic/tactical) level (task: capacity dimensioning and capacity allocation to specialities), over the intermediate (tactical/operational) (task: scheduling elective patients) to the bottom (operational) level (task: simulation of online scheduling). This game can be used perfectly to teach operating room scheduling techniques (Cardoen et al. 2009; Velásquez Flores 2008).

The evaluation of results usually takes place after each period/round (with the exception of Feldstein (1986)) so that the players can take the opportunity to improve their decision making with the new information gained. The players receive reports on performance measures in resource, process, and financial management. Furthermore, hospital mission-related performance measures (e.g., quality of care, staff satisfaction) are often provided to the players. In two games (Hans and Nieberg 2007; Schwandt 1998), players or the game host evaluate overall results of the hospitals by Data Envelopment Analysis (DEA).

2.2 Application area

The main application area for hospital management games is teaching. However, they can also be used for policy purposes to illustrate how regulations impact decision making and outcomes. Some games are also developed for improving research. For example, Rauner et al. (2008) intend to investigate COREMAIN HOSPITAL in detail by experimental economics with both teaching (e.g., game situation) and policy purposes (e.g., impact of reimbursement systems). By analyzing reimbursement systems, the basics of principle-agent theory can be explained to the players (Zweifel et al. 2005).

2.3 Target player groups

Hospital management games are developed for different target player groups such as health care leaders/policy makers, health care practitioners/professionals, hospitals staff (e.g., doctors, nurses, medical staff, technical staff, administrative, and management staff), and students of different majors (e.g., management/economics, medicine, and nursing). All games are designed to be played by hospital staff as well as economics, management, and medical students (cf. Table 2). Strategic-oriented general games are more suitable for health care leaders/policy makers and health care practitioners/professionals such as in Feldstein (1986), Meyer (1982), Rauner et al. (2008), Schwandt (1998), while functional games might be of special interest for hospital staff of a particular departments (Hans and Nieberg 2007; Hofweber 1987; Warnke 2001).

2.4 Decision making

Regarding decision making, hospital management games have a different game focus due to their emphasis on resource, process, and/or financial management in the context of the external hospital environment (e.g., legal/political conditions, competition, purchasing markets, and job markets). This determines the simulation language

Table 2 Target player groups

	Cromwell et al. (1998)	Feldstein (1986)	Flessa (2001)	Hans and Nieberg (2007)	Hofweber (1987)	Knotts et al. (1982, 1989)	Meredith (1978)	Meyer (1982), Schwandt (1998)	Rauner et al. (2008)	Schwarz (1992), Warnke (2001)
Health care leaders/policy makers		X			X				X	
Health care practitioners/professionals		X		X				X	X	
Hospital staff										
Doctors	X	X						X	X	X
Nurses	X	X					X	X	X	X
Other medical staff	X	X			X				X	
Technical staff	X								X	
Administrative and management staff	X	X				X	X	X	X	X
Students										
Management/Economics		X	X	X	X		X	X	X	X
Medicine							X	X	X	X
Nursing							X	X	X	X
Pharmacy					X					

(Brennan et al. 2006; Cooper et al. 2007; Pidd 2004) and other OR techniques used (Ozcan 2009). In several games, players can define the mission of the hospital at the beginning of the game, while players decide on resource, process, and/or financial management during all games.

2.4.1 Game focus

We distinguish three hospital management game categories for decision making: (1) resource and financial management focused games (Feldstein 1986; Flessa 2001; Hofweber 1987; Knotts et al. 1982, 1989; Meredith 1978; Meyer 1982; Schwandt 1998), (2) resource and process management focused games (Hans and Nieberg 2007; Schwarz 1992; Warnke 2001), and (3) resource, process, and financial management focused games (Cromwell et al. 1998; Rauner et al. 2008). Early games contain few player decisions due to computational limitations. The more recent the games, the more decision requirements are generally included.

Group 1: Resource and financial management focused games define structure quality as a main factor that determines the outcome. The hospital processes are modeled as a black-box using equation-based techniques neglecting queuing of patients for services (Feldstein 1986; Hofweber 1987; Knotts et al. 1982, 1989; Meredith 1978; Meyer 1982; Schwandt 1998). All games of this group do not account for staff scheduling and only (Feldstein 1986; Flessa 2001; Meyer 1982; Schwandt 1998) include for admission and/or discharge planning of patients. Early general hospital management games focus on resource and financial management with a few strategic/tactical management decisions (e.g., HOSPSIM (Knotts et al. 1982) for US, CHESS (Knotts et al. 1989) for Canada, and THE HOSPITAL GAME (Meredith 1978) for US). The STRATEGIC PLANNING GAME (Feldstein 1986) emphasizes strategic issues and thus only admission planning is included for investigating financial consequences. KLIMA (Meyer 1982) and KLIMA FORTE (Schwandt 1998) can be categorized as general hospital management games on the strategic/tactical level. Thus, process management is of less importance. Players plan resources and should detect bottlenecks. Using cause-effect-curves, quality and costs of treatment/care of patients are calculated. MOSHI (Flessa 2001) is characterized by its special focus on training health care managers to efficiently and effectively allocate key financial resources of a clerical hospital in Tanzania. It illustrates the impact of the HIV/AIDS epidemic on scarce hospital resources and even models this epidemic by system dynamics. An example for a functional hospital game is ARKTIS (Hofweber 1987) which models purchasing strategies in pharmacies.

Group 2: Resource and process management focused games consider process quality as an additional contribution to outcome quality. As process management contains more operational decisions, it requires discrete event simulation for queuing of patients (Hans and Nieberg 2007; Schwarz 1992; Warnke 2001). These games model resource management to plan the availability of human and non-human resources. To limit the number of decisions and guarantee playability in a training course of a few days, such games restrict decisions in financial management to a minimum. The general hospital game ASTERIKS (Schwarz 1992) places emphasis on operational process management with a special focus on queuing of patients and staff scheduling, not including staff rostering. This demands for discrete event simulation. Only key, crucial costs of resources are considered, while all other costs are calculated by a simple black-box algorithm. PRIMA KLINIK (Warnke 2001) is a successor of ASTERIKS (Schwarz 1992), and in the former game players can be responsible for managing either single departments or an entire hospital with the advantage of harmonizing process management of all the departments involved. It uses discrete event simulation. The OPERATING ROOM MANAGER GAME (Hans and Nieberg 2007) belongs to the group of functional hospital games with a main focus on process management in operating rooms with few resource management decisions include considerations of overtime and only some financial investment decisions. From strategic choices on capacities for an upcoming year to online planning of actual surgeries in each operating room, many functions of managing a surgery department can be experienced by the players. This again calls for discrete event simulation.

Group 3: Resource, process, and financial management focused games focus on structure, process quality, and account for reimbursement (Cromwell et al. 1998; Rauner et al. 2008). As a result, discrete event simulation for modeling patient flows is needed as in the rather simple general hospital management game DRAGON (Cromwell et al. 1998). For financial management, admission and discharge planning of inpatients together with efficient and effective resource and process management are of high importance in COREMAIN HOSPITAL (Rauner et al. 2008). The game accounts for different reimbursement systems, which makes the game unique and useable in countries with differing reimbursement systems.

2.4.2 Hospital mission

General strategic hospital goals can be defined and prioritized in many games (Flessa 2001; Hofweber 1987; Meredith 1978; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001) depending on the game focus, mostly before periodic decision making starts. This game feature is essential because in practice decision makers of hospitals also have to define their mission (e.g., quality of treatment/care, patient satisfaction, occupancy rate, dismissal rate, length of stay, costs, liquidity). The mission set often remains constant for the whole duration of the game. Thus, players have to account for the mission in the entire decision making process. It is only in COREMAIN HOSPITAL (Rauner et al. 2008) that the hospitals' mission can be changed once.

2.4.3 Resource management

Explanation of forecasting, developing, and controlling resources (Ozcan 2009) plays a key role in hospital management games. All games account for resource management decisions which can be categorized threefold: (1) capacity planning, (2) service planning, and (3) staff and non-staff resource allocation.

2.4.3.1. Capacity planning All hospital management games illustrate the crucial role of human and non-human capacity management. A shortage of capacities slows down processes, prolongs waiting for patients, increases the workload and stress of staff, lowers quality of treatment/care, and may therefore also increase costs. Enough resources have to be available especially for emergency patients and/or unexpected events. Operations Research techniques support optimizing nurse scheduling (e.g., full-time/part time nurses) (Burke et al. 2004), queuing layout (e.g., single/multiple equipments/rooms) (Ozcan 2009; Pidd 2004; Vissers and Beech 2005), and stock-keeping (e.g., number of patients in beds) (Ozcan 2009; Pidd 2004; Vissers and Beech 2005).

In a hospital, the most precious and the most delicate resources are in fact human resources, because about two thirds of hospital operating costs result from payroll expenses. Most hospital management games provide for different staff groups such as medical doctors or nurses (Flessa 2001; Hofweber 1987; Knotts et al. 1982, 1989; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001) (cf. Table 3). Only four games (Cromwell et al. 1998; Feldstein 1986; Hans and Nieberg 2007; Meredith 1978) simulate an aggregated human resource planning process. For example, players of the OPERATING ROOM MANAGER GAME (Hans and Nieberg 2007) decide on the staffing of operating rooms, while players of THE HOSPITAL GAME (Meredith 1978) choose the staffing level of the entire hospital which is expressed in the number of patient days.

Players also determine staff overtime in five games (Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001). For example, in COREMAIN HOSPITAL (Rauner et al. 2008), KLIMA FORTE (Schwandt 1998), and PRIMA KLINIK (Warnke 2001) an excessive staff workload negatively influences quality of care.

The situation on job markets (e.g., shortage of nurses) and legal restrictions (e.g., notice period) affect human resource planning as well. In seven games (Flessa 2001; Hofweber 1987; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001), hired staff is available and fired staff is dismissed after a certain delay.

In the majority of the games, non-human resources are managed by the players (e.g., beds, equipment, building/rooms, therapeutic and diagnostic procedures/service capacities, additional agencies/centers/clinics/facilities) as shown in Table 4.

Hospital management games aim at training participants in decision making for different hospital types and sizes. The number of hospital beds is normally predefined, except in Cromwell et al. (1998), Feldstein (1986), Knotts et al. (1982), Knotts et al. (1989), Meredith (1978). Emergency beds are only planned in four games (Meredith 1978; Meyer 1982; Schwandt 1998; Schwarz 1992).

Furthermore, several games illustrate consequences of decisions on equipment (Hofweber 1987; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001) and building/room planning (Feldstein 1986; Hans and Nieberg 2007; Rauner et al. 2008; Warnke 2001). In DRAGON (Cromwell et al. 1998), participants can open a pre-admission clinic, while in the STRATEGIC PLANNING GAME (Feldstein 1986) skilled nursing facilities, freestanding ambulatory care clinics, residential senior citizen retirement centres, and home health agencies can be constructed as inpatient satellite facilities.

For example, in COREMAIN HOSPITAL (Rauner et al. 2008) and PRIMA KLINIK (Warnke 2001), players can purchase or close down radiology machines to cope with

Table 3 Capacity planning for human resources

Staff	Cromwell et al. (1998), Feldstein (1986), Hans and Nieberg (2007), Meredith (1978)	Flessa (2001)	Hofweber (1987)	Knotts et al. (1982)	Knotts et al. (1989)	Meyer (1982)	Rauner et al. (2008)	Schwandt (1998)	Schwarz (1992)	Warnke (2001)
(General) staff	X	X								
Medical staff				X	X					
Ancillary/auxiliary staff		X			X					
Operating room teams							X		X	
Doctors		X								X
Assistant doctors						X		X		X
Nurses		X				X	X	X	X	X
Charge nurses						X				
Nursing students						X				
Nursing service hours				X	X					
Laboratory assistants									X	
Medical assistants		X								
Pharmacists			X							
Pharmaceutical assistants			X							
Pharmaceutical aids			X							
Radiology assistants							X		X	X

Table 4 Capacity planning for non-human resources

	Cromwell et al. (1998)	Feldstein (1986)	Hans and Nieberg (2007)	Hofweber (1987)	Knotts et al. (1982, 1989)	Meredith (1978)	Meyer (1982), Schwandt (1998)	Rauner et al. (2008)	Schwarz (1992)	Warnke (2001)
Beds										
No. of beds	X	X			X	X				
No. of emergency beds						X	X		X	
Equipment										
No. of computer systems				X						
No. of diagnostic devices							X			
No. of laboratory machines							X		X	
No. of pharmaceutical machines				X						
No. of radiology machines							X	X	X	X
Buildings/rooms										
No. of physicians' office buildings		X								
No. of radiology rooms										X
No. of operating rooms			X					X		X
Therapeutic and diagnostic procedures/service capacities					X					
Additional agencies/centers/clinics/facilities	X	X				X				

Table 5 Service planning

Service planning	Hans and Nieberg (2007)	Hofweber (1987)	Meyer (1982), Schwandt (1998)	Rauner et al. (2008), Warnke (2001)	Schwarz (1992)
Laboratory department planning					X
Nursing department planning			X		X
Operating room planning	X			X	X
Pharmacy department planning		X			
Radiology room planning				X	X

the radiology's department workload. In COREMAIN HOSPITAL (Rauner et al. 2008) players can choose among different technologies and conduct technology assessment (cf. Gold et al. 1996). KLIMA (Meyer 1982), KLIMA FORTE (Schwandt 1998), and ASTERIKS (Schwarz 1992) allow for investing in additional laboratory and radiology machines. In OPERATING ROOM MANAGER GAME (Hans and Nieberg 2007), COREMAIN HOSPITAL (Rauner et al. 2008), and PRIMA KLINIK (Warnke 2001), players also decide on opening or closing operating rooms.

2.4.3.2. Service planning After deciding on human and non-human resource capacities, players work out service planning. They determine opening hours for departments and emergency capacities (cf. Table 5). Three games (Meyer 1982; Schwandt 1998; Schwarz 1992) allow for the blockage a certain percentage of bed capacity/a certain number of beds for emergency patients. In four games (Hans and Nieberg 2007; Rauner et al. 2008; Schwarz 1992; Warnke 2001), players can reserve one operating room for emergency patients only. Players of the OPERATING ROOM MANAGER GAME (Hans and Nieberg 2007) assign the available operating room capacity to inpatient, outpatient, and emergency rooms.

2.4.3.3. Staff and non-staff resource allocation Mainly hospital management games with a focus on process management (groups 2 and 3) account for staff and non-staff resource allocation (cf. Table 6). This decision creates the pre-conditions for detailed process management, especially queuing of patients for radiology examinations/surgery as well as treatment, and staff scheduling.

For example, ASTERIKS (Schwarz 1992) focuses on resource allocation in the radiology department. Players assign radiology assistants and radiology machines to a predefined number of available radiology rooms. In the OPERATING ROOM MANAGER GAME (Hans and Nieberg 2007), participants allocate inpatient operating room capacity to specializations. PRIMA KLINK (Warnke 2001) incorporates resource allocation decisions in the radiology and surgery departments.

Table 6 Staff and non-staff resource allocation

	Hans and Nieberg (2007)	Hofweber (1987)	Rauner et al. (2008)	Schwandt (1998)	Schwarz (1992)	Warnke (2001)
Staff resource allocation						
Operating room teams			X			
Pharmacists		X				
Pharmaceutical assistants		X				
Pharmaceutical aids		X				
Radiology assistants					X	
Non-staff resource allocation						
Bed allocation to specialties				X		
Inpatient operating room allocation to specialties	X					X
Radiology machines allocation to radiology rooms					X	X

2.4.4 Process management

The hospital management games of groups 2 and 3 (Cromwell et al. 1998; Hans and Nieberg 2007; Rauner et al. 2008; Schwarz 1992; Warnke 2001) focus on decisions regarding process management with the inclusion of resource management considerations (cf. Table 7). The games of group 1 either neglect patient scheduling (Hofweber 1987; Knotts et al. 1982, 1989; Meredith 1978) or only account for admission and/or discharge planning of patients (Feldstein 1986; Flessa 2001; Meyer 1982; Schwandt 1998) as they have a more general financial-management oriented focus. All games of group 1 (Feldstein 1986; Flessa 2001; Hofweber 1987; Knotts et al. 1982, 1989; Meredith 1978; Meyer 1982; Schwandt 1998) do not account for staff scheduling.

Admission and discharge planning play a key role in managing a hospital well and have to be adjusted with the availability of resources such as beds, operating room capacity, and staff capacity. However, hospital management might optimize reimbursement by choosing suitable admission and discharge strategies as explained in detail in the section on financial management. Through hospital games, agency/game theory can be taught using the example of hospital reimbursement systems (Zweifel et al. 2005). Players are responsible for admission planning in five games (Feldstein 1986; Flessa 2001; Rauner et al. 2008; Schwandt 1998; Schwarz 1992) and for discharge planning in three games (Meyer 1982; Rauner et al. 2008; Schwandt 1998). For example, in the case of full occupation players of MOSHI (Flessa 2001) can reject potential patients. Only in Rauner et al. (2008), Schwarz (1992) participants schedule admission of patients by using prioritizing rules.

Table 7 Patient and staff scheduling

	Cromwell et al. (1998), Hans and Nieberg (2007)	Feldstein (1986), Flessa (2001)	Meyer (1982)	Rauner et al. (2008)	Schwandt (1998)	Schwarz (1992)	Warnke (2001)
Patient scheduling							
Admission planning		X		X	X	X	
Care planning						X	X
Queue planning for services							
Laboratory department						X	
Radiology department				X		X	X
Surgery department	X			X		X	X
Discharge planning			X	X	X		
Staff scheduling							
Operating room teams				X		X	
Doctors							X
Assistant doctors							X
Nurses						X	X
Radiology assistants				X		X	

After the patient is admitted, care/treatment is planned in only two games of group 2 (Schwarz 1992; Warnke 2001). The queuing of patients for services (e.g., laboratory, radiology, surgery) is considered in games of group 2 and 3 (Cromwell et al. 1998; Hans and Nieberg 2007; Rauner et al. 2008; Schwarz 1992; Warnke 2001). For example, participants of Rauner et al. (2008), Schwarz (1992), Warnke (2001) study different queuing strategies for radiology patients. First, players define priority scheduling rules. Second, players determine the queuing type (one queue for each machine or one queue for each type of radiology examination). In the surgery department, players of Cromwell et al. (1998), Hans and Nieberg (2007), Rauner et al. (2008), Schwarz (1992), Warnke (2001) only choose suitable priority rules (e.g., patients with shortest surgery time first, patients with previously postponed surgery first). In this way, players learn the basics of general queuing theory (Winston and Goldberg 2003) and priority scheduling rules (Pinedo 2008).

Apart from patient scheduling, staff scheduling is another key aspect of process management in a hospital. Nurse scheduling has attracted a lot of attention in the scientific literature (Burke et al. 2004). However, only some of the games in group 2 and 3 included this essential decision making task. In two games (Schwarz 1992; Warnke 2001), participants develop a detailed work schedule for nurses. In addition, players of Rauner et al. (2008), Schwarz (1992) investigate different schedule strategies for operating room teams and radiology assistants.

2.4.5 Financial management

The third main target of hospital management games comprises efficient and effective planning of scarce financial resources and this is included in all three game groups with a different level of complexity. Successful financial management is highly dependent

Table 8 Planning cash outflow for assets

	Feldstein (1986)	Hans and Nieberg (2007)	Hofweber (1987)	Meredith (1978)	Meyer (1982), Schwandt (1998)	Rauner et al. (2008)	Schwarz (1992)	Warnke (2001)
Equipment								
Computer systems			X					
Diagnostic devices					X			
Laboratory machines					X		X	
Pharmaceutical machines			X					
Radiology machines					X	X	X	X
Buildings/rooms								
Physicians' office buildings	X							
Radiology rooms								X
Operating rooms		X				X		X
Financial investments	X			X				

on appropriate resource management. For hospital games, financial management decisions are twofold: (1) decisions on cash outflows and (2) decisions on cash inflows.

2.4.5.1. Cash outflows In the vast majority of the hospital games, players decide on cash outflows for assets and expenditures. Few games consider optimizing strategies for purchasing material or pharmaceuticals.

Planning cash outflows for assets (equipment, buildings/rooms, and financial investments) is incorporated in two-thirds of the games (cf. Table 8). To deal with the demand for radiology examinations, players can purchase additional radiology machines in Meyer (1982), Rauner et al. (2008), Schwandt (1998), Schwarz (1992), Warnke (2001) and diagnostic devices in Meyer (1982), Schwandt (1998). Laboratory machines can be bought in Meyer (1982), Schwandt (1998), Schwarz (1992). In ARKTIS (Hofweber 1987) players can also invest in computer systems and pharmaceutical machines. However, additional machines not only cause investment costs, but also running costs that burden the restricted hospital budget. Only players of THE STRATEGIC MANAGEMENT GAME (Feldstein 1986) can invest in physicians' office building and players of PRIMA KLINIK (Warnke 2001) can open an additional radiology room, whilst players of Hans and Nieberg (2007), Rauner et al. (2008), Warnke (2001) can build additional operating rooms.

