Decision support for admission planning under multiple resource constraints

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Petra M.A. Groot

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PROEFSCHRIFT

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Chapter 1
Introduction

In this first chapter the subject of our research is introduced, i.e., improvement of the patient flow control in general hospitals by means of admission planning in situations with multiple resource constraints. Admission planning is defined within this context as being the activity in which patients are selected from a waiting list to be admitted into a hospital in a given period of time in such a way that a predefined set of goals is achieved and uncertainties such as the possibility of emergency patients to arrive are taken into account. Admitting, on the other hand, is the activity in which patients are selected from a waiting list to be admitted to the hospital during a given period of time without concern for the achievement of a predefined set of goals.

This chapter has been divided into five sections. First, the motivation for the choice of this subject is explained. Then, the scope of our study is defined. This is based upon an overview of the different types of patient flows in a hospital and upon a description of the differences between surgical and internal specialisms. Next, the research objectives are presented, followed by an explanation of the methods used to study these objectives. Finally, an explanation is given of how this book has been structured.

1.1 Motivation for this study

The working environment in which hospitals operate has changed tremendously during the last couple of decades. In the Netherlands the introduction of budget financing has brought an end to open-ended financing. The total hospital expenditures have been restricted in this way. This change has led to a scarcity of resources, in combination with a reduction in the number of available beds, a growth in the number of elderly people and a decrease in available nursing personnel. This scarcity has encouraged hospital management to use their resources more efficiently and more effectively. Similar pressures are also felt in hospitals in other countries. The need for a more efficient and effective use of resources is not always the result of just a scarcity of resources, however, but is in some cases also due to a growing competition between hospitals. This competition forces hospital management to offer their services at the lowest possible price. Competitive pressures therefore instill the need for cost reductions which can be achieved when hospitals use their resources more efficiently and more effectively.

The growing competition between hospitals has not only led to a need for low prices, but also to a need to improve the quality of the patient service. This need for quality improvement has occurred in the Netherlands also as the result of increased pressure from organizations representing patient interests. These organizations are pressuring hospitals to reduce the patient waiting times, to provide more information about scheduled admission dates, and to provide the patients with an earlier notification of their admission dates.
These changes in the hospital's working environment have forced hospital management to react. Hospital management has been forced to adjust their goals and to adapt their organization to the new environment. The main objectives for patient flow control and thus admission planning are, thus, to achieve a high utilization of all resources and a better patient service. To achieve these objectives, however, hospital management must change the way in which they control the patient flows. For example, instead of admitting a patient when a bed is available without worrying about the availability of operating capacity, a patient should only be admitted if both bed capacity and operating capacity are available. To ensure that all resources are used efficiently and effectively:

a) all of these resources have to be taken into account in some way in making an admission decision, and
b) there must be insight into the capacity needs of an individual patient for the individual processing steps.

Interviews with staff members of eight Dutch hospitals [Groot, 1989] revealed that hospital management has not yet been able to realize the new goals at the admission planning level of their organization. Regarding the efficient and effective use of resources, these interviews showed that most of the admission planners have problems with reserving capacity for emergency patients and managing the occupancy of beds, allocation of nursing personnel and use of the operating theater. The problems with reserving capacity for emergency patients are caused by the fact that:

a) information about the average number of emergency patients per day of the week is not available,
b) it is not known how much capacity has to be reserved for emergency patients to achieve a given service rate, and
c) reserved capacity is used for other patients because many specialists aim at a bed occupancy of 100%.

The problems with the occupancy of beds, nursing personnel and operating theater stem from the fact that not enough information is available about the amount of capacity needed for an individual patient and/or that the way in which admission decisions are taken does not correspond with the situation. The underlying cause of the latter fact can be either a lack of insight into the way admission decisions have to be made or due to the domination of one of the parties involved in the admission planning process.

The admission planning process is a process in which nursing personnel, operating personnel, patients and specialists are involved. Each of these parties has its own goals; these goals often do not correspond with each other. When one of the parties is dominant in the admission planning process, the achievement of the goals of the dominating party gets a higher priority than the achievement of the goals of the other parties. This may lead to admission decisions which are not optimal for the hospital as a whole.