Planning cash outflows for expenditures (cf. Table 9) is a major task in KLIMA FORTE (Schwandt 1998). In a couple of games (Knotts et al. 1982, 1989; Rauner et al. 2008; Schwandt 1998; Warnke 2001), participants plan the budget for staff education/qualification/training programs as well as for staff gratification/motivation strategies because well-educated and highly-motivated staff is vital for the quality of care. In five games (Cromwell et al. 1998; Feldstein 1986; Meyer 1982; Rauner et al. 2008; Schwandt 1998), players can purchase hospital market information including the information about competitors. In MOSHI (Flessa 2001), players determine the amount spent for medical material, can participate in a preventive maintenance program, and can spend financial resources on AIDS-prevention. THE HOSPITAL

Table 9 Planning cash outflow for expenditures

Expenditures	Cromwell et al. (1998)	Feldstein (1986)	Flessa (2001)	Knotts et al. (1982, 1989)	Meredith (1978)	Meyer (1982)	Rauner et al. (2008)	Schwandt (1998)	Warnke (2001)
AIDS-prevention			X						
Community survey					X				
Hospital certification								X	
Housekeeping				X					
Hygiene agent								X	
Library								X	
Kindergarten								X	
Maintenance				X					
Market data	X	X				X	X	X	
Material per inpatient bed day & specialty						X		X	
Medical material			X						
Paying back loans/mortgages					X				
Plant improvement		X							
Preventive maintenance program			X						
Private patients/services								X	
Promotion/public relations		X						X	
Research and development						X			
Staff education/qualification/training				X				X	
Staff gratification/motivation							X	X	X
Other expenditures		X							X

GAME (Meredith 1978) considers expenditures for paying back loans/mortgages. Further budget planning issues deal with the determination of expenditures for promotion in Feldstein (1986) and for housekeeping and maintenance in Knotts et al. (1982, 1989).

Three games allow for the planning of the purchasing strategy to reduce expenditures for materials and pharmaceuticals (Flessa 2001; Hofweber 1987; Meyer 1982). In MOSHI (Flessa 2001), all participants can jointly run a central pharmacy for drug supply in order to lower costs. Players of ARKTIS (Hofweber 1987) select suppliers and negotiate prices with pharmaceuticals. These are again game theory situations (Zweifel et al. 2005). In KLIMA (Meyer 1982), participants can choose whether or not (medical) materials should be purchased externally.

2.4.5.2. Cash inflows Cash inflow planning is a key issue for the financial management of hospitals and is thus included in about half of the games (cf. Table 10). The games in group 2 (Hans and Nieberg 2007; Schwarz 1992; Warnke 2001) neglect this issue as they focus on detailed scheduling. We distinguish the following: (1) reimbursement (2) service charges, (3) donations, (4) revenues from financial investments, and (5) the raising of external financial capital.

The insurance status of patients and the reimbursement systems of hospitals differ among countries (cf. Leidl 1998) which highly affect admission and discharge planning (cf. Rauner and Schaffhauser-Linzatti 2001, 2002; Leonard et al. 2003; Rauner et al. 2003; Schaffhauser-Linzatti et al. 2009). Consequently, hospital management games are mostly applicable to the country and its reimbursement system for which they have been developed. The only exception is COREMAIN HOSPITAL (Rauner et al. 2008) which accounts for the three main different reimbursement systems used worldwide (day-based reimbursement, DRG-based reimbursement, and global budgets).

For example, DRG-like reimbursement systems favor lucrative patient categories and force hospital management to discharge patients earlier than their day-based counterpart (cf. Leidl 1998). With the implementation of DRG systems in many European countries in the late 1990's, reimbursement-oriented hospital management games emerged (Cromwell et al. 1998; Rauner et al. 2008; Schwandt 1998).

In Rauner et al. (2008), Schwandt (1998), players can place higher priority on the admittance of lucrative patient categories. In three games (Meyer 1982; Rauner et al. 2008; Schwandt 1998), players also plan discharges. For example, in COREMAIN HOSPITAL (Rauner et al. 2008), players experience how the length of stay of patients influences reimbursement. In two games (Cromwell et al. 1998; Rauner et al. 2008), players can misqualify patients' DRG categories to increase revenue. However, a high misqualification rate might be discovered by a regulatory agency in COREMAIN HOSPITAL (Rauner et al. 2008). Then, players will have to pay a penalty as in reality. Again, here the basics of agency theory can be taught to students (Zweifel et al. 2005).

Cash inflows for reimbursement, services charges, and donations are found in few hospital management games. In the STRATEGIC PLANNING GAME (Feldstein 1986), the participants fix the charges for ambulatory care clinic visits, health care agency visits, and senior citizen retirement center rents. In MOSHI (Flessa 2001), participants determine the charge for inpatient bed days and can request dona-

Table 10 Cash inflows

	Cromwell et al. (1998)	Feldstein (1986)	Flessa (2001)	Meredith (1978)	Meyer (1982)	Rauner et al. (2008)	Schwandt (1998)
Reimbursement							
Patient insurance system							
Admission planning		X					
Price determination for not Medicaid-, Medicare-, BlueCross-reimbursed patients		X					
Price determination for private patients/services					X		X
Patient payment system							
Admission planning						X	X
Discharge planning					X	X	X
DRG-coding	X						
DRG-creep						X	
Service charges							
Charge determination for ambulatory care clinic visits		X					
Charge determination for health care agency visits		X					
Charge determination for inpatient bed days			X				
Rental charge determination for senior citizen retirement centers		X					
Charge determination for rooms				X			
Donations			X				
Revenues from financial investments		X		X			
Raising of external financial capital		X					

tions. The players of THE HOSPITAL GAME (Meredith 1978) set room rates which affect the demand of patients for hospital services. Only two games (Feldstein 1986; Meredith 1978) account for revenues from financial investments as mentioned earlier. In the STRATEGIC PLANNING GAME (Feldstein 1986), the raising of external financial capital can be planned by the players.

Table 11 OR techniques used in hospital management games

		Decision Making	OR Approach	Game
Internal Environment		**Resource Management**		
Internal Environment	Tactical/Operational Planning	Capacity Planning	Decision Making, Forecasting, Stock-keeping, System Dynamics, Technology Assessment	Cromwell et al. 1998; Feldstein 1986; Flessa 2001; Hans and Nieberg 2007; Hofweber 1987; Knotts et al 1982, 1989; Meredith 1978; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001
Internal Environment	Tactical/Operational Planning	Service Planning	Decision Making, Forecasting, Stock-keeping, System Dynamics	Hans and Nieberg 2007; Hofweber 1987; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001
Internal Environment	Tactical/Operational Planning	Human Allocation	Assignment Problem, System Dynamics	Hofweber 1987; Rauner et al. 2008; Schwarz 1992
Internal Environment	Tactical/Operational Planning	Non-human Allocation	Assignment Problem, System Dynamics	Hans and Nieberg 2007; Schwandt 1998; Schwarz 1992; Warnke 2001
Internal Environment		**Process Management**		
Internal Environment	Operational Planning	Patient Scheduling	Agency/Game Theory, Priority Rules, Simulation, System Dynamics Stock-keeping, Queuing Theory	Cromwell et al. 1998; Feldstein 1986; Flessa 2001; Hans and Nieberg 2007; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001
Internal Environment	Operational Planning	Staff Scheduling	Staff Scheduling, System Dynamics	Rauner et al. 2008; Schwarz 1992; Warnke 2001
Internal Environment		**Financial Management**		
Internal Environment	Strategic/Tactical Planning	***Cash Outflows***		
Internal Environment	Strategic/Tactical Planning	Assets	Agency/Game Theory, Decision Making, Forecasting, System Dynamics, Technology Assessment	Feldstein 1986; Hans and Nieberg 2007; Hofweber 1987; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001
Internal Environment	Strategic/Tactical Planning	Expenditures		Cromwell et al. 1998; Feldstein 1986; Flessa 2001; Hofweber 1987; Knotts et al 1982, 1989; Meredith 1978; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Warnke 2001
Internal Environment	Strategic/Tactical Planning	Purchase Planning for Expenditure Reduction		Flessa 2001; Hofweber 1987; Meyer 1982
Internal Environment	Strategic/Tactical Planning	***Cash Inflows***		
Internal Environment	Strategic/Tactical Planning	Reimbursement	Agency/Game Theory, Decision Making, Forecasting, System Dynamics	Cromwell et al. 1998; Feldstein 1986; Meyer 1982; Rauner et al. 2008; Schwarz 1992
Internal Environment	Strategic/Tactical Planning	Service Charges		Feldstein 1986; Flessa 2001; Meredith 1978
Internal Environment	Strategic/Tactical Planning	Donations		Flessa 2001
Internal Environment	Strategic/Tactical Planning	Revenues from Financial Investments		Feldstein 1986; Meredith 1978
Internal Environment	Strategic/Tactical Planning	Raising of External Financial Capital		Feldstein 1986
			OR Approach	**Game**
External Environment	Strategic/Tactical Planning	**Legal/Political Conditions**	Agency/Game Theory, System Dynamics	Flessa 2001; Hofweber 1987; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992
External Environment	Strategic/Tactical Planning	**Competition**	Agency/Game Theory, System Dynamics	Knotts et al 1982, 1989; Meredith 1978; Rauner et al. 2008
External Environment	Strategic/Tactical Planning	**Purchasing Markets**	System Dynamics	Rauner et al. 2008
External Environment	Strategic/Tactical Planning	**Job Markets**	System Dynamics	Flessa 2001; Hofweber 1987; Knotts et al 1982, 1989; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992
			OR Approach	**Game**
Benchmarking			Data Envelopment Analysis	Hans and Nieberg 2007; Schwandt 1998

2.5 Operations research techniques used

OR techniques are involved in modelling both the internal and external environments of hospitals and to facilitate the decision making of the players as shown in Table 11. Two games (Hans and Nieberg 2007; Schwandt 1998) even conduct a DEA and are thus especially suitable for illustrating the potential of DEA to players (O'Neill et al. 2008; Ozcan 2008).

Interplay and interdependencies among all decisions and environments of hospitals can be described to all players (Cromwell et al. 1998; Feldstein 1986; Flessa 2001; Hans and Nieberg 2007; Hofweber 1987; Knotts et al. 1982, 1989; Meredith 1978; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001) by system dynamics (cf. Brennan et al. 2006; Cooper et al. 2007). Agency/game theory (Zweifel et al. 2005) is relevant for decisions on financial management in all games (Cromwell et al. 1998; Feldstein 1986; Flessa 2001; Hans and Nieberg 2007; Hofweber 1987; Knotts et al. 1982, 1989; Meredith 1978; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001). Especially, optimal admission and discharge strategies for patients improve reimbursement (Leonard et al. 2003; Rauner et al. 2003; Rauner and Schaffhauser-Linzatti 2001, 2002; Schaffhauser-Linzatti et al. 2009).

For all games (Cromwell et al. 1998; Feldstein 1986; Flessa 2001; Hans and Nieberg 2007; Hofweber 1987; Knotts et al. 1982, 1989; Meredith 1978; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001), decision making rules and forecasting (Ozcan 2009) are essential methods for capacity and service planning as well as financial management. Players also conduct technology assessment (Cromwell et al. 1998; Feldstein 1986; Flessa 2001; Hans and Nieberg 2007; Hofweber 1987; Knotts et al. 1982, 1989; Meredith 1978; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001) for capacity and expenditure planning to evaluate cost-effectiveness for equipment, machines, material, and pharmaceuticals etc., (Gold et al. 1996). Once resources are allocated, assignment theory gains importance for some games (Hans and Nieberg 2007; Hofweber 1987; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001).

A group of games focuses on process and resource management and thus discrete event simulation is required (e.g., Rauner et al. 2008; Schwarz 1992; Warnke 2001). Other non-process oriented hospital games use a very high number of equations to model the system which also makes results unforeseeable (e.g., Meyer 1982; Schwandt 1998). Players of Cromwell et al. (1998), Feldstein (1986), Flessa (2001), Hans and Nieberg (2007), Meyer (1982), Rauner et al. (2008), Schwandt (1998), Schwarz (1992), Warnke (2001) can be taught the basics of queuing, priority rules, and different simulation approaches (system dynamics, discrete event simulation, agent-based simulation) (Brennan et al. 2006; Cooper et al. 2007; Ozcan 2009; Pidd 2004; Vissers and Beech 2005).

Simulation languages used in hospital management games evolved from Turbo Basic (Knotts et al. 1982, 1989; Meredith 1978); Turbo Pascal (Cromwell et al. 1998; Flessa 2001; Meyer 1982; Schwarz 1992); Delphi using Paradox database (Schwandt 1998; Warnke 2001) to Excel, Delphi, and Tecnomatix EMPower /Tecnomatix Plant Simulation (Hans and Nieberg 2007). COREMAIN HOSPITAL (Rauner et al. 2008) uses discrete event simulation in C# and ASP.NET 2.0 Web Programming Framework is realized using a distributed server-centric web application with four tiers which contains: (1) client, (2) web-server, (3) application server, and (4) database server. All simulation events and decisions of players are stored in a database for further evaluation which is unique to this game.

Stock-keeping issues (Cromwell et al. 1998; Feldstein 1986; Flessa 2001; Hans and Nieberg 2007; Hofweber 1987; Knotts et al. 1982, 1989; Meredith 1978; Meyer 1982; Rauner et al. 2008; Schwandt 1998; Schwarz 1992; Warnke 2001) are involved in capacity planning and patient scheduling (Pidd 2004; Vissers and Beech 2005; Ozcan 2009). Operating room management (Cardoen et al. 2009; Velásquez Flores 2008) is illustrated in detail by Hans and Nieberg (2007). Once the working hours of staff are planned, staff scheduling approaches are needed (Rauner et al. 2008; Schwarz 1992; Warnke 2001). None of the games includes staff rostering.

3 Conclusion

OR and management games have gained importance to better plan for scarce resources. Policy makers, practitioners, and students can study the reality in an artificial setting such as a hospital, with high learning effects. The internet has opened new possibilities to overcome the distance and time problem by bringing together participants from all over the world. This is especially essential in times of tight budgets, growing health care demand, and increasing technology costs.

Hospital management games focus differently on resource, process, and financial management. The games concentrate either on: (1) resource and financial, (2) resource and process, or (3) resource, process, and financial management decisions. Furthermore, several games also account for the influence of the external environment on hospitals. Different OR techniques have been applied (e.g., agency/game theory, assignment problem, data envelopment analysis, discrete-event simulation, priority rules, staff scheduling, stock-keeping, system dynamics). OR techniques also facilitate the decision making of players such as decision making theory, forecasting, and technology assessment.

OR methods are not only used to simulate gaming situations but at the same time are the subject of teaching. In addition, the potential of OR can be illustrated to policy makers and practitioners. This may reduces their reservations and make them more open to the promotion of OR applications in practice.

Thus, comprehensive internet-based hospital games such as COREMAIN HOSPITAL (Rauner et al. 2008) that account for the interplay of internal resource, process, and financial management with the external environment of hospitals are most promising. Furthermore, experimental economics can be applied to investigate both teaching (e.g., game situation) and policy issues (e.g., impact of reimbursement systems) in the future.

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Competition under different reimbursement systems: The concept of an internet-based hospital management game

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Abstract

We have developed an internet-based management game to illustrate the economic and organisational decision-making process in a hospital by using discrete event simulation. Up to six hospitals compete against each other for inpatients with different disease categories and budget depending on hospital mission, regional health policy, inpatient reimbursement system (day-, case- and global-budget based) as well as labour and radiology technology market for 12 decision periods. Players can evaluate alternative actions for capacity planning as well as patient scheduling and control problems depending on different game situations. The uniqueness of COREmain hospital game consists of the internet-based framework, the combination of resource, process and financial result management, the competition of hospitals within a region and the consideration of different inpatient reimbursement systems. The deployment of this game in teaching, policy and research might improve policy making both at a hospital, regional and national level and also induce further research in these fields.

Keywords: Internet-based hospital management game; Competing hospitals; Reimbursement systems; Decision support system; OR in health services; Simulation

1. Introduction

Soaring costs and reduced revenues characterise the situation in the health care systems in many countries. On average, the EU-15 countries spent 8.6% or US-$ 2278 per capita and the USA spent 13.9% or US-$ 3248 per capita (adjusted, using purchasing power parities) of its gross domestic product (GDP) for health care in 2001 (Hofmarcher et al., 2004). More than 40% of the health care costs are consumed for hospitals in industrialised countries. Expensive or "big ticket" medical technologies (BTTs) for the diagnosis and treatment of certain clinical conditions (e.g., computer tomography scanners – CTs, magnetic resonance imaging devices – MRIs) were disclosed as contributing factors to

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the increase in health care costs (Lazaro and Fitch, 1995). As another example for a major driving force of health care expenditures, policy makers identified the ageing population in developed countries (Fuchs, 1999). As a consequence, hospitals face a situation of increasing costs as well as increasing competition for decreasing budgets.

Hospital decision making has to account for the interdependencies of the internal and external environments to achieve predefined strategic goals and to survive on the market. Hospitals are complex systems consisting of the organisational culture within the top layer; the general management subsystem and the information subsystem within the middle layer; and clinical, administrative support, finance, physical facilities and marketing subsystem within the bottom layer (Duncan et al., 1995). Hospitals also interact with many stakeholders of the external environment comprising general environmental groups, regulators, vendors and suppliers, payers, recipients and impactees as well as healthcare providers (Duncan et al., 1995).

Decisions in hospital management are highly dependent on the inpatient reimbursement system of the country. Due to limited budgets, many countries changed problematic public inpatient reimbursement systems that influenced hospitals to extend the patients' length of stay (day-based system) or to increase services for patients (fee-for service-based system) in order to maximise their income to reimbursement systems that help contain costs (Klauber et al., 2004; Leidl, 1998; Schwartz et al., 1996). For example, reimbursement systems that account for diagnosis and treatment of patients (case-based systems) influence hospitals to discharge patients earlier compared to day-based systems. Such case-based systems were introduced in USA, Germany and Austria in the last years. Global budgets play a major role in shortening length of stay and in decreasing the number of unnecessary services in hospitals. Such global budget reimbursement systems were implemented in a few countries such as Canada (Leonard et al., 2003).

In addition to the reimbursement system, legal conditions impact on policy making in hospitals. For example, the Austrian Hospital Plan that regulates specialisation and the Large Devices Plan that regulates the purchase of BTTs for public hospitals play a key role in Austria (Austrian Federal Institute for Public Health, 2000). Work hour regulations for medical staff highly influence human resource management in hospitals.

The budget of a hospital depends on the reimbursement system as well as on the number, kind and average length of stay of patients treated. The higher the budget, the more resources a hospital can afford. The planning and coordination of resources such as personnel and equipment are essential for process management which impact on length of stay as well as on staff and patient satisfaction.

Chinese people used games as early as 3000 B.C. Games have been a promising approach for research, teaching and policy to investigate decision making in a complex situation in various fields of application such as military, education and business for nearly 50 years (Faria, 1998; Keys, 1997; Knotts and Keys, 1997; Summers, 2004; Washbush and Gosen, 2001; Wolfe and Roge, 1997). Computer games can be categorised as follows: adventure games, arcade games, board games, card games, puzzles, simulations, word games and miscellaneous games (Dempsey et al., 2002). A simplified model of reality is used for learning and the induced findings or knowledge are translated back to reality (Garris et al., 2002; Peters et al., 1998). For management education, games are used in strategic management/business policy, marketing, finance, management, accounting and other business fields (Faria and Wellington, 2004). In research, the game offers a stimulus to answer research questions, in teaching the game can be seen as a medium to convey cognition and skills and in policy the game helps evaluate policy options and solutions (Peters et al., 1998).

Management games use deep human inclination to play games as a source for highly motivated learning (Dempsey et al., 2002). Another major advantage of management games is that players act in an artificial simulated environment where their decisions have no direct consequences on the real world. Thus, it is possible for them to test different actions, increase their understanding of complex interdependencies and to define optimal strategies.

The success of management games depends on careful model building and evaluation of the validity of the games (Kriz, 2003; Peters et al., 1998; Thavikulwat, 2004). A systematic design process, a validity check by experts and future players as well as an extensive testing are useful steps to improve the validity of a game (Feinstein and Cannon, 2002; Peters et al., 1998). It is necessary to compress time and concentrate on main effects within the simulation model (Garris et al., 2002; Peters et al., 1998). Otherwise the effects of the game decisions will be so small that the players might loose interest. However, the environment must be realistic for the players as the game will not be accepted otherwise.

The internet technology highly impacted on simulation and gaming (Dasgupta, 2003; Kuljis and Paul, 2003; Martin, 2003). Internet-based simulation gaming allows convenient access to the game from different locations and simulation games thus become more powerful (Pillutla, 2003). However, the design of internet-based games requires a special focus on issues such as time, access, facilitation and communication (Asakawa and Gilbert, 2003).

The purpose of our internet-based management game of up to six competing hospitals aims at supporting the training of health policy makers, hospital staff as well as students in departments of business administration, economics, public management, non-profit management, hospital management, nursing management and medicine in hospital decision making. The simulation game models the management, nursing, radiology and surgery departments in a hospital. Players learn about the interdependencies of resource, process and financial result management in four departments depending on the goals of the different personnel groups: management staff, nurses, radiology assistants and physicians. Each player is responsible for one department (management, nursing, radiology, surgery). The game trains decision making within a team as decisions of one department affect the other three departments. This is why decisions should be made in agreement with the other three departments. For example, the closure of an operating theatre might increase patients' length of stay in the hospital and thus the bed occupancy rate and the workload in the nursing department might rise. We account for different patient types admitted to the hospital treated by major specialities in the hospital (e.g., internal medicine, gynecology, urology). Medical specialists indirectly play a role in this hospital game as they require certain resources (personnel, radiology machines and operating theatres) for their patients. The demand of these patients has to be met by the department players of nursing, radiology and surgery and vice versa the resources limit the patients who can be treated.

Furthermore, hospital games are useful for policy purpose to illustrate how regulations impact on hospital decision making and outcomes. Also for research purpose, hospital management games can be deployed to investigate different game situations by controlled experiments. The deployment of our hospital game in teaching, policy and research might influence policy making at a hospital level (e.g., coordination), at a regional level (e.g., cooperation) and a national level (e.g., choice of an adequate inpatient reimbursement system) as well as also induce further research in these fields.

The uniqueness of our hospital game consists of the internet-based framework, the combination of resource, process and financial result management, the competition of hospitals within a region and the consideration of different inpatient reimbursement systems. We name this game COREmain hospital: ***co***mpetition under different ***re***imbursement systems – a ***ma***nagement game via ***in***ternet for ***hospital***s. The word "core" stands for the key parts of a hospital to be represented in the hospital game. "Main hospital" symbolises a bigger hospital which is in charge of treating patients with major diagnoses from a larger catchment area. Internet-based simulation gaming allows convenient access to the game from different locations and helps simulation games become a more powerful area (Kuljis and Paul, 2003).

The paper provides a brief literature review on health care management games in the next section. Section 3 describes the design, methodology and components of the simulation game and outlines how the performance of the hospitals is evaluated. In Section 4, we illustrate the potential usage of COREmain hospital. We finally refer to issues for further research in the conclusion.

2. Literature review on health care management games

Simulation games are widely played in business and education (Achtenhagen, 1992; Bronner and Kollmannsperger, 1997; Fabel, 1993, 1998; Forseen and Paivi, 2001; Graham et al., 1992; Keys, 1997; Knotts and Keys, 1997; Summers, 2004; Washbush and Gosen, 2001; Wolfe and Roge, 1997). They are both used for training (Graf and Augustin, 1995; Högsdal, 1995) and selection of employees (Bronner et al., 1998; Sonnenberg, 1993).

In the last years, simulation games in health care education evolved (Christensen et al., 2001; Greenblatt, 2001; Lane et al., 2001; Satish et al., 2001; Streufert et al., 2001). These games help players learn essential skills regarding patients, processes and environment interaction. Topics include diseases management (e.g., inflammatory response, prostate cancer), nursing, medical competency, running of hospitals and wards as well as disaster management. For example, simulation games for hospitals focus on either the entire hospital or hospital's functions such as special departments or tasks.

The general management game "KLIMA" simulates management decisions in an environment of a reimbursement system based on payments per inpatient per day (Meyer, 1988; Meyer and Hofweber, 1988). Due to the new German diagnosis and treatment based reimbursement system, it was remodelled to a game named "KLIMA^{forte}" to investigate various management decisions within the new reimbursement system. For example, the decisions include production program planning, methods of treatment, hospital hygiene, quality management, investment planning as well as capacity utilisation and manpower planning (Schwandt, 1998).

"ASTERIKS", a discrete event simulation model, deals with scheduling and personnel planning in a hospital without accounting for reimbursement systems (Schwarz, 1992, 1993). The number of decisions were numerous and could hardly be handled within a training period of 2 days. "ASTERIKS^{PRO}" was developed based on "ASTERIKS" and allows to play different departments separately and thus reduced the number of decisions considerably (Schwarz and Henning, 1996; Warnke, 2001). These two games were developed on a Pascal platform and are not available for playing any longer.

Another example of a hospital management game is the "Canadian Hospital Executive Simulation System" based on a mathematical model that emphasis on key management decisions in each of the functional areas of the hospital (Knotts et al., 1990). The game "MOSHI" models the management of small hospitals in a developing country, Tansania (Fleßa, 1996, 1999).

Functional games include "ARKTIS" that focuses on decision making in the pharmacy of a hospital (Hofweber, 1987, 1989). The game "Staffing Persuits" was developed to assist in instructing graduate nursing students with direct or indirect staffing coordination (Nowak and Adams, 1988). The "Anesthesia Crisis Resource Management tool" (ACRM) uses a patient simulator to train anesthesiologists interacting in crews and managing crisis (Gaba et al., 2001).

While the hospital games discussed above focus on teaching, policy and research, the commercial software "Theme hospital" can be played by everyone and mainly serves as an entertainment tool (http://en.wikipedia.org/wiki/Theme_Hospital). It provides an insight into hospital management from the design of a hospital to operative management decisions such as resource planning. The players enjoy providing funny treatments to patients with unusual diseases. Due to a variety of unrealistic features, this game might not be suitable for training and teaching purposes.

Our internet-based management game of competing hospitals combines resource, process and financial result management in a setting of changeable reimbursement systems. Thus, the consequences of different reimbursement systems for decision making can be illustrated to players of different countries. The players learn about the necessity of good personnel planning and scheduling in order to reach short length of stays for patients treated with as few resources and as high revenues as possible. Our hospital game also serves the policy purpose by illustrating how regulations impact on hospital decision making and outcomes. Compared to the other hospital games, the features above together with its internet platform make the game unique and suitable for being applied in various countries with different reimbursement systems.

3. The game

3.1. General design

Before the game starts, a game host (in case of a guided class room game) or a user manual (in case of a purely internet-based game) explains the internet-based management game by describing the starting situation, possible decisions and important interdependencies within the system (see Fig. 1). The game host defines the health policy of the region which affects the decision making of the players. He/she decides among others for example about the percentage of emergency patients for each hospital, the patient categories to be treated and the reimbursement system.

The game simulates a region with up to six hospitals treating inpatients with different disease categories for 12 monthly periods of 28 days. We use a warm-up period to fill the empty hospital beds so that players can run an existing hospital. The internet software offers a communication infrastructure to enable players to exchange information and to make corporate decisions within the hospital and with other hospitals.

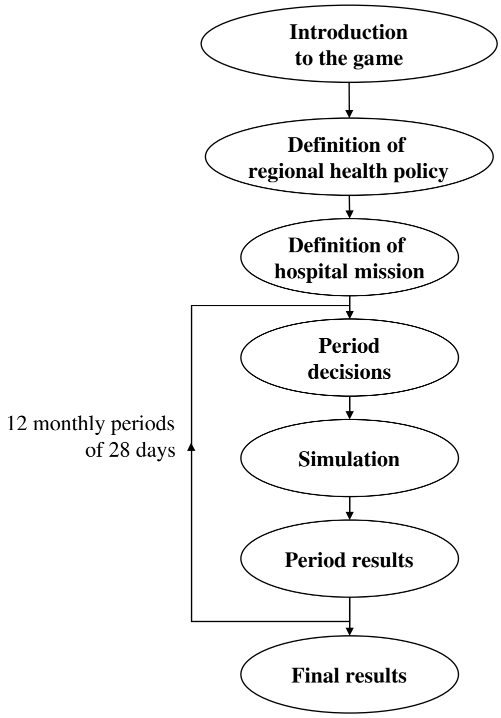

Fig. 1. The framework of COREmain hospital.

Each hospital team defines the mission of its hospital at the beginning and after six periods and aims at performing well in each period by sound period decision making resulting in good period results. The game host determines how transparent the health policy targets of the region are to the competing hospitals. The performance of each hospital is evaluated on pre-selected indicators such as number of patients, quality of medical care, patient satisfaction and staff satisfaction. The winner of the game is the hospital that performed best both in fulfilling their own hospital mission and regional health policy targets over the 12 monthly periods.

The hospitals compete against each other for inpatients with different disease categories and budget depending on hospital mission, regional health policy, inpatient reimbursement system (day-, case- or global-budget based) as well as labour market situation for medical staff and radiology technologies available. Each hospital has up to 500 beds for which we considered four departments to model the internal structure of the hospital: management, nursing, radiology and surgery (see Fig. 2). The uniqueness of our hospital game in the literature consists of the internet-based framework, the competition of hospitals within a region and the consideration of different inpatient reimbursement systems.

The regional health policy and performance of the hospital in previous periods influence on the allocation of patients to hospitals in a certain period. Depending on the labour market situation

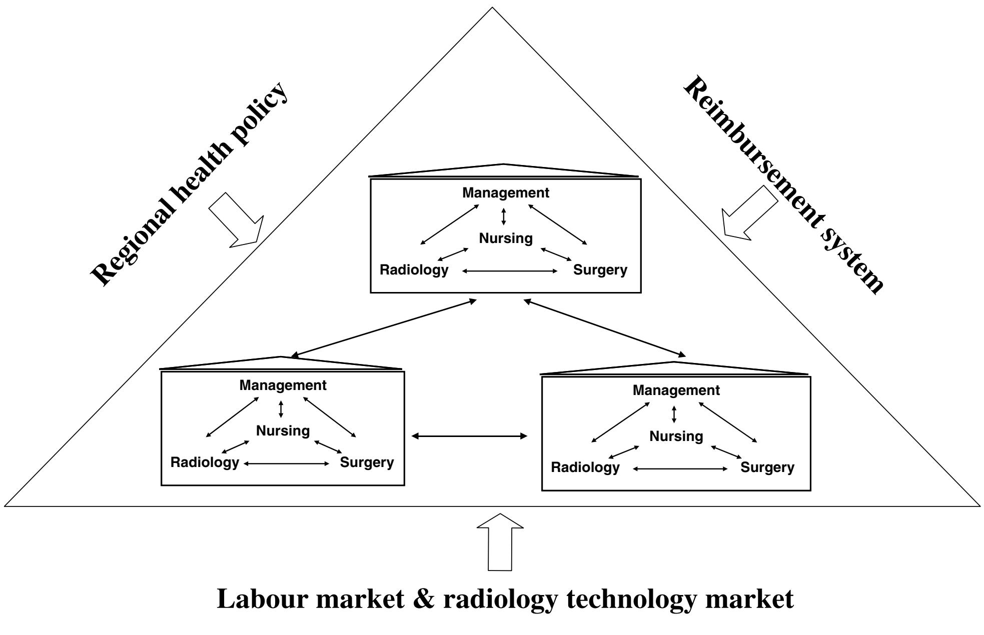

Fig. 2. General decision-making structure of COREmain hospital.

and legal regulations, newly hired staff is available quickly or slowly and staff can be fired immediately or after a certain waiting period. The radiology technology market offers several types of radiology machines that, for example, differ in purchase costs, variable running costs, examinations to be undertaken and medical quality of examinations.

Players can make alternative decisions for capacity planning as well as patient scheduling and control problems depending on different reimbursement systems. We considered four types of inpatient reimbursement systems based on: (1) inpatient days independent of diagnosis and treatment, (2) Diagnosis-related Groups (DRGs) with unlimited budget, (3) DRGs with limited budget and (4) global budgets. Currently, case-based payment systems such as DRG systems (e.g., in the USA, Germany and Austria) and global budgets (e.g., in Canada) constitute the predominant payment strategies for inpatients (Leidl, 1998; Schwartz et al., 1996). The day-based payment structure independent of diagnosis and treatment of the inpatients is seldom used nowadays. Such systems – like the pre-1997 Austrian one – caused a lot of problems as hospitals tended to discharge patients quite late resulting in a prolonged length of stay in hospitals (Rauner and Schaffhauser-Linzatti, 1999, 2001, 2002; Rauner et al., 2003, 2006). The longer patients stay in hospitals, the more resources are needed (e.g., staff, beds) and the more costly patients become.

DRG-like reimbursement systems force hospitals to discharge inpatients earlier compared to day-based ones, whereupon global budgets have an even higher effect as the given budget covers all expenses of hospitals and is independent of the inpatient categories treated. DRG-like systems also cause problems for health care systems such as decline of health care quality, “cream-skimming” of lucrative patient categories and “DRG-creep”, the classification of cases to better reimbursed DRG-categories (Feldstein, 1993; Fetter, 1991; Zakoworotny, 1993). Using global budgeting, decision makers have to ensure that the quality of care does not decrease due to cost cuts as a result of regulations (Feldstein, 1993; Neubauer and Demmler, 1991). Leonard et al. (2003) demonstrated for several main clinical categories that with the Austrian DRG-like reimbursement system inpatients stayed longer than in Canada where hospitals operate under global budgets.

Within each hospital, players make decisions on resource, process and financial result management as displayed in Fig. 3. We aimed at considering main components of the decision-making process in management, nursing, radiology and surgery with simultaneously keeping manageable the number of decisions to be undertaken by the players.

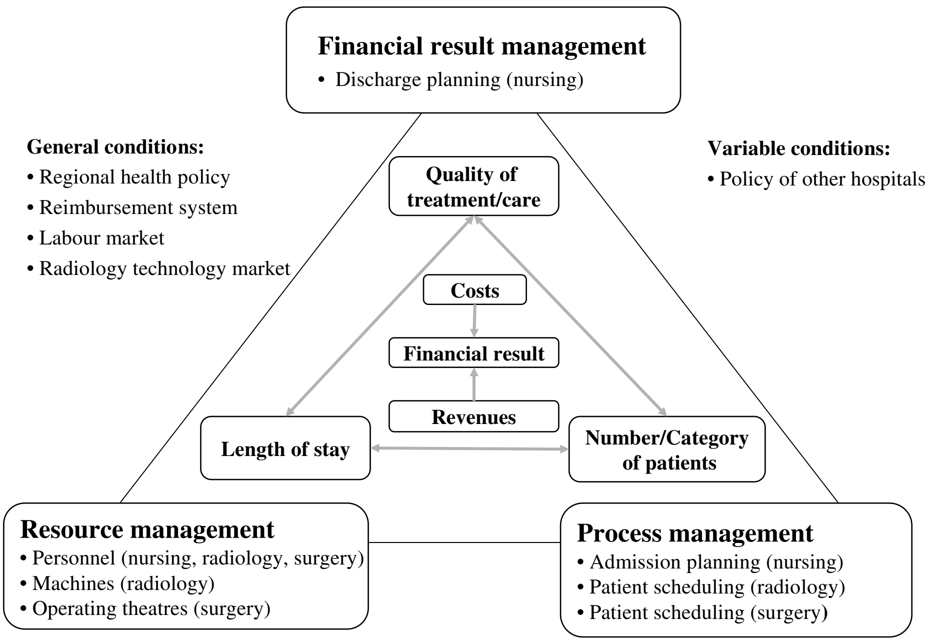

Fig. 3. Resource, process and financial result management of COREmain hospital.

The players manage resources such as personnel (nursing, radiology, surgery), machines (radiology) as well as operating theatres (surgery). They are also responsible for process management consisting of admission planning and patient scheduling in radiology and surgery. The financial result management determines the discharge policy of patients. All management decisions are influenced by general and variable conditions by mutually influencing each other. For example, the more resources are available, the more patients can be admitted and the shorter the waiting times for radiology and surgery. The better the process management, the earlier patients can be discharged.

Depending on the resource, process and financial result management, a certain number of patients per category is treated in the hospital with a certain quality for a certain period of time. The higher the number of patients competing for limited resources in a hospital is, the longer the length of stay of patients. Furthermore, a medically too short stay of patients in a hospital might negatively influence the quality of care. A decreased quality of care might attract less patients in the subsequent period depending on the quality of care provided by the other competing hospitals in the region.

The number of patients per category, the length of stay of the patients and the quality of care and treatment as well as the reimbursement system determine the financial result of a hospital, the costs minus the revenues. High total costs might be incurred by a large number of not-cost covering patients treated, a high number of personnel, a large number of high-tech radiology machines, the opening of many operating theatres, a poor process management, a long average length of stay of patients as well as high variable and fixed accounting costs. Total revenues depend on the reimbursement system, on the policy of the other hospitals as well as on the number and category of patients treated.

3.2. Software technology and methodology

We defined key requirements for the software technology: (1) the game should be internet-based, (2) the simulation data should be stored in a database, (3) the development software should not be too expensive, (4) the development software technology should be "state of the art" and (5) a thin client concept should be implemented (Steinbauer, 2005). Based on these requirements, our PhD student Joerg Gesslbauer of the University of Applied Sciences Wiener Neustadt, Austria, has chosen the object-oriented programming language C# and the ASP.NET 2.0 (Active Server Page.NET) Web Programming Framework based on the .NET Framework to realise a distributed and server-centric web application with four tiers (Stahlknecht and Hasenkamp, 2005): (1) client, (2) web-server, (3) application server and (4) database server.

The client is represented by a web-browser, which runs on the player's computer and displays dynamic HTML pages (Lubkowitz, 2005) built on the ASP.NET 2.0 technology. It performs the task of the user interface of the game. An ASP.NET 2.0-compatible web-server like the Microsoft Internet Information Services (IIS) fulfils the functions of both the second and third tier: The web-server receives a request from any web-browser and runs an ASP.NET 2.0 program (the business logic) directly on the server. Afterwards, it sends back the output (in terms of HTML) to the client. The client can view the HTML page by the web-browser. For the development process, we use the Microsoft Visual Studio 2005 Standard Edition, which integrates a complete set of development tools for building ASP.NET Web applications among other features. The fourth tier, the database server, stores the data for the game. We have chosen the Microsoft SQL Server Express database server because it is a very reliable and up-to-date database system and is furthermore absolutely free for use.

The game is based on a discrete-event simulation. Patients are individually generated and wait for admission to a certain hospital. A patient can either be admitted or refused by a hospital. After being admitted, each patient is individually tracked through the hospital undergoing nursing, radiology and surgery. Finally, the patients are discharged. To account for these different states, a state chart machine is used and the information is stored in databases.

We are currently in the final stage of development of COREmain hospital game. The business logic with all main formulas is derived based on our past experience with hospital games as well as research in the field of hospital management and cooperation with hospitals on different practical projects. We are gathering data from hospitals (management, nursing, radiology, surgery), collecting data from companies that sell radiology machines and obtaining data from health ministries on inpatient reimbursement systems. We use this data gathering process for detailed evaluation of our business logic and consequently for further refinement of the business logic by next months. The main data required for the business logic are entered by the developer (see Fig. 4). The game host defines the game condition.

The implementation of COREmain hospital should be finished by summer 2007. The data entry part for the player interface as well as the database including the state chart machine are implemented. An exemplary interface for the data entry by the nursing player is given in the next session. We are currently programming the business logic and the simulation (hospital model on the server) as well as the communication platform and the evaluation part including period and final results (player interface). The internet-based technology centrally administers all data, period and final results, as well as the communication messages written among the players. Thus, all information and results from one game can easily be analysed compared to other games. This is especially useful for the experimental investigation of COREmain hospital which is a topic for further research.

The communication platform plays a key role in the interaction process among the players. Here the different players of a hospital (management, nursing, radiology, surgery) exchange information for coordinating strategies within a hospital. If the game is played centralised in one room (e.g., PC laboratory), then this communication platform will become less important compared to a decentralised game situation (e.g., different PC laboratories, PCs at work or home) in which the players can not communicate face to face. The decentralised game situation requires the internet-based approach and enables to overcome local and temporal restrictions. It is planned that different groups (students, researchers, policy makers) from different countries (e.g., European countries, US, Canada) play the game together. Furthermore, the management player of a hospital can exchange information for example on market data or on the hospital's evaluation process and might establish strategic alliances with other hospitals. Especially for inter-hospital communication, the internet-based approach is beneficial for centralised games as this prevents the uncontrolled face-to-face communication among players from different hospitals and also complicates spying.

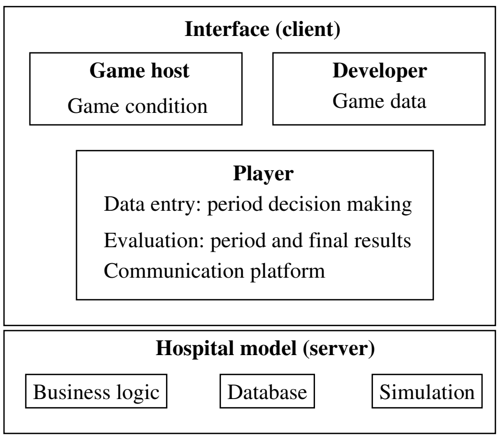

Fig. 4. The structure of COREmain hospital software.

The evaluation interface is essential for the hospital players to improve decision making for the next period in order to gain and sustain their competitive edge. This is why we are constantly improving the interfaces of our hospital game using feedback from testing games with students, researchers and policy makers. We will also further improve our business logic as well as interface based on that testing experience keeping in mind that the degree of detail is sufficient and that the game does not become too complex. This main refinement process of COREmain hospital might continue until summer 2007.

3.3. Period decision making

The key aspect of this game comprises the illustration of management staffs', nurses', radiology assistants' and surgery teams' decision making on the hospital's performance by focusing on four main departments: (1) management, (2) nursing, (3) radiology and (4) surgery. The game participants are responsible for one or more of these four departments.

The decisions of the players depend on the general and variable conditions of the game as well as on the patient-category-mix and the percentage of emergency patients. The game host can consider up to 15 operative (e.g., total hip replacement, caesarean section, hysterectomy, prostatectomy) and non-operative (e.g., acute myocardial infarction, stroke, asthma) patient categories covering a wide range of speciality areas in a hospital (e.g., internal medicine, gynecology, urology). We have gathered data on treatment paths for the main Austrian operative and non-operative cases. The treatment paths are not hard-coded and can be defined in a game editor interface. A treatment path for a patient category contains the radiology examinations desired and their duration as well as for operative-cases also the kind of surgery needed and its duration. Furthermore, the game host defines the minimum medical-induced waiting times for radiology examinations and surgeries. The nursing category varies within the different states of the treatment path. Potential length of stay boundaries as well as the amount of reimbursement per patient category can be determined by the game host in the game editor.