Regarding the patient service, the interviews conducted by Groot [1989] showed that the eight hospitals had problems with scheduling admissions and providing a notification of admission at least a couple of days before the actual admission date. In addition they all encountered difficulties with controlling the throughput of patients based upon their urgency. The problems with the notification of admission a couple of days before the actual admission date usually are caused by the fact that there is no insight into the availability of resources in the future. The problems with the control of the patient throughput according to their urgency occur because the urgency factor is not explicitly defined. This results in urgency being defined and used inappropriately. Summarizing, it can be said that some of the main causes of the problems of controlling the patient flows by means of admission planning are due to a lack of knowledge and information about:

1) the capacity needs of an individual patient for the individual processing steps,
2) the availability of resources in the future, and
3) the type of policies that have to be used in a given situation to achieve the objectives mentioned above.

In a previous study, Kusters [1988] has presented a set of models with which:

1) the capacity needs for an individual patient can be estimated, and
2) the available bed capacity, nursing capacity and operating capacity can be predicted.

His prediction model for the availability of bed capacity in the future is an extended version of the model described by Rubenstein [1977]. Starting with the available number of beds on day t (the decision moment), the model predicts the available beds on day t+y (the admission moment) by predicting the changes that will take place in the time between these two moments. According to Kusters these changes are:

a) the number of waiting list admissions on the days t+1,...,t+y-1;
b) the number of emergency admissions on the days t+1,...,t+y;
c) the number of discharges on the days t+1,...,t+y.

This latter term is composed of the following factors:
1) the number of discharges out of the patients present on day t;
2) the number of discharges out of the emergency patients admitted on day t+1,...t+y;
3) the number of discharges out of the waiting list patients admitted on day t+1,...t+y-1.
His prediction model for the availability of nursing capacity in the future is based upon a workload measurement system called the factor evaluation method (de Vries [1984]). This model is also based upon predicting the changes that will take place between the decision moment and the admission moment.
Kusters's prediction model for the availability of operating capacity is based upon predicting the amount of operating capacity required for already scheduled patients. Kusters states that the required amount of capacity for already scheduled patients within one operating session can be predicted based upon the sum of the expected average operation times for each operation.
Each of the above mentioned prediction models has been tested to determine the reliability of the predictions using historical data from two hospitals. The results of these tests demonstrated that the predictions are fairly accurate and reliable enough to use as a basis for admission planning. Although these models appear to be appropriate for supporting admission planners, they have not been used in practice as yet.

Several studies can be found in the literature about the formulation of admission policies. These policies can be classified into two groups according to the way in which the actual situation is taken into account.
The first group of studies concerns hospitals which follow an admission policy in which the actual situation is not taken into account. Admission decisions in this group are based upon the historical numbers of admissions and discharges. The studies carried out by Elmore and Zimmerman [?] and Amladi, Bliven and Butler [1985] are examples of this approach. This type of approach is not effective in situations in which the objective of implementing an admission policy is to control the occupancy of the resources in the hospital. In addition, both of these studies take only bed capacity into account, so they cannot be used in situations in which other scarce resources need to be included.
The second group of studies takes the actual situation into account in one way or another. Included in this group are studies which have been carried out by Hancock and Walter [1983], Rubenstein [1977] and Barrick [1985]. All three of these studies take the actual situation into account. In this way, they all deal with admission policies which are suitable for controlling the occupancy of resources in a hospital. Nevertheless, the policies evaluated in these studies take only bed capacity into account and, therefore, are not suitable for use in situations in which other resources are scarce. A study carried out by Kusters [1988] also presents an

admission policy. Although this policy takes more than one resource into account, the consequences of working with such a policy are not investigated.
Although several admission policies are described in the literature, it can be concluded that only one of these policies is suitable for use in a situation in which resources other than just the bed capacity are scarce. The consequences of working with this policy are unknown, however.

To summarize, the working environment within which hospitals operate has changed during the last couple of decades. These changes have forced hospital management to use their resources more efficiently and effectively and to provide better patient service. Interviews in hospitals have revealed that hospital management has not been able to adapt their admission policies to new situations because they often lack insight into the future resource availability and/or have an admission policy which is not suitable for use in situations in which resources are scarce.
The study carried out by Kusters offers us a method for gaining insights into the future availability of bed capacity, nursing capacity and operating capacity. Therefore, the approach chosen for the present study is to develop and test a decision support system for admission planning in which the results of Kusters's study are used in addition to results from own research to provide admission planners with information about the future resource availability. Only one admission policy could be found in the literature which is suitable for use in a situation in which resources other than just bed capacity are scarce. The consequences of working with this admission policy were not investigated, however. Therefore, in addition to the development of a decision support system for admission planning, we have also investigated which requirements an admission policy must meet in order to be suitable for use in a situation in which both bed capacity and operating capacity are scarce and have formulated and tested an admission policy which meets these requirements.