Patients of category $i (i = 1, \ldots, 15)$ are assigned to hospital j in each decision period $t (p_{i,j,t})$. In the region, there are n hospitals. Eq. (1) illustrates this allocation process accounting for both a fixed allocation part determined by the game host (first term) and a variable allocation part depending on the performance of the hospitals in the past three periods (second term):

$$p_{i,j,t} = \alpha P_i + \left(\frac{\sum_{k=1}^{3} \sum_{u=1}^{3} \omega_k \rho_u M_{j,k,t-u}}{\sum_{j=1}^{n} \sum_{k=1}^{3} \sum_{u=1}^{3} \omega_k \rho_u M_{j,k,t-u}} \right) \cdot (1 - n\alpha) \cdot P_i$$
$$\forall i = 1, \ldots, 15; \; j = 1, \ldots, n; \; t = 1, \ldots, 12. \qquad (1)$$

The game host defines a fixed percentage of patients allocated to a hospital (α) and the total number of category i patients to be treated in the region during the simulation game (P_i), whereby $\alpha \cdot n <= 1$. If $\alpha \cdot n = 1$, then only a fixed percentage of patients is allocated among the hospitals, while $\alpha \cdot n = 0$ means that the allocation of patients is only dependent on the performance of hospital j in previous periods (ρ_u is the weight for three previous periods, where the sum over these weights equals one). The better the performance of hospital j in the three previous periods $t - u$, the more patients can be attracted in period t. We account for three performance measures k for each hospital j in period $t - u$ ($M_{j,k,t-u}$): (1) quality of medical care, (2) patient satisfaction and (3) staff satisfaction. These performance measures are aggregates of outcome measures. For example, quality of medical care is a function of (1) average length of stay of patients, (2) dismissal rate of emergency patients, (3) motivation of staff, (4) workload of nurses, (5) workload of surgery teams, (6) overtime of radiology assistants and surgery teams and (7) medical quality of machines in radiology. The game host determines the weighting of these three performance measures (ω_k).

3.3.1. Management

At the beginning and after six periods, the player of the management component decides on the mission of the hospital by weighting the mission criteria. The following mission criteria can be selected: (1) high quality of medical care, (2) high patient satisfaction, (3) high staff satisfaction, (4) high occupancy rate, (5) short length of stay, (6) high number of patients discharged, (7) high regional market share, (8) high/low severity index, (9) low dismissal rate, (10) high surplus and (11) low costs. In case of a DRG-based reimbursement system, we have three more mission criteria: (12) high number of DRG-points, (13) not-discovered DRG-creep and (14) high value per DRG-point. At the end of each game period, it is checked whether or not a hospital has fulfilled its own mission. The hospital that both fulfilled its own mission and the regional mission best, is the winner of the game period. Thereby it is important that the management communicates the general mission strategy to the other three departments in order that nursing, radiology and surgery base their resource, process and financial result management decisions on that hospital mission.

To account for problems with DRG-systems, we modelled DRG-creep in this game. In DRG-based reimbursement systems, hospitals might intentionally misqualify patients to better reimbursed categories to increase their revenues (Feldstein, 1993; Fetter, 1991; Zakoworotny, 1993). However, such a behaviour is often investigated by regulatory agencies or government institutions. For example, several Austrian hospitals even used an optimisation software to increase DRG-like points by shifting patients to other categories. This was the reason why the government introduced an anti-optimiser software to trace so-called "black sheep" hospitals. Such hospitals had to pay a penalty for their behaviour (Rauner and Schaffhauser-Linzatti, 1999, 2001, 2002).

The management player determines the percentage of DRG-creep in each period keeping in mind that if the misqualification rate is too high, this rude behaviour might be disclosed by the regulatory agency and then the hospital will have to pay a penalty. In case the misqualification rate is below a boundary defined by the game host, the management might be successful in increasing their DRG-points. Increased DRG-points lead to an increased revenue in a DRG-system with unlimited budget. In a DRG-system with limited budget, it depends on the DRG-points gathered by the other hospitals whether or not increased DRG-points raise the revenue (Rauner and Schaffhauser-Linzatti, 1999, 2001, 2002; Rauner et al., 2003).

To obtain information on the competitive behaviour of other hospitals, the management player can purchase market data of other hospitals from a regional authority or he/she can exchange data for free via the communication platform with management players of other hospitals by undergoing a data-sharing coalition. Furthermore, the management player can make investments to increase staff satisfaction which has an impact of the quality of care as well as consequently on the number of patients attracted by the hospital in subsequent periods.

3.3.2. Nursing

The nursing player schedules admissions of patients using scheduling rules and plans discharges depending on the hospital management's objectives as well as on the general and variable conditions of the region. Furthermore, the resource, process and financial result management also impact on admission and discharge strategies. The nursing player can prioritise patient categories and reject operative patients if the surgery waiting lists are getting too long. A fixed number of non-emergency patients or a number of non-emergency patients up to a certain percentage of the non-emergency capacity can be admitted. Fig. 5 illustrates key factors influencing the length of stay of patients. Waiting times due to limited capacities and organisational deficiencies as well as boundaries for the minimum medical and medical recommended length of stay result in the organisationally possible length of stay. Due to the reimbursement system or other economic reasoning, the organisationally possible length of stay might be increased up to an economically desired length of stay. This real length of stay impacts on the financial result depending on the reimbursement system. Each day in a hospital is costly as variable nursing and material costs arise.

As DRG-based reimbursement systems are mainly independent of inpatients' length of stays and only provide low compensations for extended length of stays and global budgeting even neglect length of stays, the nursing player will discharge patients earlier in these two systems compared to inpatient day-based reimbursement systems. In the later systems, the longer patients stay, the higher is the reimbursement. Such systems tend to discharge patients with expensive treatments late compared to patients with cheap treatments because cheaper patients' costs can be covered with a shorter length of stay (Rauner and Schaffhauser-Linzatti, 1999, 2001, 2002; Schwartz et al., 1996). For example, Rauner et al. (2006) found that patients with knee joint damages stayed 5.93 days under an inpatient day-based reimbursement system in Austrian hospitals in 1996. After the introduction of a DRG-like system in Austria in 1997, this length of stay dramatically decreased from 5.47 days in 1997 to even less than 4.5 days in 2002 (Rauner et al., 2006).

The nursing player also decides about human resource planning such as hiring and firing full-time and part-time nurses as well as determining nurses'

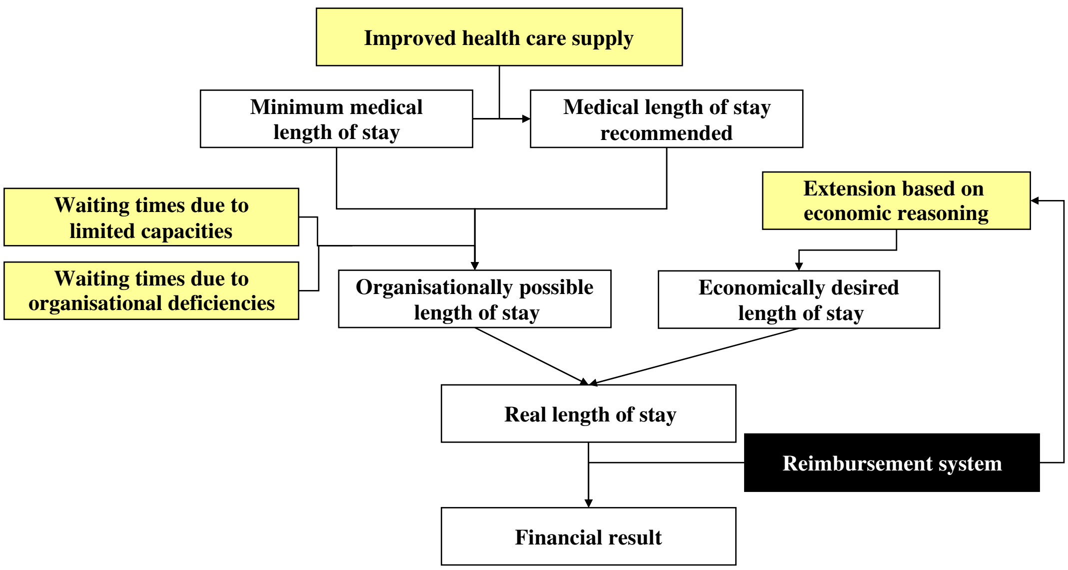

Fig. 5. Factors influencing the length of stay of patients.

overtime depending on admission and discharge planning. Fig. 6 illustrates the user interface for the nursing player with respect to human resource planning. In case of a high workload of nurses, the staff and patient satisfaction decrease resulting in a negative impact on the number of patients attracted by the hospital in the subsequent periods.

3.3.3. Radiology

The radiology department plays a crucial role in a hospital as treatment and care strategies as well as surgery of a patient depend on his/her radiology's statement. The decision making of this player is depended on the general and variable conditions of the region, the hospital's mission and the decisions made in management, nursing and surgery.

The radiology player defines the opening hours of the radiology department. Outside the opening hours, one radiology assistant is on duty to examine emergency patients. The player also selects scheduling rules for patients waiting for a radiology examination. For example, the player determines the type of queuing strategies: (1) one queue for each machine or (2) one queue for each type of radiology examination. Next, the player chooses the priority for radiology examinations such as first arrived patient first (first-in first-out), patients with shortest/longest examination first and patients with previously postponed examinations first.

To cope with the radiology's department workload, the player can purchase and close radiology units. The radiology department of a hospital can have up to 20 picture diagnostic sites with different machines out of a range of 10 different machine types (e.g., CT, MRI). The developer defines which machines are available for purchase and which examinations of which quality can be undergone by each machine type.

The radiology player is also involved in the human resource planning process by hiring and firing full-time and part-time radiology assistants as well as determining radiology assistants' overtime.

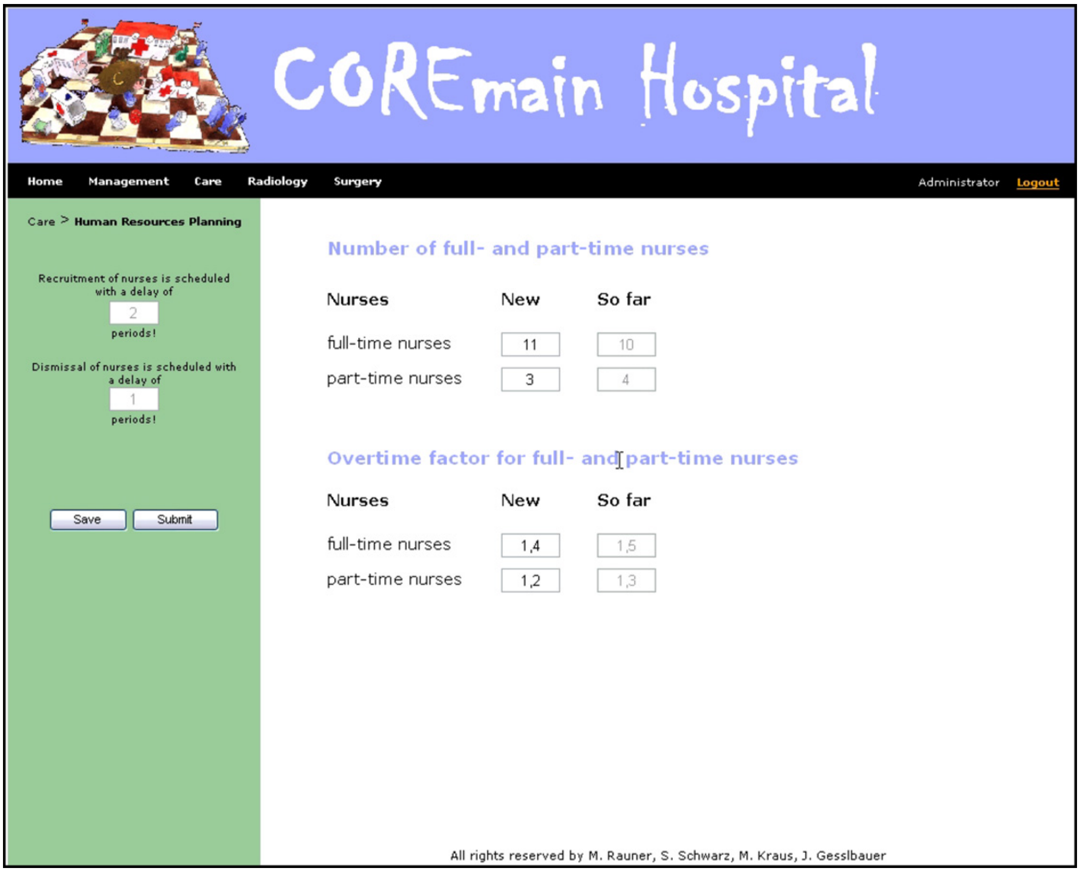

Fig. 6. The human resource planning interface of COREmain hospital for the nursing player.

3.3.4. Surgery

Similar to radiology, the surgery department with its operating theatres is another main component of a hospital. The surgery department is highly dependent on the radiology department because for most operative patients a radiology examination is done before the surgery. Operative patients can only be discharged after having undergone a surgery which again impacts on the discharging policy of the nursing department.

The surgery player decides on opening hours of the operating theatres. Outside the opening hours, one surgery team is on duty but only in case of emergency. The surgery player can also reserve an operating room for emergency patients only. To deal with the demand for surgeries, the surgery player can open and close operating theatres. Up to 12 operating rooms can be opened. In case of reimbursement systems that promote a short length of stay of patients such as DRG-based and global budget systems, a higher incentive for opening additional operating rooms will be induced.

The surgery player also chooses scheduling rules for operative patients. For example, he/she can prioritise patients with previously postponed surgeries, patients with long/short surgery times and patients who were booked first for the surgery. Emergency patients always have highest priority for surgery.

Furthermore, the player can hire and fire full-time and part-time surgery teams and determine surgery teams' overtime.

3.4. Period and final results

At the end of each period the performance of hospitals is evaluated. We have selected the following performance measures: (1) quality of medical care, (2) patient satisfaction, (3) staff satisfaction, (4) occupancy rate, (5) length of stay, (6) number of patients discharged, (7) regional market share, (8) severity index, (9) dismissal rate, (10) surplus, (11) costs and – in case of a DRG-based reimbursement system – (12) number of DRG-points, (13) not-discovered DRG-creep and (14) value per DRG-point. Each of the performance measures is an aggregate of a number of outcome measures as described for quality of medical care at the beginning of Section 3.3.

Depending on the decisions of the players and the mission of their hospital, each hospital obtains different performance measures. A non-profit private hospital might aim at a high quality of medical care and a low dismissal rate of patients keeping in mind costs, while a for-profit hospital wants to gain a surplus by specialising in profitable patients regardless of dismissing less profitable patients. Here, the players learn how the management is influenced by hospital types (e.g., for-profit hospital, non-profit private hospital, public hospital), different reimbursement systems and the actions taken by other hospitals in the region.

We calculate main nursing, radiology, surgery and additional costs. Nursing costs comprise full-time, part-time and overtime staff costs as well as variable material costs per day depending on the nursing category for patients treated. We acknowledge that the nursing category of patients varies during the stay in the hospital. The radiology costs cover full-time, part-time and overtime staff costs, variable and fixed material costs as well as deduction costs for picture diagnostic machines. The surgery costs include full-time, part-time and overtime staff costs, variable and fixed material costs as well as deduction costs for operating theatres. Additional costs are costs for extra, not-modelled staff, motivation costs for staff, costs for purchasing market data of other hospitals from a regional authority and penalty costs for discovered DRG-creep.

The revenue of a hospital depends on the reimbursement system. In a day-based system, the number of inpatients treated and the payment per inpatient day is of importance. Depending on the performance of a hospital in relation to the other hospitals of the region in period t, each hospital obtains a budget share of the total budget of the region in a global budget reimbursement system. The game host determines the weights for performance measures used for global budget allocation.

In a DRG-based system, the number of and payment for patients per category depending on the patients' length of stay and DRG-creep activities influence the hospital's income. If a limited-budget DRG-reimbursement system is played, then a hospital's income will be dependent on the number of patients per category, the payment for each patient category depending on the patients' length of stay and DRG-creep activities of the other hospitals. Eqs. (2) and (3) exemplarily illustrate the budget allocation formula for a limited-budget DRG-reimbursement system. As mentioned above, all hospitals report data on the number and length of stay of patients treated in each category. Using that information, DRG-points are calculated for each hospital which might be increased due to DRG-creep. This calculation process is slightly different in several countries and we accounted for the German and Austrian systems as these two systems are good representatives of the DRG-systems worldwide (Federal Ministry of Health and Women, 2005; Klauber et al., 2004; Leidl, 1998; Schwartz et al., 1996). The variable $\mathrm{DRG}_{j,t}$ denotes the total DRG-points gathered by hospital j in period t and the parameter B_t the total budget of the region in period t. Then, the value per DRG-point v_t can be determined in period t (see Eq. (2)):

$$v_t = \frac{B_t}{\sum_{j=1}^{n} \mathrm{DRG}_{j,t}} \quad \forall t = 1, \ldots, 12. \tag{2}$$

After calculating the DRG-point value, the budget ($b_{j,t}$) can be allocated to hospital j in period t according to Eq. (3):

$$b_{j,t} = v_t \mathrm{DRG}_{j,t} \quad \forall j = 1, \ldots, n; \;\; t = 1, \ldots, 12. \tag{3}$$

In such a system, a hospital with fair behaviour might obtain a low budget share even when reporting a high number of DRG-points (non-DRG-creep) because other hospitals have cheated. On the other hand, the more obvious the cheating is, the higher the chance that a hospital is punished and has to pay a penalty.

The period financial result of a hospital is given by the difference between the revenues and the costs in a certain period. The winner of the game is the hospital that performed best both in fulfilling their own mission targets and health policy targets of the region over the 12 monthly periods.

4. Potential usage of CORE main hospital

As discussed before, management games play a key role in teaching, policy and research. COREmain hospital is planned to be deployed in all these three fields.

In a first step, COREmain hospital will be used for teaching students and practitioners resource, process and financial management by considering different general environmental conditions (e.g., regional health policy, reimbursement system, labour market, radiology technology market). They will also learn how to coordinate strategies within a hospital among different personnel groups: management staff, nurses, physicians and radiology assistants. In addition, they can experience how cooperation strategies among hospitals can be beneficial for a hospital region.

The next step will be the application of COREmain hospital to investigate key concepts of hospital policy and management. We plan to incorporate key Austrian decision makers in health policy. For example, the Vienna hospital compound could analyse how coordinated specialisation strategies regarding treatment of certain patient groups, purchase and usage of radiology machines as well as opening/closure of operating theatres will increase the overall regional hospital efficacy by lowering overall regional hospital costs. Decision makers in the Austrian Ministry of Health and Women could experience the obstacles as well as economical, ethical and political consequences of inpatient reimbursement systems. This might help improving the existing Austrian reimbursement system.

Based on our experience gained in application steps one and two, we will improve COREmain hospital to make it most suitable for teaching and policy. Here we have to balance the degree of detail with the complexity of the game. In a final step, we plan to utilise COREmain hospital for research purpose. Experimental economics has gained importance since the early 1930ies and has been applied to many economic problems such as public goods, coordination problems, auctions, bargaining, industrial organisation, asset markets and individual decision making (Kagel and Roth, 1995). Past hospital management games were not investigated in detail by experimental economics. Thus, we will experimentally analyse different game situations with both teaching and policy purpose. We could compare differences between pure internet-based games and workshop games where players personally meet and interact. Moreover, we might study different player groups (e.g., students, researchers and practitioners with medical, management or regulatory background) or mixed player groups with different knowledge levels about running a hospital and reimbursement systems. Furthermore, we can experimentally evaluate the impact of different reimbursement strategies from a single hospital and overall hospital region perspective.

5. Conclusion and further research

The changing situation in hospital markets requires well-trained personnel for management in hospital. Health care policy makers such as ministries of health also have to understand and estimate the impact of regulations on hospital management and outcomes before introducing them. Special attention needs to be paid to personnel planning (Docteur, 2003) and purchase of expensive equipment such as BTTs (Lazaro and Fitch, 1995) because they incur most of the costs in hospitals. Due to numerous interdependencies among internal hospitals' decisions and the external environments of hospitals, decision making in a hospitals is of high complexity. Hospital managers choose different strategies depending on the reimbursement system, labour and radiology technology market, regional and national health policy as well as legal conditions. The changes of reimbursement and legal systems in many countries during the last decades provoked an extensive need for advanced training of decision makers in the hospital sector.

Trial and error decisions in hospitals would not only cause enormous costs and endanger the existence of the hospital and in consequence might even put patients' lives at risk. For this reason, management games can play an important role in this field to train and support decision makers. When setting up a hospital game, a modeller has to focus on the main decision making effects and compression of time to achieve good training results and desired quality of the decision support. Hospital games help students and hospital staff understand decision making in complex situations. Furthermore, hospital games illustrate to health care policy makers how regulations impact on hospital decision making and outcomes. Also for research purpose, hospital management games can be used to investigate different game situations by controlled experiments. The deployment of our hospital game in teaching, policy and research might influence policy making both at a hospital level (e.g., coordination), at a regional level (e.g., cooperation) and a national level (e.g., choice of adequate inpatient reimbursement systems) and also induce further research in these fields.

The management game presented in this paper is a promising tool for training decision making in hospitals. The uniqueness of our hospital game consists of the internet-based framework of competing hospitals, the combination of resource, process and financial result management in a set-up of changeable reimbursement systems and environmental conditions. The players learn about the independencies among and the varying goals in key departments: management, nursing, radiology and surgery. We compressed the time to 12 gaming periods of 1 month each. We will start to evaluate this system with students, researchers and policy makers the next months by investigating different game situations in detail. Based on this experience, we will adapt the game regarding main issues if necessary. Here we have to balance the degree of detail with the complexity of the game.

For further research, a laboratory or a transport system within a hospital might be modelled to illustrate further decision making in these fields. For example, bottlenecks due to the transport system could be investigated. The impact of different technologies on service time and costs could be studied in laboratory decision making. Another extension of the game might be the inclusion of ambulatory care. Currently, we account for a general nursing department but one could also consider specific nursing departments for major specialities (e.g., internal medicine, gynecology, urology). However, such extensions might complicate the system in such a way that the game might become too complex.

Currently, the reports provided to the hospital player list for example occupancy rates of nursing beds, radiology units and operating theatres. One might consider providing a graphical interface which illustrates the flow of single patients through the hospital (from admission to discharge) during a simulation period.

Another interesting field of research could be the comparison of learning behaviour, game results and overall success of pure internet games where the players never meet each other personally with a gaming set-up of a two-day workshop where players personally meet and interact. Moreover, the outcome of our game could be studied when applied to different player groups (e.g., students, researchers and practitioners with medical, management or regulatory background) or to mixed player groups with different knowledge levels about running a hospital and reimbursement systems.

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A cross-national comparison and taxonomy of DEA-based hospital efficiency studies

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Abstract

This paper provides the first taxonomy of hospital efficiency studies that uses data envelopment analysis (DEA) and related techniques. We provide a systematic review of 79 such studies published from 1984–2004 that represent 12 countries. Only studies written in English are considered. A cross-national comparison reveals significant differences with respect to important study characteristics such as type of DEA model selected and choice of input and output categories. Compared with US studies, European efforts are more likely to measure allocative rather than technical efficiency, use longitudinal data, and use fewer observations. We take a longitudinal perspective that illustrates the *life cycle* of this research, as well as its diffusion across disciplines. Our taxonomy can be used by policy makers and researchers to review past, and assemble new, DEA models.

Keywords: Data envelopment analysis; Stochastic frontier analysis; Hospital efficiency; Taxonomy

1. Introduction

In Europe and elsewhere, public pressure and executive interest for cost containment have led to numerous studies of the organizational causes of excess resource utilization, leading national governments to seek new approaches to solve these important problems. Efficiency measurement represents a first step towards the evaluation of a coordinated health care system, and constitutes one of the basic means of audit for the rational distribution of human and economic resources.

Data envelopment analysis (DEA) has proven to be an effective and versatile tool for health care efficiency measurement, and its use has spread throughout the world. This paper provides a systematic review and taxonomy of hospital efficiency studies that utilize DEA and related techniques for efficiency measurement. DEA was first used to measure the technical efficiency of US hospitals more than 20 years ago. In our taxonomy, we review 79 hospital efficiency studies representing 12 countries and four continents [1–79]. We

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included all studies published in refereed journals or books that were either published or available in pre-print during the period 1984–2004.

In order to keep our survey project within resource constraints, technical reports and proceedings were excluded, as were papers published in a language other than English. The essential features of each study were summarized; these included: choice of input and output categories; type of efficiency measured (technical vs. allocative); time frame considered (single year vs. multiple years); and the type of DEA model chosen. A longitudinal perspective illustrated the life cycle of this research through the stages of early adoption, rapid growth, and maturity.

Some recent studies have reviewed the relevant literature with respect to DEA in general [80], and non-parametric and parametric efficiency studies within health care in particular [81,82]. Our paper extends this previous work in several important ways. First, we examine cross-national differences in various study characteristics, as well as how the local environment influences both the input and output category selection and the specific methodology chosen.

Second, we provide a taxonomy of hospital efficiency studies based on the type of efficiency measured and the input and output categories selected. Third, we trace the life cycle of this research and its diffusion across countries and related disciplines. And, finally, we identify how model specification has changed over time in response to changes in hospital financing.

We hypothesize that the external environment frames many aspects of model development in DEA: from the questions asked, to the data available, to the input and output categories selected. We focus on hospitals in order to highlight potential differences across countries, and to explain these differences in terms of environmental factors, such as the organization and financing of the respective health care systems.

A taxonomy of hospital efficiency studies has several important, practical benefits. Firstly, it can serve as an early map to an unknown territory. Further, it can help decision-makers evaluate potential and existing DEA models. Using our taxonomy, policy makers can, perhaps, more easily assemble new DEA models that best meet their requirements via a step-by-step process: from selection of the "best" method, to the choice of input and output categories, to the presentation of results.

The remainder of the paper is organized as follows: In Section 2, we provide an overview of DEA and related techniques for efficiency measurement. In Section 3, we describe the taxonomy of efficiency studies and our statistical methods. Section 4 contains the results of our cross-national comparisons, as well as other methodological considerations. Sections 5–7 provide a summary of the input and output categories used and the leading contributors in this area, with the final section concluding the paper.

2. Data envelopment analysis and related techniques

We begin with some basic terminology for efficiency measurement. A firm is considered *technically efficient* if it produces the maximum feasible output for a fixed level of inputs, or, alternatively, uses the minimum resources to produce a given level of output. Much of the seminal work on technical efficiency and its relationship to production functions is due to Farrell [83].

Allocative efficiency is more encompassing than technical efficiency in that it requires information on the relative prices of inputs and outputs. A firm is allocatively efficient if it produces a given level of outputs at the lowest possible cost, or, alternatively, maximizes benefit (often revenue) for a given cost constraint. Technical efficiency implies a minimum of wasted resources; importantly, it does not imply cost minimization or benefit maximization.

Efficiency measurement techniques in general consist of four classes, depending on whether they are parametric or non-parametric, and whether they are deterministic or stochastic. Each set of techniques has its own strengths and weaknesses. Parametric techniques are regression-based approaches in general, and assume a specific functional form for the frontier, whereas non-parametric techniques do not. Parametric techniques are susceptible to model misspecification, as the efficiency scores are sensitive to distributional assumptions regarding the error term [84].

Deterministic methods do not contain a random error component. Hence, they may be sensitive to extreme observations since they assume that the observed distance to the frontier is due to inefficiency. Stochastic methods are less sensitive to outliers since part of the distance to the frontier can be attributed to random error.

In Section 2.1, we outline the deterministic non-parametric DEA approach and then discuss the parametric stochastic Frontier analysis (SFA) in Section 2.2. The Malmquist index is explained in Section 2.3.

2.1. Data envelopment analysis

The DEA formulation presented in (1a)–(1c) is also known as the *CCR ratio model* after its inventors, Charnes, Cooper, and Rhodes [85]. In the present paper, however, we use the term "DEA" in its broadest possible sense to refer to an entire class of non-parametric, deterministic techniques for efficiency measurement.

As many readers may know, the basic DEA model can be formulated as follows: Suppose there are n decision-making units (*DMUs*), each of which uses m inputs to produce s outputs. Let x_{ij} be the amount of input i ($i = 1,\ldots, m$) used by DMU_j ($j = 1,\ldots, n$); and, let y_{rj} be the amount of output r ($r = 1,\ldots, s$) produced by DMU_j ($j = 1,\ldots, n$). Note that, in all DEA models, x_{ij} and y_{rj} are treated as constants. The variables u_r ($r = 1,\ldots, s$) and v_i ($i = 1,\ldots, m$) are weights. The technical efficiency of DMU_0 is then given by

$$\max = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \tag{1a}$$

subject to

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leqslant 1 \quad \text{for}\, j = 1,\ldots,n, \tag{1b}$$

$$u_r \geqslant 0, v_i \geqslant 0 \quad \text{for}\; r = 1,\ldots,s;\; i = 1,\ldots,m. \tag{1c}$$

The set of constraints in Relation (1b) limits all efficiency scores to a maximum value of unity. The variables u_r and v_i are stated in "efficiency units" that are obtained by solving the maximization problem; it evaluates the behavior of each DMU_0 relative to the performance of all $j = 1,\ldots, n$ *DMU*s. To illustrate the logic of the ratio model, suppose that the numerator in (1a) is fixed. (This is feasible because every ratio has a representative for an arbitrary value of the numerator.) For any such value, the denominator must be minimized (subject to the constraints) as a necessary condition of maximization. Conversely, if the denominator is fixed ($\neq 0$), then the numerator of (1a) must be maximized. Hence, the numerator and denominator are jointly optimized. No other choice of weights can better the resulting efficiency score when these same weights are assigned to all *DMUs*.

The CCR *ratio model* generalized the engineering-science definition of efficiency from its usual one-output-to-one-input ratio in order that the resulting measure could comprehend multiple outputs and multiple inputs without recourse to externally imposed weights. This model provided a basis for unifying DEA with long-standing approaches to efficiency evaluation in other fields, most notably welfare economics and its concept of "Pareto–Koopmans" efficiency.[1]

The *ratio model* was identified as a fractional programming problem in Charnes et al. [85]. By choosing a representative value for the denominator[2], it can be replaced in its input oriented form by an equivalent linear programming formulation as follows (the weight μ_r results from the weight u_r in the Charnes–Cooper transformation):

$$\max \sum_{r=1}^{s} \mu_r y_{r0} \tag{2a}$$

[1]This is similar to the concept of "technical efficiency", as defined earlier. See Cooper et al. [86] for further details.

[2]This is known as the Charnes–Cooper transformation [87].

subject to

$$\sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leqslant 0 \quad \text{for } j = 1, \ldots, n, \tag{2b}$$

$$\sum_{i=1}^{m} v_i x_{i0} = 1, \tag{2c}$$

$$\mu_r \geqslant 0,\ v_i \geqslant 0 \quad \text{for } r = 1, \ldots, s;\ i = 1, \ldots, m. \tag{2d}$$

An alternative, output-oriented model formulation results if, in (1a), the numerator is fixed to 1 and the denominator is minimized.

Taking the dual problem of (2a)–(2d) yields the input-oriented dual form of DEA, as follows:

$$\min\ \theta \tag{3a}$$

subject to

$$\sum_{j=1}^{n} x_{ij} \lambda_j \leqslant \theta\, x_{i0} \quad \text{for } i = 1, \ldots, m, \tag{3b}$$

$$\sum_{j=1}^{n} y_{rj} \lambda_j \geqslant y_{r0} \quad \text{for } r = 1, \ldots, s, \tag{3c}$$

$$\lambda_j \geqslant 0 \quad \text{for } j = 1, \ldots, n. \tag{3d}$$

Here, variable θ_0 represents the radial efficiency of DMU_0 and variable λ_j is the weight placed by DMU_0 on DMU_j. Those $DMUs$ for which $\lambda_j > 0$ comprise DMU_0's *efficient reference set*. Movement toward the best-practice frontier is achieved by reducing current levels of inputs while maintaining the same level of outputs. $DMUs$ for which the optimal solution $\theta < 1$ are inefficient.

For some applications, the goal is to increase outputs for a fixed quantity of inputs. The corresponding dual form of the *output-oriented* model is given by

$$\max\ \phi \tag{4a}$$

subject to

$$\sum_{j=1}^{n} x_{ij} \lambda_j \leqslant x_{i0} \quad \text{for } i = 1, \ldots, m, \tag{4b}$$

$$\sum_{j=1}^{n} y_{rj} \lambda_j \geq \phi\, y_{r0} \quad \text{for } r = 1, \ldots, s, \tag{4c}$$

$$\lambda_j \geqslant 0 \quad \text{for } j = 1, \ldots, n. \tag{4d}$$

Here, $DMUs$ for which the optimal solution $\phi > 1$ are inefficient. The vast majority of DEA studies in health care use the input-oriented model since the goal is to reduce costs rather than increase the volume of services provided.

While the CCR envelopment model (3a)–(3d) assumes constant returns-to-scale (CRS), the model can be easily modified to incorporate variable returns-to-scale (VRS) by adding the following convexity constraint:

$$\sum_{j=1}^{n} \lambda_j = 1. \tag{5}$$

This formulation is called, alternatively, the *VRS model* and the *BCC model*, after its developers, Banker, Charnes, and Cooper [88].

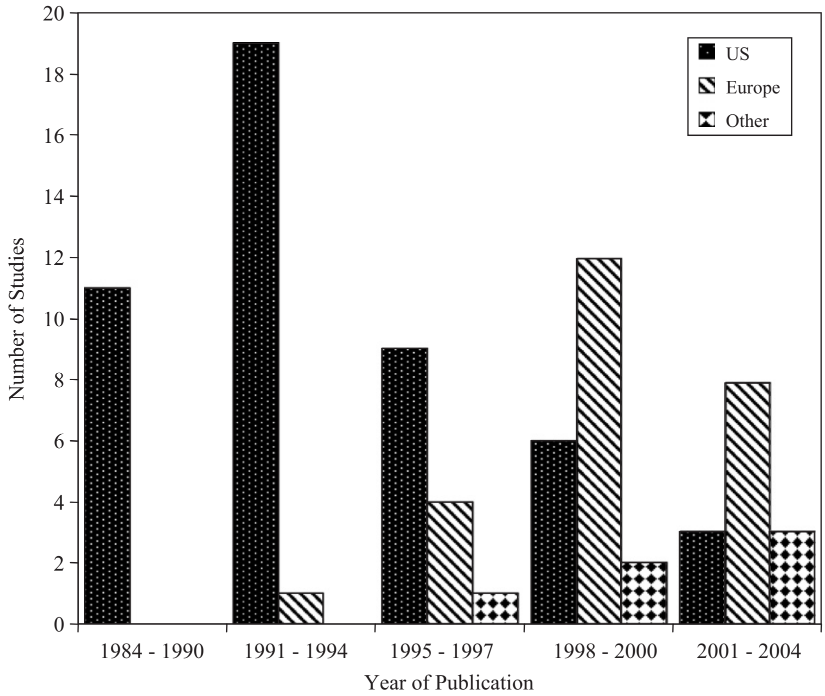

Fig. 1. Number of DEA hospital efficiency studies over time, and by country.

Sherman [72] first applied DEA to measure the efficiency of seven US teaching hospitals more than 20 years ago. DEA has since been applied to other health care providers, including physicians [89,90], nursing homes [91], and health maintenance organizations [92].

The pattern of DEA hospital efficiency studies over time is presented in Fig. 1. From 1984–1994, there were 30 published DEA papers involving US hospitals. By the late 1990s, the number of such studies seemed to have peaked. Although the first study of European hospitals [23] did not appear until 1994, such DEA applications spread rapidly thereafter. Since 1998, Europe has passed the US in number of studies published per year. Beginning in 1997, several studies from other countries have appeared, including Canada [32,68], Kenya [39], Taiwan [14], and Turkey [22,70]. Clearly, the proliferation of DEA studies for measuring hospital efficiency did not occur "overnight." Rather, the original idea required adaptation and re-interpretation to suit each context.

DEA's main advantages for health care applications are its flexibility and versatility; it requires no information on relative prices, and can easily accommodate multiple inputs and outputs. It is also computationally easy to use. Yet, these strengths also give rise to some practical limitations. For instance, the lack of restrictions on prices can lead to difficulties. When the number of observations is small relative to the sample size, efficiency scores can become inflated. A large proportion of firms may thus be identified as efficient due to a lack of sufficient degrees of freedom. A need then arises to discriminate among efficient units, such as by incorporating information on the relative values of the inputs and outputs.

A number of techniques have been developed over time in an effort to extend DEA toward the measurement of both allocative and technical efficiency. These include the cone-ratio [93] and assurance-region (AR) [94] approaches, which impose reasonable bounds on the input and output weights in objective function (1a) and relation (1b). When relative prices are known, then allocative efficiency can be estimated using *allocative efficiency* DEA models, as first developed by Färe et al. [95].

Numerous extensions and diagnostics have been developed to address the limitations of deterministic methods (for a bibliography, see Cooper et al. [96]). Stochastic DEA is a variation of the original DEA model that can separate inefficiency from random error [97]. It has generated a good deal of work in recent years [98,99].

2.2. Stochastic Frontier analysis

A number of studies have compared DEA with parametric techniques for efficiency measurement, most notably SFA [17,25,26,38,40,41,100]. SFA is an econometric technique for estimating production functions and measuring allocative and technical efficiency [101,102]. The basic model can be expressed as follows:

$$y_i = f(x_{i,}\beta) + v_i + u_i \quad \text{for } i = 1, \ldots, m. \tag{6}$$

Here, y_i ($i = 1, \ldots, m$) is the maximum output obtainable from x_i, a vector of non-stochastic inputs; β is an unknown parameter vector to be estimated; v_i is statistical noise, assumed to be distributed as N(0,σ^2); and u_i represents technical inefficiency, with $u_i \leqslant 0$ [101,102].

Unlike ordinary least-squares (OLS) regression, SFA models the error term in two parts: The first (u_i) measures the distance from the frontier (inefficiency), while the other (v_i) measures statistical noise. As a parametric technique, SFA results are less sensitive to extreme observations. However, it requires strong assumptions about the distribution of the error terms, which makes it vulnerable to model misspecification. SFA measures both allocative and technical efficiency; hence, it requires information on relative prices.

Several studies have compared SFA and DEA for both European and US hospitals with mixed results. In the European studies, there was generally broad agreement between DEA and SFA for overall levels of inefficiency. However, some differences arose in efficiency scores for individual facilities. In a study of 232 English hospitals, for example, Jacobs [38] found a correlation of 0.42–0.63 between DEA and SFA scores, where the discrepancy was attributed, in part, to statistical noise. Linna and Hakkinen [41] found similar correlations (0.28–0.59) between the techniques in a study of 95 Finnish hospitals. In contrast, a study of 186 US hospitals by Chirikos and Sear [17] found very low correlations (0.13–0.33) between the two methodologies. Whereas SFA suggested that smaller hospitals were more efficient than larger ones, the DEA model found just the opposite.

One reason given for the discrepancy involves how each model handles extreme observations [38]. SFA results are based on average parameter values; hence, the effect of outliers tends to be smoothed away. In contrast, DEA contains no statistical error term, and, thus, extreme observations can have a significant impact on the frontier. Several methods have recently been developed to address this issue, including the "envelopment map" as described in Cooper et al. [96], bootstrapping methods [103], and sensitivity analysis [86].

Whereas the perceived advantages of SFA versus DEA have been well-documented, especially in the economics literature, its potential drawbacks for hospital efficiency studies have received less attention. SFA, for example, cannot readily identify the source of the inefficiency, which makes it difficult for hospital managers to take remedial action [100]. Does the inefficiency then stem from using the wrong mix of inputs (allocative inefficiency), using too much of some inputs (technical inefficiency), or because it is too large or too small (scale inefficiency)?

Unlike DEA, SFA cannot readily accommodate multiple outputs and inputs simultaneously. Hence, SFA applications will typically use either one input (total cost) or one output (total revenue). Whereas it is possible to use multivariate SFA to accommodate multiple dependent variables, the problem then becomes how to combine residuals from the different models.

Another basic difference between the two techniques invovles the principle of optimization. DEA performs a separate such step for each hospital, where the focus is on the individual institution. In contrast, SFA requires only two optimization steps, regardless of the sample size: The first estimates the parameters of the production frontier, while the second estimates the distance of each hospital from the frontier. The primary aim of SFA is to estimate empirical production functions for a collection of hospitals rather than measure inefficiency for an individual facility. As such, SFA is better suited for health care policy analysis than for managerial decision-making at a given hospital.

2.3. The Malmquist index

The Malmquist index is one of the most frequently used techniques to measure productivity changes over time. First introduced by Sten Malmquist [104] in the context of consumer theory, it was later adapted to productivity measurement by Caves et al. [105]. Färe et al. [23] extended its use to decompose productivity changes into changes in both technical efficiency and the best-practice frontier (also called ''technology''). The main disadvantage of the Malmquist index is the necessity to compute the distance function. The distance functions employed by Färe et al. [23] are the reciprocal of the Farrell [83] output-oriented technical efficiency measures, and are similar to the DEA output-oriented model [106]. Thus, a score of greater than one implies productivity regress, whereas a score of less than one implies a positive gain in efficiency over time.

The Malmquist index can be further decomposed by disaggregating changes in technical efficiency into changes in scale efficiency and input congestion [23]. In terms of computational steps, the index typically requires solving six linear programs for each unit under analysis [73]. This technique was later extended to measure both allocative and technical efficiency for the case where input prices are known [39].

3. Description of taxonomy

An important distinction in hospital efficiency studies is whether the research measured technical efficiency alone, or some combination of technical and allocative efficiencies. Allocative models assume that relative prices are known and are reasonably stable, and that there is substitutability among the inputs. If the focus is on the health care *system* (i.e., for health care *policy*), then it is usually preferable to measure allocative efficiency, also referred to as ''cost efficiency.'' On the other hand, if the focus is on the individual hospital (i.e., for health care *management*), then it is often preferable to identify the source of the inefficiency in order to take remedial action. The crux of the issue is whether to assign global prices or to give individual hospitals some flexibility with respect to the input and output weights in Objective Function (1a).