1.2 Scope

The scope of our study is defined and deliniated in this section. First, the different types of patient flows in a hospital are described. Subsequently, the differences between surgical and internal specialisms are described. Finally, the scope of the present study is defined in terms of types of patient flow and specialism to be covered.

1.2.1 Patient flows in a hospital

There are several ways to classify the patient flows in a hospital. The classification scheme which is most relevant for our study is presented in this section.

An initial classification of patient flows can be made based upon the part of the hospital visited by the patients. This classification results in an outpatient flow[1] (visiting only the outpatient clinics) and an inpatient flow (visiting only the hospital). This study only involves inpatient flows. It is not necessary to take the outpatient flow into account in the admission planning function, although it is possible that a patient in the outpatient flow becomes a patient in the inpatient flow. This can be seen in the form of a waiting list which is essentially a buffer between these two parts of a hospital.

Figure 1.1 represents the inpatient flows at an aggregate level. Three patient flows are represented in this figure. The incoming stream is represented by two flows. A distinction between these two flows has been made because these flows are treated differently. The first flow within the incoming stream consists of elective patients. These are patients who may be put on a waiting list since their admission dates can be postponed. The second flow consists of emergency patients. These are patients who must be admitted into the hospital immediately. It is not possible to chance the admission dates for these patients. The output of the hospital consists of patients who are discharged.

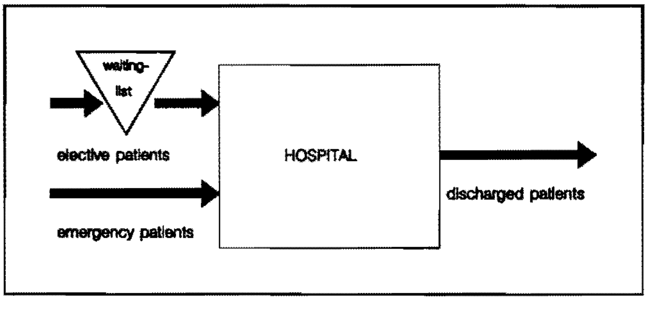

Figure 1.1: The inpatient flows at an aggregate level

When the patient flows are studied in more detail, it becomes clear that there is more than one flow of elective patients since each specialism in the hospital has its own flow of elective patients. The same applies for the flow of emergency patients. A distinction between these flows can be based upon the diagnosed ailment of the patient. Every specialism treats its own set of diagnosed ailments. This model is represented in Figure 1.2.

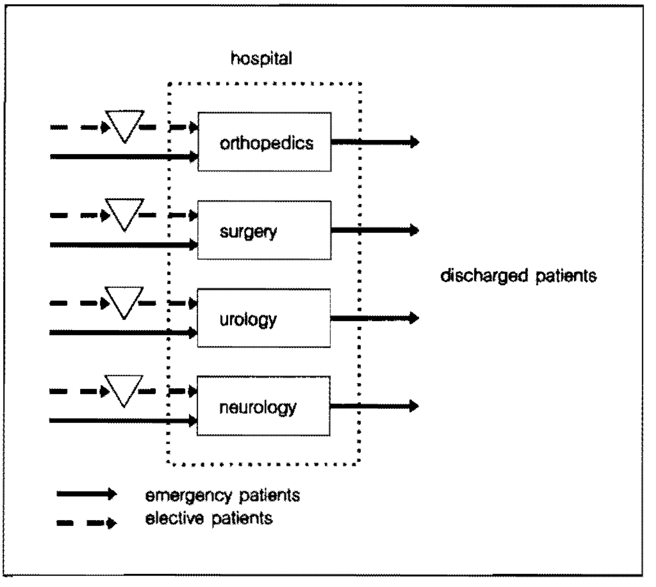

Figure 1.2: Patient flows per specialism

Our study is focused primarily on planning and controlling the patient flows for a single specialism. Factors influencing the choice of this approach have been:

1) the fact that the use of admission planning for patient flow control for one specialism is, in most hospitals, relatively independent from the use of admission planning for patient flow control for other specialisms. Although all specialisms share resources (e.g. bed capacity and operating capacity), parts of these resources are often allocated to a specific specialism as described in Chapter 2 of this book. Thus, our choice of approach implies a simplification of the control problem rather than emphasizing a need for flexibility.
2) the fact that controlling the patient flow for one (surgical) specialism is basically the same as controlling the patient flow for multiple (surgical) specialisms, but the situation is easier to analyze when the problem is restricted to a single specialism.

1.2.2 Internal versus surgical specialism

In a hospital two different types of specialisms can be distinguished, namely, the so-called internal specialisms and the so-called surgical specialisms. Surgical specialisms are concerned with operating on patients. For patients being admitted by these specialisms, the specialist generally knows exactly what the patient's problem is and which operation needs to be performed. This results in a fairly predictable throughput and use of capacity for these patients in the hospital (see Kusters [1988]). The internal specialism can be found at the opposite end of the predictability scale. This specialism usually admits a patient into the hospital in order to determine what is the matter with him. This leads to a set of examinations. The outcome of the first examination provides the basis for choosing a new examination. Therefore, it is much more difficult to predict the throughput for these patients in the hospital. It is difficult to predict how much capacity these patients will use in the hospital.

Since some knowledge of the required amount of resources is necessary to be able to improve the control of patient flows by means of admission planning, a surgical specialism has been chosen as the basis. First, an insight must be gained into the patient throughput in the hospital and the capacity needed by these patients in the hospital in order to improve the control of the patient flows for internal specialisms.

The scope of our research will thus be restricted to investigating only the inpatient flows for a single surgical specialism.

1.3 Research objectives

The decision to restrict our study to improving the control of the patient flows by means of admission planning for a single surgical specialism has been explained in the previous section. It was also stated in a previous section that some of the admission planning problems typically encountered by hospitals are due to:

1) a lack of insight into the future resource availability, and
2) following admission policies which are not suitable for situations in which more than one resource is constrained.

Regarding the first problem, it was concluded that the study carried out by Kusters [1988] could theoretically provide a partial solution to this problem, but that his approach had not yet been implemented in practice. With regard to the second problem, we stated that the literature did not provide us with any examples of admission policies which would be appropriate for use in the type of situation studied in this research.

Based upon the aforementioned findings, we have decided to focus our research primarily on the formulation, construction and testing of a decision support system for admission planning. This decision support system must be constructed in such a way that it is able to provide an admission planner with all of the information required to make admission decisions such that the admission planning goals can be achieved. As such, the decision support system must, among other things, provide better insight into the future resource availability. To achieve this, the prediction models originally developed by Kusters [1988] are used.

A lack of information is generally not the only problem which prevents the achievement of the new admission planning goals. As stated earlier, a failure to achieve admission planning goals can also be attributed to the use of admission policies which are not suitable for situations in which both bed capacity and operating theater capacity are scarce. Therefore, in addition to the construction of a decision support system, we have investigated here which requirements have to be met by an admission policy which is suitable for use in the aforementioned situations. As part of our analysis, new admission policies are formulated and compared to the policies currently used by most hospitals.

1.4 Methods used

Our study can be divided into two parts. The main part of our research consists of the development and testing of a decision support system for admission planning. The intended use of this decision support system is to support an admission planner in making admission decisions by providing him with information about the future resource availability.

The initial development of the decision support system has been based upon an analysis of the primary process and the results of Kusters's study. The analysis of the primary process has provided us with insights into the admission planning goals, the ways in which these goals can be achieved and the information which is required for that purpose. Subsequently, the decision support system was modified in some areas. These modifications were based upon the reactions of project sponsors and users in the hospitals in which the decision support system was first introduced and used.

The decision support system was tested in the surgery departments of three different hospitals. We chose to experiment with additional cases in order to be able to make comparisons between the cases and to gain insights into the situations in which the implementation of the decision support system can best contribute to improving the admission planning function. The cases were selected on the basis of the following criteria:

- availability of the information required for the prediction models developed by Kusters;
- cooperation of the parties involved in the admission planning process;
- choice of the department in which the system would be implemented.