Assigning global prices to US hospitals can be problematic for a number of reasons. Although price data may exist, they frequently do not reflect the actual costs of services provided, and, hence, may contain little, if any, economic information [11,84].

Most US hospitals operate as free-standing businesses that compete with each other for patients, and there is no central authority that sets budgets. Only 26% of US community hospitals are publicly financed, while approx. Fifteen percent are part of investor-owned chains [107]. Thus, in practice, many American hospitals tend to act as if they were independent businesses. That is, they pursue strategies that maximize their own individual welfare rather than that of a global hospital system. For example, one hospital may develop a comparative advantage in neurosurgery or cardiac surgery in order to attract patients from nearby, competing hospitals [108]. On the other hand, there is a high degree of horizontal integration among such hospitals, and this may, to some degree, curtail the autonomy of individual facilities.

In addition, non-profit hospitals cannot be assumed to be revenue-maximizers since their mission will typically include other dimensions, such as providing charity care, research, and teaching. Hence, there are good reasons to choose a model that allows for some flexibility in determining the optimal set of ''weights'' for the input and output categories in Objective Function (1a). However, giving hospitals total freedom with respect to the relative weights may also be problematic since the DEA model may assign zero weights to important inputs or outputs.

Our proposed taxonomy of efficiency studies is presented in Fig. 2, with a summary of the essential features of each study listed in Tables 1 and 2. Studies were classified into four groups depending on the type of efficiency measured (technical vs. allocative), and whether the study measured a single period or multiple time periods. We thus obtain the following four groups of investigated studies: (1) technical efficiency with a single time period; (2) technical efficiency with multiple time periods; (3) allocative efficiency with a single time period; and (4) allocative efficiency with multiple time periods.

In practice, the distinction between allocative and technical efficiency is often a matter of degree, depending on the amount of flexibility given to the relative weights of the input and output categories in Objective Function (1a). A study was considered to measure allocative efficiency if it used a global set of relative prices for all hospitals. To illustrate, adding various cost components (e.g., labor, capital, and other operating expenses) to obtain ''total costs'' would be an example of allocative efficiency [17].

The classification in Fig. 2 is thus a necessary over-simplification. Nevertheless, it does provide a useful mental map of these studies, since one must know what the objective is prior to determining the best way to

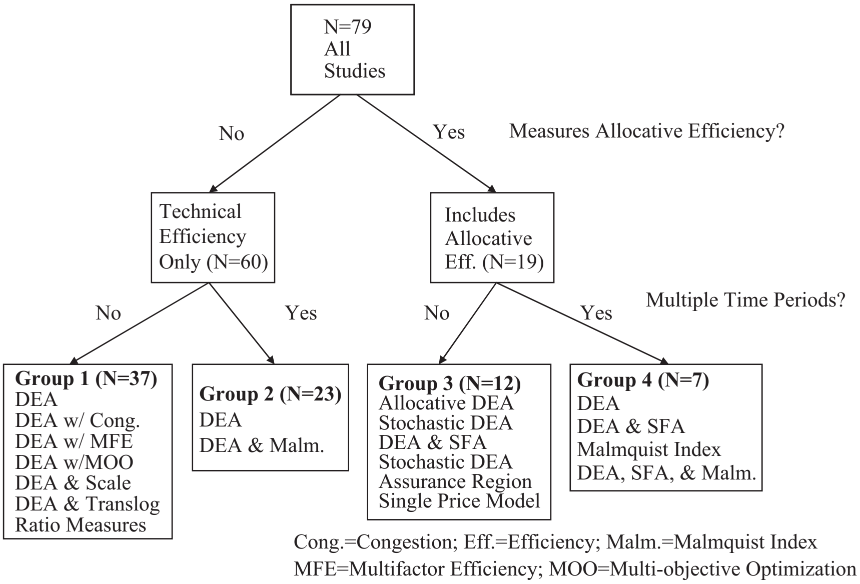

Fig. 2. Categorization of hospital efficiency studies and associated efficiency models.

achieve it. Having defined the criteria by which the studies were catagorized, we now consider each of the four groups presented in Fig. 2.

Group 1:

Thirty-one of the 37 studies in this group used the "standard" DEA model, as defined previously. Novel applications and extensions include DEA with congestion [30], multifactor efficiency [55], multi-objective optimization [7], scale efficiency [44], and translog cost functions [4]. Congestion in DEA occurs when inefficiency is caused by excess resource use that generates a decline in output [95,109]. Grosskopf et al. [30] examined congestion in teaching hospitals and found that 20 percent of overall inefficiency was due to the excess use of residents. O'Neill [55] used multifactor efficiency to assess the performance of 27 urban hospitals and found this technique offers several benefits that enhance and complement existing performance measures in DEA.

Multifactor efficiency is an alternative to radial super-efficiency that incorporates the slack values from the super-efficient model [55,110]. Banker et al. [4] compared the VRS–DEA model (see Eq. (5)) with translog cost functions for measuring hospital efficiency and found that the former offers the advantage of distinguishing scale efficiency from overall efficiency. Ozcan and McCue [62] showed that financial ratios, constructed by DEA, to assess the performance of 170 acute care non-profit US hospitals were an effective overall financial performance measurement compared to standard financial performance ratios. Nineteen of these facilities were considered top performers based on the DEA model.

Group 2:

Fifteen of the 23 studies in this group used DEA alone to measure changes in technical efficiency over time. Seven studies used DEA in combination with the Malmquist index [10,23,45,49,68,73,74]. One advantage of this approach is that it can measure technological change (i.e., movement of the efficient frontier) over time as well as changes in the efficiency of individual facilities, e.g., hospitals. Ehreth [21] used various clinical output–input ratios to measure efficiency changes over time. She found the technical efficiency measure to be the most robust measure of those evaluated for the hospital example presented.

Using longitudinal data has several advantages compared with the use of cross-sectional data. Comparing the same hospital with itself over multiple years provides additional insights, and a further validity check on data accuracy. For pooled analysis, such a comparison may allow for increased discrimination among efficient units and the inclusion of additional variables. This is especially true for European studies that typically involve fewer hospitals.

Table 1
Summary of hospital efficiency studies that use DEA and technical efficiency ($N = 60$)

Reference	Group	Year	Country	Efficiency model	Type of efficiency	No. of *DMUs*	No. of input categories	No. of output categories	*DMU*–categories ratio	Multiple years	Mean efficiency scores	Percent efficient *DMUs*
[5]	1	1995	US	DEA	Tech.	284	6	2	35.5	N	0.82	0.20
[11]	1	1996	US	DEA	Tech.	2246	7	6	172.8	N	0.83	0.21
[16]	1	1994	US	DEA	Tech.	189	2	2	47.3	N	0.65	N/A
[18]	1	1998	Spain	DEA	Tech.	94	4	8	7.8	N	0.94	0.53
[20]	1	1991	US	DEA	Tech.	105	9	2	9.5	N	N/A	0.55
[22]	1	1997	Turkey	DEA	Tech.	573	3	3	95.5	N	N/A	0.09
[24]	1	1996	US	DEA	Tech.	360	2	6	45.0	N	0.79	N/A
[27]	1	1987	US	DEA	Tech.	82	4	4	10.3	N	0.94	N/A
[28]	1	1993	US	DEA	Tech.	108	4	4	13.5	N	0.86	0.15
[29]	1	2001	US	DEA	Tech.	792	6	5	72.0	N	0.72	0.21
[31]	1	2003	US	DEA	Tech.	254	6	3	28.2	N	0.71	N/A
[32]	1	2001	Canada	DEA	Tech.	168	5	3	21.0	N	0.74	N/A
[33]	1	1994	US	DEA	Tech.	93	3	3	15.5	N	0.90	0.54
[36]	1	1995	UK	DEA	Tech.	75	6	6	6.3	N	0.97	0.75
[37]	1	1990	US	DEA	Tech.	213	5	3	26.6	N	N/A	0.25
[39]	1	2002	Kenya	DEA	Tech.	54	11	8	2.8	N	0.96	0.74
[50]	1	1998	Norway & US	DEA	Tech.	228	3	5	28.5	N	0.92	N/A
[56]	1	1992	US	DEA	Tech.	40	3	5	5.0	N	0.85	0.23
[57]	1	1995	US	DEA	Tech.	319	4	2	53.2	N	0.86	0.19
[59]	1	1993	US	DEA	Tech.	3000	4	3	428.6	N	N/A	0.45
[60]	1	1992	US	DEA	Tech.	3000	4	3	428.6	N	N/A	0.43
[61]	1	1992	US	DEA	Tech.	1535	4	3	219.3	N	0.88	0.44
[63]	1	1996	US	DEA	Tech.	85	4	2	14.2	N	0.65	0.09
[65]	1	1992	US	DEA	Tech.	158	5	3	19.8	N	0.85	0.32
[70]	1	2000	Turkey	DEA	Tech.	80	6	3	8.9	N	0.88	0.45
[71]	1	1989	US	DEA	Tech.	159	7	6	12.2	N	N/A	0.67
[72]	1	1984	US	DEA	Tech.	7	3	4	1.0	N	N/A	0.71
[75]	1	1990	US	DEA	Tech.	41	4	4	5.1	N	0.95	0.27
[76]	1	1992	US	DEA	Tech.	41	6	5	3.7	N	0.98	N/A
[78]	1	1996	US	DEA	Tech.	170	4	2	28.3	N	0.78	0.11
[79]	1	1992	US	DEA	Tech.	22	1	3	5.5	N	0.68	0.14
[30]	1	2001	US	DEA w/ Congestion	Tech.	213	6	5	19.4	N	0.82	N/A
[55]	1	1998	US	DEA w/ MFE	Tech.	27	4	4	3.4	N	0.98	0.55
[7]	1	1987	US	DEA & MOO	Tech.	160	3	15	8.9	N	N/A	0.64
[44]	1	1990	US	DEA & Scale	Tech.	55	3	2	11.0	N	0.92	0.38
[4]	1	1986	US	DEA & Translog	Tech.	114	4	3	16.3	N	N/A	0.41
[62]	1	1996	US	Ratio Measures	Tech.	170	N/A	N/A	N/A	N	N/A	0.11

[8]	2	1988	US	DEA	Tech.	52	4	9	4.0	Y	0.96	N/A
[9]	2	1993	US	DEA	Tech.	89	5	5	8.9	Y	0.96	0.68
[12]	2	1998	US	DEA	Tech.	1545	7	6	118.8	Y	0.93	N/A
[14]	2	1998	Taiwan	DEA	Tech.	6	3	2	1.2	Y	0.95	0.34
[15]	2	2000	US	DEA	Tech.	80	4	2	13.3	Y	0.78	0.12
[19]	2	1991	US	DEA	Tech.	300	20	31	5.9	Y	N/A	N/A
[34]	2	2000	US	DEA	Tech.	20	4	2	3.3	Y	0.88	0.35
[35]	2	2002	Austria	DEA	Tech.	31	4	2	5.2	Y	0.96	0.45
[42]	2	1994	US	DEA	Tech.	1535	4	3	219.3	Y	0.88	0.44
[43]	2	1996	Norway	DEA	Tech.	46	3	8	4.2	Y	0.94	0.31
[54]	2	1983	US	DEA	Tech.	16	1	3	4.0	Y	0.90	0.31
[58]	2	1994	US	DEA	Tech.	124	6	2	15.5	Y	0.95	0.60
[64]	2	1997	UK	DEA	Tech.	75	6	6	6.3	Y	0.92	0.51
[66]	2	2000	Spain	DEA	Tech.	141	4	8	11.8	Y	0.93	0.58
[77]	2	1999	US	DEA	Tech.	316	4	2	52.7	Y	0.83	0.14
[10]	2	1995	US	DEA & Malmquist	Tech.	1545	7	6	118.8	Y	0.87	N/A
[23]	2	1994	Sweden	DEA & Malmquist	Tech.	17	2	3	3.4	Y	N/A	N/A
[45]	2	1999	UK	DEA & Malmquist	Tech.	75	5	4	8.3	Y	0.90	N/A
[49]	2	2000	UK	DEA & Malmquist	Tech.	23	5	4	2.6	Y	N/A	N/A
[68]	2	2003	Canada	DEA & Malmquist	Tech.	15	4	1	3.0	Y	0.93	0.20
[73]	2	2001	Spain	DEA & Malmquist	Tech.	20	4	5	2.2	Y	0.92	0.48
[74]	2	2000	Austria	DEA & Malmquist	Tech.	22	3	2	4.4	Y	0.95	0.56
[21]	2	1994	US	Ratio Measures	Tech.	N/A	N/A	N/A	N/A	Y	N/A	N/A

Tech. = technical; MFE = mult-factor efficiency; MOO = multi-objective optimization.

Table 2
Summary of hospital efficiency studies that use DEA and allocative efficiency ($N = 19$)

Reference	Group	Year	Country	Efficiency model	Type of efficiency	No. of *DMUs*	No. of input categories	No. of output categories	*DMU*–categories ratio	Multiple years	Mean efficiency scores	Percent efficient DMUs
[1]	3	1999	Greece	Allocative DEA	Alloc.	98	8	4	8.2	N	0.75	0.22
[2]	3	2001	Greece	Allocative DEA	Alloc.	98	8	4	8.2	N	0.81	0.44
[51]	3	1990	US	Allocative DEA	Alloc.	60	5	5	6.0	N	N/A	0.40
[52]	3	1992	US	Allocative DEA	Alloc.	300	1	9	30.0	N	N/A	0.44
[53]	3	1995	US	Allocative DEA	Alloc.	314	4	8	26.2	N	N/A	N/A
[25]	3	2001	Greece	DEA & SFA	Alloc.	91	1	4	18.2	N	0.77	0.20
[38]	3	2001	UK	DEA & SFA	Alloc.	232	1	11	19.3	N	0.94	0.47
[41]	3	1998	Finland	DEA & SFA	Alloc.	95	1	8	10.6	N	0.89	N/A
[69]	3	1993	US	Stochastic DEA	Alloc.	40	4	4	5.0	N	0.93	0.63
[13]	3	1994	US	Allocative DEA	Tech. & Alloc.	123	6	3	13.7	N	0.94	0.76
[67]	3	2000	Spain	Assurance Region	Tech. & Alloc.	94	4	8	7.8	N	0.97	0.73
[3]	3	2004	Spain	Single Price Model	Tech. & Alloc.	27	2	4	4.5	N	0.91	0.56
[6]	4	2003	Norway	DEA	Tech. & Alloc.	48	4	2	8.0	Y	0.80	N/A
[48]	4	1999	UK	DEA	Tech. & Alloc.	23	5	4	2.6	Y	0.97	N/A
[17]	4	2000	US	DEA & SFA	Tech. & Alloc.	186	6	4	18.6	Y	0.97	N/A
[26]	4	1996	Spain	DEA & SFA	Tech. & Alloc.	75	3	11	5.4	Y	0.96	N/A
[40]	4	1998	Finland	DEA, SFA & Malm.	Tech. & Alloc.	43	1	7	5.4	Y	0.93	N/A
[46]	4	2000	UK	Malmquist Index	Tech. & Alloc.	75	5	4	8.3	Y	0.90	N/A
[47]	4	2003	Greece	Malmquist Index	Tech. & Alloc.	30	3	3	5.0	Y	0.98	0.30

Alloc. = allocative; Tech. = technical; Malm. = Malmquist index; SFA = stochastic Frontier analysis.

Group 3:

Group 3 studies used a variety of approaches to extend the standard DEA model toward allocative efficiency. As mentioned previously, three studies of European hospitals used DEA in combination with SFA [25,38,41]. In spite of the many benefits of stochastic DEA, only one study, by Retzlaff-Roberts and Morey [69], used this approach. They applied a goal-programming version of stochastic allocative DEA to 40 US hospitals, as this technique offered the advantage of separating statistical noise from inefficiency. They identified 15 of the 40 facilities as significantly inefficient.

In a study of 94 Spanish hospitals, Puig-Junoy [67] used the AR approach, which sets reasonable bounds on relative prices. The author concluded that Spanish acute care hospital costs were, on average, 24.5% higher than needed if all facilities were operating on their cost efficiency frontiers. Privately financed hospitals were found to be more efficient than public and non-profit institutions. The degree of market competition contributed positively to increased levels of technical efficiency.

Six studies [1,2,13,51–53] used allocative DEA, an extension of standard DEA, when relative prices are known and relatively stable [95]. Ballestero and Maldonado [3] applied the Single Price Model, which derives a common set of DEA prices, to rank the activities of 27 Spanish hospitals. They found ten globally efficient *DMUs* and 11 scale efficient *DMUs*.

Group 4:

Five of the seven studies in Group 4 used DEA in conjunction with another technique such as SFA [17,26], the Malmquist index [46,47] or both [40]. These studies required a more complex design than those using cross-sectional data. Most included comparisons or extensions of these methodologies. Linna [40] applied four different DEA models, two SFA models, and one Malmquist productivity index model to measure the cost efficiency of Finnish hospitals from 1988 to 1994. They found that the choice of modelling technique did not affect the results. Maniadakis and Thanassoulis extended the Malmquist index to accommodate prices in their studies of 75 English hospitals [46] and 30 Greek hospitals [47]. They showed, for example, that, in Greece, productivity regressed in the year after reforms but progressed thereafter. The net progress was due to both inputs and costs.

3.1. Statistical methods

Studies were classified into three groups based on their country of origin: Europe ($n = 25$), US ($n = 48$), and other countries ($n = 6$). Statistical tests were used to identify significant differences between Europe and the US for various study characteristics: number of *DMUs*, input categories, output categories, allocative efficiency (Y/N), multiple time periods (Y/N), average efficiency score, and the percentage of efficient units (see Table 3). The Wilcoxon rank sum test was used to test for significant differences in the ordinal variables, while the chi-squared test was used for categorical variables. Several studies used alternative model specifications. In these cases, the number of input and output categories was based on the "full model," with all categories included. Categories that were aggregated prior to solving the DEA were counted as one category. For example, "total costs" was considered a single category, even though it included both "labor" and "material costs" [41].

Table 3
Cross-national comparisons of hospital DEA studies

	Europe	US	Other countries	Difference: US−Europe	*P*-value
Number of studies ($N = 79$)	25	48	6		
Study characteristics					
DMUs	75	440	149	365.1	0.001
Inputs	3.8	4.8	5.5	1.0	0.110
Outputs	5.4	4.7	3.2	−0.7	0.041
Inclusive allocative efficiency	52%	12%	0%	−40%	0.000
Multi-year	60%	25%	33%	−35%	0.006
Average efficiency score	91%	86%	89%	−5%	0.050
% Efficient	47%	37%	37%	−10%	0.081

More than 80% of the 79 studies in the sample provided detailed results on efficiency scores (see Tables 1 and 2). Efficiency results were typically reported for two or more groups. In these cases, a weighted average was computed in which the efficiency scores were weighted by their respective sample sizes (e.g., for teaching and non-teaching hospitals). In order to provide a consistent basis for comparison, we used the "pure technical efficiency" scores wherever possible. These are equivalent to the VRS–DEA scores. When these were not available, we employed the "technical efficiency" scores (equivalent to the CCR model), followed by "overall efficiency" scores.

4. Results of cross-national comparisons

4.1. General findings

As shown in Table 3, significant differences exist between Europe and the US in terms of important study characteristics. Fifty-two percent of European studies incorporated allocative efficiency, compared with 12% of US studies. Sixty percent of European studies used panel data, compared with 25% of the US studies. Of those studies that used panel data, eight of 15 (53%) of the European studies used the Malmquist index approach. In contrast, only one of 15 US studies (7%) did so [10].

Average efficiency scores and the percentage of efficient hospitals were both slightly higher for European studies (91% vs. 86%; $p = 0.05$) and (47% vs. 37%, $p = 0.08$), respectively. The average number of hospitals was significantly larger in US studies (440 vs. 75; $p<0.01$). European studies tended to use slightly fewer input categories (3.8 vs. 4.8; $p = 0.110$) but more output categories (5.4 vs. 4.7; $p<0.05$).

European studies were significantly more likely to use panel data than were US studies. Panel data offer several advantages over cross-sectional data, especially for measuring the impact of changes in hospital reimbursement. During the 1990s, many European countries implemented market-based reforms through alternative systems of hospital financing [111]. For example, countries such as Austria and Germany switched from a day-based to a diagnosis-related groups (DRG)-based financing system of inpatients, which was first implemented in the US [112–114]. DRGs are a classification of inpatient cases into clinical groupings based on expected resource use. Classification is based on variables such as: major organ system, age, sex, whether surgery was performed, and whether complications or co-morbidities were present.

Several European studies (e.g., [6,26,35,45,49,74]) have used DEA to measure potential changes in technical efficiency over time as a result of new financing systems. Sommersgutter–Reichmann [74] used the Malmquist index to measure changes in efficiency for 22 Austrian hospitals and found a significant positive shift in efficiency due to the new system. Another study of 31 Austrian hospitals [35] over a similar time period found no significant change in efficiency. Efficiency gains were found following changes in hospital financing for several other countries, however, including Spain [26], the United Kingdom [45], and Norway [6]. On the other hand, it was not clear why the Malmquist index was seldom used in US studies compared to European efforts.

Due to a larger American population, US studies had significantly more hospitals (440 vs. 74) and hospitals-per-category (53 vs. 8; $p<0.001$) than did the European studies. This may partially explain the observed difference in efficiency scores between the European and US studies. When the number of observations is small relative to the number of input and output categories, efficiency scores will tend to be biased upwards. According to the "Golden Rule" of DEA, the sample should have at least three times as many *DMUs* as the total number of output and input categories [115]. Only six studies had a ratio of less than three observations per category [14,39,48,49,72,73]. One caveat for the use of these statistical tests is the assumption that the current studies comprise a random sample from an infinite population. In this case, however, the population of hospital efficiency studies is obviously finite.

4.2. Other methodological considerations

4.2.1. Input vs. output orientation

Hospital managers and policy-makers generally have more control over their inputs than their outputs, and, in a majority of countries, the emphasis is on controlling costs rather than increasing demand for health care.

Hence, the vast majority of studies analyzed here used the input-oriented DEA model, as presented in (3a)–(3d).

Burgess and Wilson [10–12] used both input- and output-oriented DEA models in their studies of US hospitals. For example, they showed that since technical inefficiency could be reflected in radial, slack, or scale inefficiency, it was difficult to generalize which hospital ownership type was more or less efficient than another [11].

The Malmquist index approach commonly employs the output-oriented DEA model (see (4a)–(4d)). For this approach, a score of less than one indicates technological progress, whereas a score greater than one indicates regress. In this regard, Färe et al. [23] investigated 17 Swedish hospitals and found a wide variation in performance during the period 1970–1985. Technical inefficiency was present while technical regress was fairly common. A recent study by O'Neill and Dexter [108] used an output-oriented DEA model to identify best-practices in market capture for eight different surgical specialties. The goal was to increase surgical volumes by identifying overlooked surgical markets.

4.2.2. *DEA under constant and variable returns-to scale*

About half the efficiency studies used the CRS model, which assumes CRS. The remainder used either VRS–DEA or both VRS and CRS, as given by (3a)–(3d) and (5), respectively. Numerous studies have found evidence of scale economies in hospital efficiency [1,49,56,70]. Athanassopoulos et al. [1], for example, found that 68% of rural, Greek hospitals could increase performance by expanding their scale of operations. Sahin and Ozcan [70] found that efficient hospitals in Turkey were almost twice as large as inefficient ones, as measured by number of beds. Ozcan [56] showed the effect of scale size on efficiency scores for US hospitals, and recommended grouping hospitals by bed size.

Several studies [e.g., 11,34] applied both the VRS and CRS models in order to distinguish "scale efficiency" from "pure technical efficiency." Maindiratta [44] introduced "size efficiency" in DEA, which is similar to the concept of the "most productive scale size" (MPSS) for a fixed level of production. The MPSS of an efficient unit refers to the point (on the efficient frontier) at which maximum average productivity is achieved for a given input/output mix [116]. At MPSS, constant returns to scale are operating; after reaching MPSS, decreasing returns to scale set in.

4.2.3. *DEA with quality measures*

Only six of 79 studies included quality measures, with four of these involving US efforts [19,52,53,55]. The measures included "risk-adjusted in-hospital mortality" [52,53,55,70], "risk-adjusted readmissions" [19], "number of clinically active infections" [73], and "complications" [19]. Selected obstacles have precluded quality considerations in efficiency studies, including the lack of a widely accepted quality measure, and the reluctance of many providers to release outcomes data.

Some have argued that resource use seeming to be inefficient, could enhance the quality of care, and that apparent gains in efficiency may come at the expense of quality [117]. In a study of 41 US hospitals, for example, Valdmanis [75] found that public hospitals were more efficient than private, non-profit facilities. She hypothesized that the observed differences in efficiency may have been due to a lower quality of care in public hospitals. While some have criticized hospital DEA studies for excluding quality measures [118], there is little evidence that efficient facilities provide better or worse quality care than their inefficient counterparts. More research is needed in this area, especially at the physician-level [89].

5. Input categories

Hospital input categories fall into three broad sub-categories: capital investment, labor, and other operating expenses. We thus further classified our input categories into the following sub-categories: "beds" (Section 5.1; Table 4), "clinical staff" (Section 5.2; Table 5), "non-clinical staff" (Section 5.3; Table 6), "working hours" (Section 5.4), "services offered" (Section 5.5), "costs" (Section 5.6; Tables 7–9), and "atypical and specific input categories" (Section 5.7).

In Tables 4–9, the rows contain the inputs and their sub-categories. A column covers studies with similar input sub-categories. For example in Table 7, studies [2,16] both consider operating expenses measuring the value of non-labor inputs. This is indicated by an "X" at the intersection of the respective row and column.

5.1. Beds

The number of fully staffed hospital beds is most often used as a proxy for hospital size and capital investment. Fifty-five of the 79 studies included the number of beds as an input category. Three of the studies [25,38,40] that did not include "beds" used only one input category, "hospital costs." Each of these studies also used SFA along with DEA. As noted previously, SFA cannot readily accommodate multiple inputs and outputs. This may explain why "beds" was excluded as an input from these studies.

Several studies disaggregated hospital beds into acute-care and long-term care, acute and intensive care unit (ICU) beds, long-term beds, and the number of beds and wards (see Table 4). Sherman [72], for example, used the "number of bed-days available." DesHarnais et al. [19] distinguished between "acute beds," "pediatric beds," "obstetric beds," "psychiatric beds," "sub-acute/long-term care beds," and "intensive care/other special beds."

5.2. Clinical staff

About two-thirds of hospital operating costs are due to payroll expenses. Labor costs vary significantly by geographic region; hence, the majority of studies included the "number of clinical staff" as a proxy for "labor costs" (see Table 5). Most studies that did not include "clinical staff" used "labor costs" instead. Hospital clinical staff consists of physicians, nurses, and other health/medical personnel. Several studies disaggregated "physicians" into "specialist" and "generalist physicians" [22,70], "medical residents" [29–31], and the "surgeons" [1]. The nursing category has been further disaggregated into "registered nurses," and "licensed practical nurses" in several studies [10–12,29–31].

Six studies [7,8,24,37,55,74] defined "number of personnel" as a general labor input category. Hollingsworth and Parkin [36] and Parkin and Hollingsworth [64] assigned atypical clinical labor parameters to inputs. These included "trained, learning, and other nurses," "junior and senior non-nursing medical and dental staff," and "professional, technical, administrative, and clerical staff."

5.3. Non-clinical staff

Several studies included the number of "non-clinical staff" as a hospital input. This category included "technical, managerial, and other staff" (see Table 6). Sexton et al. [71] used "number of health technical staff," while Kirigia et al. [39] employed "number of technical and technological staff" as input categories. Eight studies [2,14,32,39,47–49,56] considered administrative staff in their input set.

Four studies [9–12] added the "number of non-clinical staff" as an input category, two [18,67] included "number of other non-sanitary staff," and 15 studies [5,6,26,29–31,39,43,45,46,50,58,66,73,76] considered "number of other staff."

Table 4
Input categories: number of beds

Study (citation number)	[1–3,5,8,13,15,18–20,22,24,26,29–36,42,43,45,46,48–53,55–61,63–67,69,70,73,74,76–78]	[37]	[9–12]
Beds			
No. of beds	X		
No. of acute beds			X
No. of acute and ICU beds		X	
No. of long-term hospital beds			X

Table 5
Input categories: clinical staff

	[1]	[2]	[5]	[6,26,50]	[8,32,48,49]	[9,66,73]	[10–12]	[14,18,33,45–47,67]	[15,34,42,57,59,60,61,63,77,78]	[19]	[22]	[27,28]	[29–31]	[36,64]	[39]	[43]	[56]	[58]	[65]	[68]	[69]	[70]	[71]	[72]	[75]	[76]
Physician																										
No. of physicians				X				X					X			X*			X	X	X		X		X	X
No. of physicians plus house staff												X														
No. of part-time physicians																							X			
No. of surgeons	X																									
No. of specialized medical doctors/attendings											X											X				X
No. of general medical doctors	X										X											X				
No. of doctors in laboratory examinations	X																									
No. of medical residents/interns													X										X		X	
No. of medical officers/pharmacists/dentists															X											
No. of provider staff (physicians, psychologists)			X															X								
Nurses																										
No. of nurses and/or nursing staff	X*	X	X		X			X							X	X*						X	X		X*	X
No. of registered nurses							X			X			X				X									
No. of licensed practical nurses							X			X			X				X*									
No. of nursing support staff										X							X*	X								
No. of trained, learning, and other nurses														X												
Medical/clinical/health staff																										
No. of non-physician staff												X									X			X	X*	
No. of non-physician and part-time staff									X										X							
No. of professional allied health staff										X							X									
No. of non-professional health staff																	X									
No. of medical/clinical/health staff		X				X																				
No. of junior/senior non-nursing medical and dental staff														X												
No. of long term care staff							X																			
No. of stretchers																				X						
No. of other medical/clinical/health staff							X			X																

*Combined into one input category.

Table 6
Input categories: non-clinical staff

	[1]	[2]	[5,6,26,29–31,43,45,46,50,58,66,73]	[9–12]	[14]	[18,67]	[19]	[32,48,49]	[39]	[47]	[56]	[70]	[71]	[76]
Technical staff														
No. of health-technical staff													X	
No. of ancillary technical staff							X							
No. of technical and technological staff									X					
Management and administrative staff														
No. of clinical officers									X					
No. of management staff	X													
No. of administrative staff		X*						X	X		X			
No. of administrative and other staff										X				
No. of general and administrative staff					X									
Other staff														
No. of non-clinical staff				X										
No. of other non-sanitary staff						X								
No. of house staff														X
No. of supporting staff							X							
No. of subordinate staff									X					
No. of ancillary service staff								X						
No. of other professionals												X		
No. of other staff			X						X					X

*Combined with another input category of Table 5 (“no. of nursing and management staff”).

Table 7
Input categories: capital investment and operating expenses

	[2,16]	[4,36,37,64]	[5,6,15,34,42,55–61,63,65,77,78]	[17]	[19]	[25,40]	[27,28,69,75,76]	[51]	[52]	[54]
Operating expenses										
Total operating expenses, excluding salary, interest and depreciation			X							
Operating expenses measuring the value of non-labor inputs	X									
Capital charge										
Total costs of the resources (staff earnings, operating expenses, supplies)						X				
Total inpatient costs										X
Total other inpatient charges				X						
Total other expenses				X						
Fixed costs										
Capital/capital assets/capital charge/capital costs		X		X						
Net plan assets							X	X		
Total interest expenses									X	
Total depreciation				X						
Total deprecation, interest, and fees					X					
Annual expenditures										
Total annual expenditures								X		

Table 8
Input categories: labor costs

	[1]	[3]	[4,44]	[7,16,23]	[17]	[20]	[35]	[48,49]	[52]	[53]
General labor costs										
General labor costs, including salary and benefits	X			X						X
Nursing staff costs										
Expenditures for salaries and benefits for nurses									X	
Nursing services dollars			X							
Wages and salary to patient care staff					X					
Registered nurse salaries						X				
Licensed practical nurse salaries						X				
Other nursing salaries						X				
Medical staff costs										
Expenses for medical staff							X			
Expenses for para-medical staff							X			
Expenses for specialists								X		
Total non-nursing medical staff costs		X								
Expenditures for graduate medical education									X	X
Other staff costs										
Expenses for administrative staff							X			
Expenditures for salaries and benefits for other personnel									X	
Expenditures for fees									X	X
Expenditures for all "other"									X	X
Wages and salary to non-patient care staff					X					
Administrative and general services dollars			X							

5.4. Working hours

The "number of working hours" was a seldom-used input category for hospital efficiency analyses. Notable exceptions are, for example, Burgess and Wilson [9] as well as Linna and Häkkinen [41]; both studies included "physician working hours." Dittman et al. [20] and Quellette and Vierstraete [68] took "nursing hours" and "non-physician hours," respectively, into account.

5.5. Services offered

The number of hospital services has also been used as a proxy for capital investment. This was most common for studies of US hospitals since the necessary data are published in the American Hospital Association (AHA) annual survey [119]. In the non-US studies, however, this category was generally not included as input. Fifteen studies [5,15,34,37,42,56–61,63,65,77,78] used "service mix" as a capital input. Service mix is the total number of diagnostic and special services for both inpatients and outpatients. O′Neill [55] included the "number of technological services" as an input category. This is a measure of a hospital's technological complexity, as well as its capacity to perform complicated surgical procedures such as bypass surgery and organ transplants.

5.6. Costs

The bulk of a hospital's operating costs are due to labor and salaries and other expenses that vary significantly by geographic region. Accurate data on capital investment is difficult to obtain, creating the need to use proxy categories, such as "beds" and "services." Thus, practical considerations have often precluded the use of cost data. Nevertheless, many studies have included various types of cost data in their input set. These can be divided into the following subcategories: "operating expenses and capital investment" (Section 5.6.1), "labor costs" (Section 5.6.2), and "supply and non-labor costs" (Section 5.6.3).

Table 9
Input categories: supply and non-labor costs

	[1]	[2]	[4,44]	[6]	[7,20]	[8]	[23]	[32]	[36,64]	[39]	[41]	[66,73]	[68]	[71]	[72]	[74]
Equipment costs																
Total costs of equipment											X*			X		
Total expenditures for equipment and furniture													X			
Total costs of maintenance of equipment, vehicles, and buildings										X						
Medical supply costs																
Medical supply costs/medical expenses		X		X												
Total expenses for external medical services																X
Total costs of supplies and purchased services															X	
Total costs of services and supplies of all types								X								
Non-pharmaceutical supply costs										X						
Food costs																
Total costs of food and rations										X						
Drug and pharmaceutical costs																
Total costs of drugs and supplies														X		
Pharmaceutical supply costs	X	X							X	X						
Material costs																
Total costs of purchased material											X*	X				
Non-labor costs																
Total non-labor costs	X															
Non-payroll expenses						X										
Real non-labor expenditures							X									
Other costs																
Other supply costs		X														
Total other costs											X*					
Other direct expenses/dollars					X											
Ancillary services dollars			X													

*Combined into one input category.

5.6.1. Operating expenses and capital investment

Sixteen US studies included ''operating expenses excluding payroll, capital, and depreciation'' as an input category [5,6,15,34,42,55–61,63,65,77,78], as shown in Table 7. This category is commonly reported in the AHA Annual Survey [119]. Five studies [27,28,69,75,76] used ''net plant assets'' as an input category, while Morey et al. [51] defined ''total annual expenditures'' as the cost input, apart from ''net plant assets.'' Three studies [36,37,64] presented ''capital assets'' as an input category, while Chirikos and Sear [17] sub-divided hospital costs into ''total other inpatient charges,'' ''total other expenses,'' ''capital costs,'' and ''total depreciation.''

5.6.2. Labor costs

Most studies omitted ''labor expenses'' since these vary significantly by region (see Table 8). Both US and non-US studies accounted for this category at similar levels of use. Staff costs were variously sub-divided into ''general labor,'' ''nursing staff,'' ''medical staff,'' and ''other staff.'' Morey et al. [52] used a regional adjustment factor to control for local variation in wage rates.

5.6.3. Supply and non-labor costs

''Supply and non-labor costs'' were included as an input category twice as frequently in non-US studies since US-based efforts generally employed ''operating expenses.'' These costs were variously sub-divided into ''equipment costs,'' ''medical supply costs,'' ''food costs,'' ''drug and pharmaceutical costs,'' ''material costs,'' ''non-labor costs,'' and ''other costs'' (see Table 9). Several authors employed ''medical supply costs'' [2,6,32,39,72,74] and ''drug and pharmaceutical costs'' [1,2,36,39,64,71] in their input data set.

5.7. Atypical and specific input categories

Atypical input categories were found in two studies. Valdmanis [76] and Grosskopf and Valdmanis [27] defined ''number of admissions'' as an input category, while Maniadakis et al. [45] and Maniadakis and Thanassoulis [46] used ''cubic metres of the hospital building.'' Morey et al. [51] added ''type of ownership'' to their input set.

Young [79] considered ''labor hours per average daily census,'' while Jacobs [38] introduced ''cost index'' as an input. Sahin and Ozcan [70] did the same with ''revolving funds expenditure,'' while Ozcan [56] used ''number of full-time-equivalents excluding physicians,'' ''physicians and dentists on salary,'' ''physicians on the medical staff,'' and ''teaching full-time-equivalents.''

Three studies [28,37,51] included the DRGs ''case mix index'' as an input, which captures the variation in both the complexity and resource-intensity of inpatient cases. In general, however, use of this factor as an input should be avoided since it is more a characteristic of hospital outputs.

6. Output categories

In order to handle the variety of hospital output categories found in the literature, we identified four sub-categories: (1) ''medical visits, cases, patients, and surgeries'' (Section 6.1; Table 10), (2) ''inpatient days'' (Section 6.2; Table 11), (3) ''admissions, discharges, and services'' (Section 6.3; Table 11), and (4) ''atypical, teaching, and specific output categories'' (Section 6.4; Table 12).

Tables 10–12 contain the outputs and their sub-categories. The logic of these tables corresponds to that used to construct tables of the input categories.

6.1. Medical visits, cases, patients, and surgeries

The vast majority of studies included outpatient visits as an output category (see Table 10). Eleven studies [3,19,29,30,36,45,46,52,53,64,76] disaggregated outpatient visits into ''emergency'' and ''non-emergency.''

Twelve studies [18,22,24,27,28,31,33,51,67,69,75,76] included ''surgeries'' as an output factor, while seven [9–12,26,29,30] distinguished between ''inpatient surgeries'' and ''outpatient surgeries.''

Table 10
Outpatient categories: medical visits, cases, patients, and surgeries

	[1,2]	[3,36,64]	[5,6,14,15,25,32,34,42,50,55,56–61,63,65,66,70,73,77,78]	[8]	[9–12]	[18,67]	[19]	[22]	[23]	[24]	[26]	[27,28,33,51,69,75]	[29,30]	[31]	[39]	[40,41]	[43]	[45,46]	[48,49]	[52]	[53]	[68]	[74]	[76]
Medical visits																								
No. of outpatient visits		X	X		X	X	X						X		X		X	X		X	X			X
No. of outpatient and emergency visits								X				X		X										
No. of emergency room visits		X					X						X			X		X		X	X			X
No. of special clinic visits															X									
No. of maternal, child health, family planning visits															X									
No. of dental care visits															X									
No. of scheduled and follow-up visits															X									
No. of doctor visits									X															
Cases																								
No. of cases																						X		
No. of day cases																		X						
No. of cases treated in major DRG categories				X																				
No. of cases treated in non-major DRG categories				X																				
Patients																								
No. of inpatients								X					X	X										
No. of outpatients										X													X	
No. of medical patients	X																X		X					
No. of subacute/long-term patients							X																	
No. of surgical patients	X																X		X					
No. of accident and emergency patients																			X					
No. of maternity patients																			X					
No. of newborns delivered																					X			
No. of normal newborns delivered																				X				
No. of abnormal newborns delivered																				X				
Surgeries																								
No. of surgeries						X		X		X		X		X										X
No. of inpatient surgeries					X						X		X											
No. of outpatient surgeries					X		X				X		X							X	X			

Table 11
Output categories: inpatient days

	[4,50,72]	[5,9,20,35,37,40,41,47,58,65]	[10–12]	[14]	[17]	[18]	[23,32]	[24]	[25]	[26]	[27,51,69,75]	[28]	[36]	[43]	[44]	[52,53]	[54]	[56]	[66]	[67,73]	[76]
General inpatient days																					
No. of inpatient days		X																			
No. of Medicare inpatient days					X													X			
No. of Non-Medicare inpatient days																		X			
No. of Medicaid inpatient days					X																
No. of simple/general/medical inpatient days				X*					X	X				X					X		
Acute inpatient days																					
No. of acute care inpatient days			X	X*		X*		X			X									X	X
No. of acute medical inpatient days													X								
No. of acute surgical inpatient days													X								
No. of acute medical-surgical inpatient days												X									
No. of sub-acute inpatient days						X*		X								X					
No. of intensive care inpatient days				X*		X		X		X	X	X							X	X	X
No. of complex inpatient days														X							
Long-time care inpatient days																					
No. of chronic care inpatient days				X*																	
No. of long-term care inpatient days			X				X							X					X	X	
No. of long-term care and other inpatient days						X															
No. of rehabilitation days																X					
Special hospital division inpatient days																					
No. of surgical inpatient days									X	X				X	X				X		
No. of obstetric inpatient days										X											
No. of obstetrics and gynaecology inpatient days													X						X		
No. of psychiatric inpatient days																			X		
No. of maternity inpatient days																	X				
No. of newborn inpatient days										X											
No. of paediatric inpatient days										X							X*		X		X
Age group specific inpatient days																					
No. of adult/routine-aged inpatient days																	X*				X
No. of elderly inpatient days																					X
No. of inpatient days for certain age groups	X																				
Other inpatient days																					
No. of other inpatient days					X								X		X		X				

*Combined into one input category.