Our objective was to select a number of cases for which all of the information required for the prediction models was available, the cooperation of the parties involved in the admission planning process was secured and the department in which the system was to be implemented was different from the other cases but was still present in almost every general hospital.

A combined case study approach has been chosen as the basis for studying the implementation of the decision support system. Each case study is used not only to test the results of Kusters's prediction models using a longitudinal design, but also to explore:
a) whether the system can improve the performance of the admission planning;
b) in what way admission planners use the system;
c) whether admission decisions are made entirely on the basis of the information provided by the system.

The research strategy used here is similar to a case study strategy as defined by Yin [1989]. In his book a case study is defined as being an empirical inquiry:
- that investigates a contemporary phenomenon within its real-life context;
- when the boundaries between the phenomenon and its context are not clearly evident; and
- whereby multiple sources of evidence are used.

The contemporary phenomenon investigated in the cases is the implementation of a decision support system in the surgery division of a hospital. The boundaries between the phenomenon and its context are not always clearly evident in the cases because changes in patient flows and procedures also effect the performance of the admission planning function.

The other part of our research consists of the design and testing of admission policies which:
- are suitable for situations in which both bed capacity and operating theater capacity are constrained;
- result in a high occupancy of the aforementioned resources;
- improve the patient service.

The design of admission policies which are suitable for the previously described situations is based upon an analysis of the primary process and the results of simulating the admission policies currently used in most hospitals. An analysis of the primary process provided us with insights into the possible ways to control the process and, more generally, into the requirements which need to be satisfied by a new admission policy. Simulations of the currently used admission policies allowed us to identify the shortcomings with respect to the details of these policies and, therefore, provided us with ideas for improving these policies.

The admission policies were tested based upon a simulation study. In this study, both the newly designed and currently used admission policies were simulated in a number of different situations. The situations differed with respect to:

- the ratio between length of stay and operating time for each patient category;
- the length of the waiting list;
- the number of available beds.

On the basis of the simulation results, the newly designed admission policies were adjusted where necessary and conclusions were formulated about the best admission policy for each given situation.

1.5 Structure of this book

This book consists of ten chapters. In this first chapter a general overview of the study is presented. The subject of our research is described, the scope of our research is defined and the specific problems are identified which this research addresses. In Chapter 2 the subject of patient flow control by means of admission planning is placed within the total framework of patient flow control in hospitals. This chapter should be of specific interest to a reader who is not familiar with the way in which Dutch hospitals operate. Chapter 3 focuses on the subject patient flow control by means of admission planning. First, an overview is presented of the goals of admission planning as described in the literature and used in practice. Subsequently, the primary process is analyzed. Based upon this analysis, the control possibilities and the information required for control purposes are described. This chapter forms a starting point for both the development of the decision support system and the formulation of new admission policies. Chapter 4 describes in detail the decision support model which has been developed and the method used to implement this model. Three separate case studies are presented in detail in chapters 5, 6 and 7. In each of these chapters, attention is paid to the situation in the respective hospitals, the performance indicators for admission planning set by the parties involved in the admission process, the actual implementation of the decision support model with an evaluation of the predictions made by the model, the performance before and after the introduction of the model and an evaluation of the usability of the constructed model. Chapter 8 compares the results of the case studies and provides an explanation of why differences are apparent. Chapter 9 describes the development of a set of admission policies, the design of a simulation study in which these admission policies are tested and the results of this simulation study. Finally, in Chapter 10, the main conclusions of this research are summarized and recommendations for further research are made.

Chapter 2
Patient Flow Control in Hospitals

In Chapter 1 it was stated that hospitals are interested in ways to improve the effectiveness and efficiency of their operations. This fact is also supported by the extensive amount of literature on this subject, as is shown in a review article of Smith-Daniels c.s. [1988]. However, study of this literature teaches us that most of the research in this area is limited to only a small part of the patient flow control and lacks a description of the position of the research within a larger framework. Until recently, such a framework specifically designed for hospitals has not been available. Two suitable frameworks are now available which have been designed based on production control principles and insights into the way hospitals currently operate ([Groot, Kremer and Vissers, 1993] and [Kusters, 1991]). This chapter summarizes the framework developed by Groot, Kremer and Vissers. This framework does not describe the optimal way in which hospital activities can be controlled, but instead describes a logical way in which hospital activities can be coordinated given the way in which hospitals are currently organized. In this chapter this framework is used to position our research in a larger context and to determine the degrees of freedom available at the operational level of the patient flow control in hospitals.
First, it is made plausible that production control principles can be applied to health service organizations. In the same section the principle of decomposition, used to construct the framework, is presented. Then a description of the total framework is given. Subsequently, the levels of control within the framework are described. Finally, an outline is given of the degrees of freedom available at the lowest level of the patient flow control.

2.1 Production control

Bertrand, Wortmann and Wijngaard [1990] define production control as the coordination of supply and production activities in manufacturing systems to achieve a specific delivery flexibility and delivery reliability at minimum cost. To determine if this definition is applicable in a hospital setting, it is ascertained that the terms used in the definition can be translated into comparable terms which are relevant for hospitals. Following this approach the coordination of supply and treatment activities in health service organizations can be substituted for the coordination of supply and production activities in manufacturing systems. The supply in health service organizations is not formed merely by goods, but exists primarily of people with health problems. The treatment activities in a health service organization focus on solving or reducing the health problems of the patients. Therefore, a health service organization consists of skilled personnel such as nurses, doctors and anaesthetists, and treatment facilities such as operating theaters and X-ray equipment. The coordination of supply and treatment activities in health service organizations or, more generally, in non-profit organizations is not aimed at achieving a specific delivery flexibility and delivery reliability at minimum cost, but, according to Anthony [1980], at providing the best possible service with the available resources. This agrees with the main goal most hospitals have, namely, the treatment of as many patients as possible with the available resources, starting from a predefined mix of patients. Production control in hospitals, thus, can be described as the coordination of supply and treatment activities in health service organizations to achieve the best possible service with the available resources. We have demonstrated that it is possible to change the definition of production control in such a way to make it applicable to hospitals. This makes it plausible that production control principles, with slight improvements, can be applied to the control of the patient flows in hospitals.

Decomposition is a method which is frequently used in situations in which a production control structure is designed for a specific manufacturing system. Decomposition means breaking down a complex problem into a number of smaller, less complicated problems. These smaller problems are related to each other, but are also relatively independent from each other. Decomposition can be done in a number of ways. In their work on hierarchical planning, Hax and Meal [1975] use decomposition based upon levels in the product structure: items (products), families (groups of products that make use of the same machines) and types (groups of families with analogous production costs and demand patterns). Another way of breaking down a problem into sub-problems is decomposition based upon the decisions that have to be taken. An example of this kind of decomposition is given by Anthony [1965]. He proposed that managerial activities fall into three broad categories, often referred to as strategic planning, tactical planning and operational control. Strategic planning clearly has a long term scope and is the responsibility of senior management. Tactical planning is a medium term activity involving middle and top management, concerned with the effective use of existing resources within a given market situation. Finally, operational control involves short term activities, typically executed by lower levels of management and non-managerial personnel to carry out the day-to-day activities of the organization efficiently.

In manufacturing systems, decomposition according to levels in the product structure is used most frequently. This happens almost naturally, since capacity planning is a derivative of product planning in many manufacturing systems. In those systems, products often can be produced to stock. This means that all available capacity can be used with very little unutilized capacity. In hospitals, capacity planning is of much more significance than in the aforementioned systems, since patient care cannot be kept in inventory for future consumption, patient care can only form a buffer prior to the treatment process. This means that hospitals have more difficulty utilizing all available capacity (especially when the number of patients on the waiting list decreases enormously). A poor allocation of resources may lead more directly to a loss of capacity utilization. The most important factor in capacity planning is the planning horizon. This is the reason for using the type of decision that has to be made as the basis for decomposition.

As is shown in this section, the definition for production control as used by Bertrand, Wortmann and Wijngaard [1990] can be translated into a comparable definition for production control in hospitals:

> Production control is the coordination of patients and treatment activities in health service organizations to achieve the best possible service with the available resources.

The fact that the definition of production control can be interpreted in such a way that it is suitable for health service organizations, makes it plausible that production control principles can be applied to health service systems. This means that one of the techniques which could be used to design a framework for production control in hospitals is decomposition based upon the type of decision to be made.