Table 12
Output categories: admissions, discharges, and services

	[1,2,47]	[3]	[6,7,9,15,20,23,24,32–35,42,45,46,52,53,57,59–61,63,70,77,78]	[10–12]	[13]	[17,26,40,41]	[18,67]	[25]	[37]	[39]	[55]	[56]	[64]
Admissions													
No. of admissions						X			X				
No. of general medical admissions										X			
No. of paediatric admissions										X			
No. of maternity admissions										X			
No. of amenity ward admissions										X			
Discharges													
No. of discharges			X				X					X	
No. of Medicare discharges with DRG-High												X	
No. of Medicare discharges with DRG-Medium												X	
No. of Medicare discharges with DRG-Low												X	
No. of Non-Medicare discharges												X	
No. of medical discharges											X		
No. of acute medical discharges		X											X
No. of medical-surgical acute care discharges					X								
No. of medical-surgical intensive care discharges					X								
No. of surgical discharges											X		
No. of acute surgical discharges		X											X
No. of acute care inpatient discharges				X									
No. of obstetrics and gynaecology discharges													X
No. of maternity discharges					X								
No. of other speciality discharges													X
Services													
No. of day care services							X						
No. of ambulatory services									X				
No. of ancillary services								X					
No. of laboratory examinations	X												
No. of medical/clinical examinations	X												

6.2. Inpatient days

Prior to 1983, American hospitals were reimbursed based primarily on total costs; hence, there was little incentive to reduce patient length of stay [111,112]. This changed with the implementation of the Prospective Payment System based on DRGs. Under the new system, the hospital would be paid the same amount for each Medicare patient within a DRG category, regardless of the costs incurred [112]. This represented a significant shift from the "inpatient day" to the "case" as the primary means of hospital reimbursement.

The "gold standard" in the US for measuring inpatient activity is thus DRG-adjusted discharges. As shown in Fig. 3, the use of "inpatient days" as an output category has been steadily decreasing in US studies, from 80% in 1985 to zero currently. In testing alternative model specifications, Ozcan [56] found that efficiency scores were highly sensitive to the form of this category and recommended using "cases" rather than "inpatient days."

In contrast, the reimbursement systems in European countries are more complex and varied [111]. Within the last decade, several countries, such as Austria, Germany, Norway, Spain, and the UK, have moved from "cost-based" to more "case-based" reimbursement in order to better control health care expenditures. Europe has thus followed the lead of the US DRG-system by introducing elements of competition and "deregulation" into hospital financing. Hence, we can expect to see a shift away from "patient days" and toward "adjusted discharges" as a measure of hospital output. Hofmarcher et al. [35], for example, included both "inpatient days" and "discharges" in their model because, at the time, the reimbursement system in Austria was based on inpatient days, independent of diagnoses and treatment. In a later Austrian study by Sommersguter-Reichmann [74], however, "inpatient days" were excluded since this was no longer the main basis for hospital reimbursement.

To capture case-mix, patient days were often disaggregated by: method of payment (e.g., ordinary inpatients and Medicaid/Medicare patients); care intensity (e.g., acute, intensive, and long-term patients); and hospital division (e.g., medical, surgical, obstetric, and psychiatric). Table 11 displays all output sets for this category.

Many studies incorporated treatment intensity by differentiating among "acute care" [10–12,14,18,24,27,51,67,69,73,75,76], "intensive care" [14,18,24,26–28,51,66,67,69,73,75,76], and "long-term

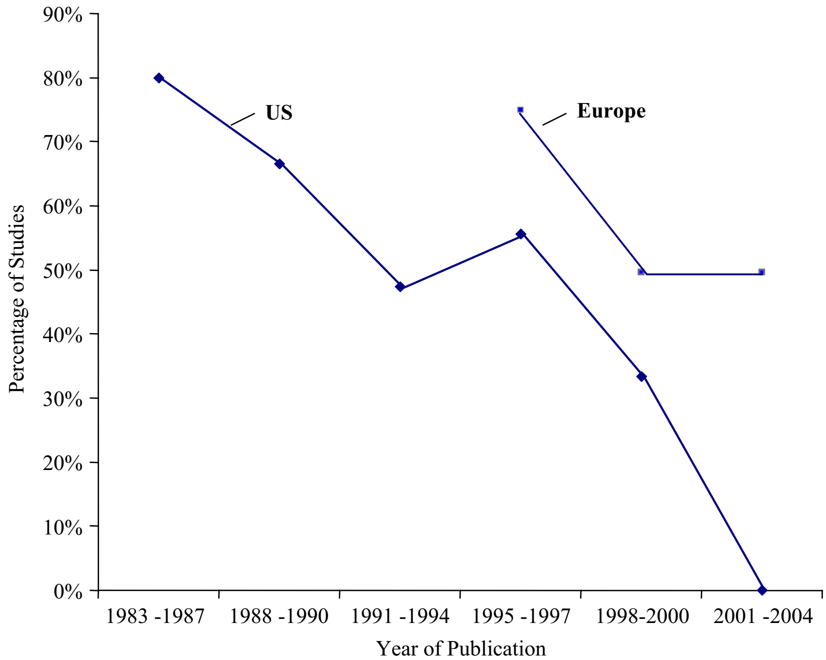

Fig. 3. Percentage of studies that use inpatients days as an output category, shows significant decline due to changes in reimbursement.

care'' [10–12,23,32,43,66,67,73]. A few studies [25,26,43,66] differentiated between ''medical inpatient days'' and ''surgical inpatient days'' within this output group.

6.3. Admissions, discharges, and services

Only a handful of studies, mainly non-US efforts, used the ''number of admissions'' as an output factor. Several studies included DRG-adjusted discharges either as a single output category or as part of their larger output set (see Table 12). A few studies used intermediate hospital products as outputs, such as ancillary services [25] and laboratory examinations [1,2,47].

6.4. Atypical, teaching, and specific output categories

Several US studies addressed the problem of how to compare teaching and non-teaching hospitals [29–31,53,55,56]. The former require additional resources to support their educational mission [53], where medical residents are a source of inexpensive labor. Thus, hospital teaching can be viewed as both a labor input and a teaching and research output. Fourteen studies [18,19,40–42,51,55,56,59–61,65,67,72] included teaching sub-categories in their efficiency analyses. Sherman [72], for example, used ''number of nursing students'' and ''number of interns and residents receiving a 1-year training at the hospital.'' Linna [40] and Linna and Häkkinen [41] proposed ''number of residents,'' ''clinical training weeks of nurses,'' and ''clinical training weeks of medical students'' as outputs. Ozcan et al. [60], Lynch and Ozcan [42], Ozcan and Lynch [61], and Ozcan and Luke [59] included ''sum of medical and dental trainee full time equivalents'' and ''other professional trainee full time equivalents'' as outputs for their efficiency measurements. Ozcan [56] defined ''number of teaching full-time equivalent staff (FTEs)'' as an output factor, while O′Neill [55] used ''residents trained.'' Linna [40] and Linna and Häkkinen [41] measured hospital research as the ''number of scientific publications.'' Morey et al. [52,53] measured teaching output in terms of dollars spent on graduate medical education. Two studies assessed hospital performance using various clinical [21] and financial [62] ratios.

7. Leading contributors to the literature

A summary of the leading individual contributors to the literature studied here is presented in Table 13. Yasar Ozcan was one of the first to adopt DEA for health policy analysis and has authored or co-authored 16 studies on hospital efficiency through 2004 (see Table 13). In addition to numerous studies of US community hospitals, he has examined specialty hospitals, such as military [5,58], psychiatric [63], and teaching [53], as well as two recent studies of Turkish hospitals [22,70].

Vivian Valdmanis has published nine studies of US hospitals, with her recent work focused on reimbursement for teaching and non-teaching hospitals [29–31]. A frequent co-author of Valdmanis, Shawna Grosskopf, has focused on DEA with congestion [30] and the Malmquist index for longitudinal data [23]. Richard Morey has studied allocative DEA [51], DEA with quality considerations [52], and stochastic DEA [69]. James Burgess and Paul Wilson co-authored four studies that examined Veterans Affairs and other US hospital types using panel data and the Malmquist index [9–12].

Table 13
Leading contributors to hospital efficiency literature, by author

Author	Current affiliation	Number of papers
Yasar Ozcan	Virginia Commonwealth University	16
Vivian Valdmanis	University of the Sciences in Philadelphia	9
Shawna Grosskopf	Department of Economics, Oregon State University	6
Richard Morey	School of Hotel Management and Tourism, Griffith University, Queensland, Australia	5
James Burgess	US Dept. of Veterans Affairs	4
Bruce Hollingsworth	University of New Castle upon Tyne, UK	4
Nikolaos Maniadakis	Patras General University Hospital, Greece	4

On the European side, among the leading contributors were Bruce Hollingsworth, Nikolaos Maniadakis, and Emmanuel Thanassoulis. Their frequent collaborations include measuring the effect of market-based reforms on UK-hospital efficiency [45], and extension of the Malmquist index to include price information [46,47].

Prior to 1994, most DEA studies of hospital efficiency appeared in either management science/operations research or health policy and management journals. The outlets that published the most studies during the period 1984–2004 were as follows: *The Journal of Medical Systems* (10), *Health Care Management Science* (HCMS) (9), *Medical Care* (8), *European Journal of Operational Research* (5), *Health Services Research* (4), and *Socio-Economic Planning Sciences* (4). Other notable outlets include *Omega* (3) and *Management Science* (2). HCMS is a relatively new journal that began in 1998 and has affiliations to both US and international/non-US universities. The nine HCMS studies in this review came from a diverse group of countries, including: Austria [35,74], Canada [32], Greece [1], the UK [38,45], the US [29,55], and Spain [66].

The last decade has seen the diffusion of DEA research into related disciplines, such as economics, health economics, and policy analysis. Consider the diversity of journals in which such studies have appeared: *Applied Economics* [46,64], *Journal of Econometrics* [44], *Health Economics* [40], *The Journal of Productivity Analysis* [10,24], *Journal of Public Economics* [76], *Journal of Accounting and Public Policy* [8], *Review of Industrial Organization* [18], and the *IMA Journal of Mathematics Applied in Medicine & Biology* [36]. "Frontier-based techniques for efficiency measurement" was also the subject of a special issue of the *Journal of Health Economics* (vol. 13, 1994).

8. Discussion and conclusions

When the first study on DEA for health care efficiency measurement was published by Sherman [72] more than twenty years ago, it would have been hard to imagine the rapid growth and wide-ranging influence of this research framework. In tracing the diffusion of these studies, the current paper has identified insights into the process by which research ideas spread. The concept of "DEA for hospital efficiency" has proven to be both relevant across disciplines, and surprisingly fluid and versatile, as it has been adapted to numerous health care systems. Taken collectively, the 25 European studies published since 1994 in English have re-vitalized this area, and shown DEA to be a valuable tool for health care policy-making and resource allocation decisions. The European studies differ from their US counterparts in that the majority incorporated price information, used panel data, and combined DEA with other techniques, while, in some cases, extending existing models [23,47].

The external environment was seen to exert significant influence on DEA model development, thus leading to noteworthy differences between US and European studies. In European countries, for example, Health Authorities influence resource allocation, reimbursement, and hospital priorities. In contrast, the US system is more decentralized, and strategy is generally set by the executives of each hospital or hospital system. Thus, as noted previously, the European studies were more likely to measure allocative efficiency and use DEA in conjunction with other techniques, such as SFA and the Malmquist index.

DEA and SFA were found to yield similar efficiency estimates for European hospitals [38,41], but divergent results for their US counterparts [17]. This suggests that allocative inefficiency is more of a problem in the US than in Europe. Such inefficiency occurs when hospitals compete in a medical "arms race" by purchasing expensive technology in order to attract physicians and patients [57]. This strategy might be locally optimal but globally inefficient, since it leads to excess hospital capacity and partially empty surgical suites for some high-technology procedures, such as organ transplantation.

The taxonomy proposed here can serve as a useful tool for policy makers in assembling new DEA-models via a step-by-step process: From selection of the best method, to choice of the input and output categories, and, finally, to presentation of the results. Looking forward, the question arises as to what sort of work remains to be done? Much of the attention to date has been on health policy rather than health management; that is, on the health care system rather than the individual institution. In our view, DEA has yet to make significant inroads into several important areas where it could be of real value, e.g., in support of managerial decision-making within hospitals and outpatient settings.

Several recent studies have begun to move in this direction. O'Neill and Dexter [108], for example, used DEA to determine appropriate levels of capacity expansion for hospital surgical specialties. Also, Chilingerian and Sherman [120] employed DEA to develop quality frontiers for primary care physicians.

Some of the obstacles that have hampered efforts to date include the complexity of health care processes, and the ambiguity surrounding the definition of appropriate input and output categories, as well as the lack of reliable cost data. Yet, this "quagmire" of performance assessment in health care also represents an opportunity for the continued diffusion of DEA in the area.

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Section 3: Annex

Abstract

In Europe, the US, and other Western countries, the interest of executives in containing health care costs and increasing the sector's efficiency has been high on the political agenda. Careful planning and coordination of resource, process, and financial management is imperative for increasing the efficiency of hospitals, which consume a large share of total health care expenditures. To reduce this financial burden, national, regional, and local governments search for suitable approaches.

A first step towards the evaluation of a health care system and, as a consequence, the efficient distribution of human and economic resources in these sectors, is efficiency measurement. Reviewing the application of efficiency measurements in the hospital sector was, therefore, the key motivation for deriving a taxonomy of hospital efficiency studies, which classifies studies using data envelopment analysis (DEA) and related techniques. In this taxonomy a particular focus was placed on identifying the most important input and output variables. The analysis of the input variables served to identify key categories in the decision making processes, whereas the analysis of the output variables aimed at identifying key categories for performance measurement. In the course of the analysis of the input variables, three broad categories were derived: "capital investment", "labor", and "operating expenses". Analyzing the output variables led to "medical visits, cases, patients, and surgeries", "inpatient days", and "admission, discharges, and services" being identified as major categories.

In contrast to ex-post efficiency evaluations using DEA or similar techniques, simulation games, which reproduce the complex decision making processes within hospitals, enable ex-ante evaluations of reforms and the training, for example, of present or future hospital managers. To assess the current state of the art of hospital management games a comprehensive literature review was conducted. A taxonomy was derived to determine the state of the art of existing hospital games, their main characteristics as well as their shortages with respect to, for example, the adaption to new reimbursement systems. This taxonomy categorizes and investigates such games in terms of general classification attributes, application area, target player groups, decision making, and the OR techniques used. The analysis reveals that the core of hospital management games consists of the modeling of the complex decision making processes in internal resource, process, and financial management in the context of the external hospital environment. It also highlights the increasing importance of hospital management games and OR techniques in planning the use of scarce resources in times of tight budgets, growing health care demand, and increasing technology costs.

Having determined the most important variables for decision making and hospital performance, and knowing the state of the art of hospital management games, the business logic of *COREmain hospital*, an internet based hospital management game, was derived. *COREmain hospital* illustrates the economic and organizational decision making processes in

a hospital by using discrete event simulation. The game simulates a region with up to six hospitals competing against each other for inpatients in different disease categories and budgets contingent on hospital missions, regional health policy, inpatient reimbursement systems (day-, case-, or global-budget based) as well as labor and radiology technology markets. Twelve decision periods are simulated. Within different game situations, the players can evaluate the outcome of alternative decisions, as, for example, in capacity planning and patient scheduling. The performance of each hospital is evaluated on pre-selected performance measures at the end of each period. The winner of the game is the hospital player group which performed best both in fulfilling their own hospital mission targets and the regional health policy. *COREmain hospital* is unique due to the internet-based framework, the combination of resource, process, and financial result management, in a set-up with interchangeable reimbursement systems and environmental conditions. It is a promising tool for training more efficient decision making in hospitals. It seeks not only to help students and hospital staff understand decision making in complex situations, but also to illustrate to policy makers how potential changes in regulation impact hospital decision making and outcomes. Its deployment in teaching, policy, and research might improve policy making at the hospital, regional, and national levels.

Zusammenfassung

In Europa, den USA und vielen anderen westlichen Ländern sind Maßnahmen zur Kostendämpfung und Effizienzsteigerung im Gesundheitssektor seit geraumer Zeit Gegenstand der politischen Diskussion. Eine sorgfältige Planung und Koordination von Ressourcen, Prozessen und Finanzen ist eine Grundvoraussetzung, um die Effizienz von Krankenhäusern, die für einen großen Anteil der Gesundheitsausgaben verantwortlich sind, zu steigern. Dementsprechend suchen nationale, regionale und lokale Regierungen nach geeigneten Ansätzen, um diese finanziellen Belastungen zu reduzieren.

Ein erster Schritt in die Richtung der Evaluierung von Gesundheitssystemen und infolgedessen eine effiziente Verteilung von Human- und ökonomischen Ressourcen stellt deren Effizienzmessung dar. Um verschiedene Ansätze der Effizienzmessung im Krankenhaussektor bewerten zu können, wurde eine Taxonomie, die auf die Untersuchung und Klassifizierung von Krankenhauseffizienzstudien mittels Data Envelopment Analysis (DEA) oder verwandter Methoden abzielt, erstellt. Ein spezieller Fokus dieser Taxonomie liegt auf der umfassenden Analyse von Input- und Outputvariablen, die bei der Effizienzbestimmung von Krankenhäusern eingesetzt werden. Die Untersuchung der Inputvariablen diente der Identifizierung wichtiger Größen in Entscheidungs- und Planungsprozessen. Die Analyse der Outputvariablen zielte auf das Eruieren zentraler Kennzahlen für die Performance Messung ab. Bei der Analyse der Input- und Outputvariablen konnten jeweils drei zentrale Kategorien ermittelt werden: "capital investment", "labor" und "operating expenses" im Bereich der Inputgrößen und "medical visits, cases, patients, and surgeries", "inpatient days" und "admission, discharges, and services" im Bereich der Outputgrößen.

Im Gegensatz zu ex-post Effizienzanalysen mittels DEA oder verwandter Methoden, ermöglichen Planspiele, die den komplexen Entscheidungs- und Planungsprozess in Krankenhäusern abbilden, eine ex-ante Evaluierung von Reformvorhaben. Zudem tragen sie zum Beispiel zur Ausbildung von gegenwärtigen und zukünftigen Krankenhausmanagern bei. Um den aktuellen Stand existierender Planspiele, ihre Hauptcharakteristika und ihre Schwächen (z.B. fehlende Adaptierung an geänderte Patientenvergütungssysteme) zu erfassen, wurde eine umfassende Literaturrecherche durchgeführt. In diesem Zusammenhang wurde eine Taxonomie erstellt, die derartige Krankenhausplanspiele hinsichtlich allgemeiner Klassifizierungsmerkmale, Anwendungsgebiete, Zielgruppen, Entscheidungs- und Planungsprozesse sowie eingesetzter OR-Methoden untersucht und kategorisiert. Die Untersuchung der einzelnen Spiele zeigt, dass die Modellierung der internen Entscheidungs- und Planungsprozesse unter Berücksichtigung externer Gegebenheiten das Herzstück eines jeden Planspiels darstellt. Die Untersuchung veranschaulicht ebenfalls, dass Krankenhausplanspiele und Operations Research in Zeiten von knappen Budgets, steigender Nachfrage nach Gesundheitsversorgung und steigenden Technologiekosten in der Verwendung von knappen Ressourcen sehr an Bedeutung gewonnen haben.

Mit Kenntnis der wichtigsten Größen in Entscheidungs- und Planungsprozessen und zur Performance Messung sowie des State-of-the-art von Krankenhausplanspielen wurde die Business Logik von *COREmain hospital*, einem internet-basierten Krankenhausplanspiel, entwickelt. *COREmain hospital* bietet einen Einblick in den ökonomischen und organisatorischen Entscheidungs- und Planungsprozess zentraler Aufgaben im komplexen System Krankenhaus. Die Prozesse werden unter Zuhilfenahme von Diskreter-Event-Simulation simuliert. Die bis zu sechs Krankenhäuser einer Region konkurrieren über eine Dauer von zwölf Perioden um Patienten und Budget in Abhängigkeit von ihrer Mission, der regionalen Gesundheitspolitik, dem Patientenvergütungssystem (Tagespauschalen, Fallpauschalen, globales Budget), der Arbeitsmarktsituation und den am Markt verfügbaren Röntgengeräten. Die Spieler lernen in einer komplexen, interdisziplinären Entscheidungssituation zielgerichtete Entscheidungen zu treffen. Dabei können sie unterschiedliche Managementstrategien z.B. im Bezug auf Kapazitäts- und Ablaufplanung anwenden und ihre Auswirkungen prüfen. Die Performance eines Krankenhauses wird anhand vordefinierter Zielvorgaben nach jeder Spielperiode gemessen. Sieger ist jenes Krankenhaus, das sowohl die selbst definierten als auch die regional vorgegeben Ziele bestmöglich erreicht. Die Innovation von *COREmain hospital* im Vergleich zu existierenden Krankenhausplanspielen besteht in den internet-basierten Rahmenbedingungen, der Verbindung von Ressourcen-, Prozess- und Finanzmanagement und der Möglichkeit zur Simulierung unterschiedlicher Patientenvergütungssysteme. Es ist ein vielversprechendes Trainingsinstrument, um die Grundlagen für einen effizienten Entscheidungs- und Planungsprozess zu vermitteln. Das Planspiel möchte nicht nur Studenten und Krankenhauspersonal die Entscheidungsfindung in komplexen Situationen verdeutlichen, sondern auch Entscheidungsträgern die Auswirkungen von geänderten Bestimmungen auf die Entscheidungsbildung in Krankenhäusern veranschaulichen. Der Einsatz dieses Planspiels in Lehre, Politik und Forschung könnte zu verbesserten Entscheidungs- und Planungsprozessen auf Spitals-, regionaler und nationaler Ebene beitragen.

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