2.2 Framework for production control in hospitals

To design a framework for production control in hospitals, the production control problem can be broken down according to the types of decisions to be taken in such organizations. These decisions are then arranged in such a way that the decisions with more impact in the future are placed at a higher level in the framework and provide boundaries for the decisions at a lower level. Applying this type of decomposition to the production control decisions in a hospital leads to five levels (Table 2.1).

Some remarks about the chosen levels can be made. Firstly, the levels called strategic planning and main patient flow planning together form the strategic planning level used by Anthony [1965]. The strategic planning level is not part of what is commonly referred to as production control, however. The capacity allocation level and the capacity scheduling level together form the tactical planning level. Finally, operational planning is comparable to Anthony's operational control level.

Questions	Decision makers	Level	Horizon
What is the future direction of the hospital?	Board of Directors	Strategic planning	2 - 5 years
What will the hospital activities be in the coming period?	Top mana-gement	Main patient flow planning	1 - 2 years
How are the capacities allocated to functions or departments?	Top and middle ma-nagement	Capacity alloca-tion	months -1 year
How are the capacities scheduled in time?	Middle manage-ment	Capacity scheduling	weeks - months
Which patient is treated at what time?	Admission planner	Operational planning	days - weeks

Table 2.1: Production control decisions in a hospital

To guarantee that decisions at a lower level of control are taken and executed within the boundaries set at a higher level, a control function needs to be implemented. This function collects the results based upon a predefined set of performance indicators. This set of performance indicators must be constructed in such a way that, firstly the decision itself can be evaluated and deviations from the expected results can be explained. In addition, it is necessary to be able to evaluate whether the health service organization as a total is heading in the planned direction. According to Monhemius [1988] and In 't Veld [1988], different types of control can be used in this type of situation:

a) feedback control, using output information as a signal to control the process by means of controllable input variables;
b) feed-forward control, using input information as a signal to control the process by means of controllable input variables.

Both means of control can be used to coordinate different processes at the same level and to coordinate processes at different levels. Using these controls in combination with the levels of production control described above, the following framework can be derived (Figure 2.1).

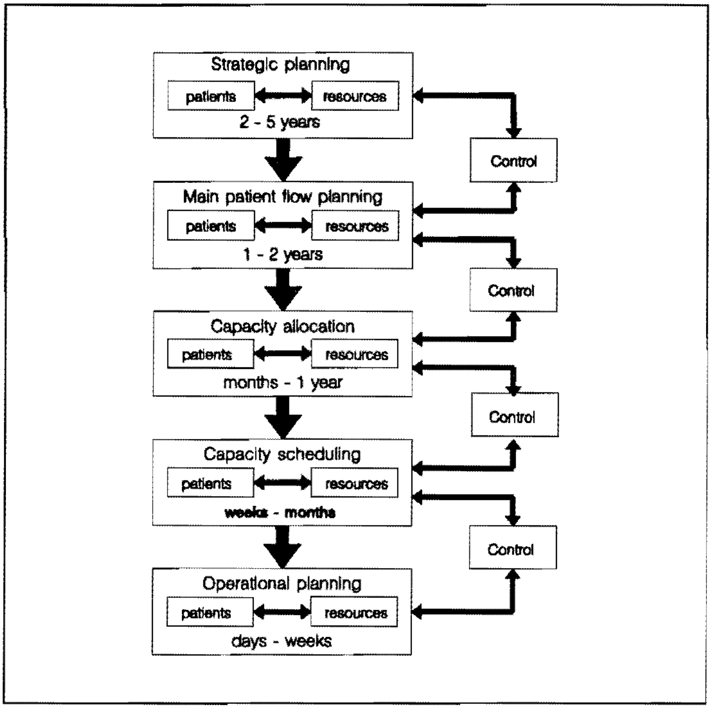

Figure 2.1: Framework for production control in hospitals

2.2.1 Strategic planning

Strategic planning is the highest level of control within this framework. As indicated above, however, this is not a part of what usually is called production control. Nevertheless, this level is taken into account in our framework in order to be able to deal with situations in which health insurance companies and national and regional governments impose quantitative and financial budgets upon hospitals. These budgets significantly influence decisions taken at the strategic planning level and at the main patient flow planning level. At the strategic planning level decisions are made concerning the direction in which a hospital is heading in the coming two to five years. Therefore, on the one hand decisions are taken concerning the type and quantity of patient flows in the future. On the other hand, decisions are taken regarding investments and the divestment of resources. In Table 2.2 the decisions regarding patient flows and capacities at this level of planning and the necessary control functions are presented.

Decisions regarding the patient flows	Decisions regarding capacities	Control functions
the area served by the hospital, treatment policies (inpatients vs. outpatients), addition or removal of a func-tion or specialism, increase or decrease of a function or specialism	investments or divestment of resources, cooperation with other institutions, priority-setting	horizontal: coordination of demand and supply; feedback: realized versus expected patient flows; feed-forward: consequences of changes in population and technology; vertical: boundaries for the number of patients within a certain flow and for the total amounts of available capacity (aggregated)

Table 2.2: Decisions and control function at the strategic planning level

2.2.2 Main patient flow planning

Main patient flow planning is the second level of control in the framework. Decisions regarding the patient flow consist of determining the number of patients per diagnosis family. In most hospitals a diagnosis family represents the diagnoses within a specialism. In order to determine the number of patients within such a family, the demographic characteristics of the population surrounding the facility, historical data regarding the number of patients in that family and quantity budgets dictated by the health insurance companies are used as input data. In Holland, the quantity budgets consist of the permissible numbers of nursing days, admissions, first outpatient visits and day admissions per year. These measures say nothing about the amount of capacity required or about the number of potential patients within a family. As such, these budgets only function as restrictions for the lower level decision process. A rough estimate of the necessary capacities per function or department is required. In production control terminology this is called a rough-cut capacity plan. A decision must be made regarding how much capacity a diagnosis family needs based upon the number of patients within this family and how much extra capacity is needed to guarantee that this number of patients can be treated in the coming year, given a certain occupancy. Finally, it is necessary that the decisions concerning the patient flows and the capacities are consistent with each other and with the decisions taken at the strategic planning level. Table 2.3 summarizes the decisions which need to be taken at the second level and the control functions which need to be executed.

Decisions regarding the patient flows	Decisions regarding capacities	Control functions
amount of patients per diagnosis family, quantity budgets health insurance companies	rough outline of required capacities per diagnosis family	horizontal: coordination of demand and supply; vertical: readjustment of standards concerning the occupancy of resources, determination of standards for the length of the waiting list and the maximum waiting time for patients per function or specialism

Table 2.3: Decisions and control functions at the main patient flow planning level

2.2.3 Capacity allocation planning

The third level in our framework is called the capacity allocation level. The decisions taken at this level are concerned with the allocation of capacities to functions and specialisms. These decisions are taken approximately once each year. To make the allocation decisions, the patient flow is divided further into diagnosis groups. Diagnosis groups are formed within diagnosis families (mostly equal to the diagnoses within a specialism) and use the same amounts of capacity. Each diagnosis family can be divided into one or more diagnosis groups. For each diagnosis group the expected number of patients in the coming period is determined. Based upon the expected number of patients in the coming period, the required capacity per diagnosis group is calculated. Depending on the resource type, the allocation of capacity can take place in different ways:

- a lump sum allocation of capacity (e.g. full time equivalents of nursing capacity)
- a specific allocation of capacity in time (e.g. blocks of operating capacity during certain hours on certain days)

Table 2.4 provides an example of the decisions and control functions at this level of planning.

2.2.4 Capacity scheduling

The fourth level in our framework is called capacity scheduling. This level usually cannot be found in production control structures for manufacturing systems. This level is added to the production control structure of hospitals because part of the capacity in hospitals is allocated to specialisms based upon lump sum requirements. (This way of allocating capacity can also be found in some job shops in which capacity is assigned to large customer orders). In a later stage, this lump sum is translated into a schedule in which the use of capacity per unit of time is determined (e.g. for nursing schedules). The way in which such a schedule is made can affect the performance in other parts of the hospital (e.g., the nursing schedule affects the

Decisions regarding the patient flows	Decisions regarding capacities	Control functions
expected number of patients per diagnosis group	allocation of capacities to functions or specialties	horizontal: coordination of demand and supply per specialism; vertical: feedback about capacity use per function or specialism, expected available capacity per function or specialism

Table 2.4: Decisions and control functions at the capacity allocation level

throughput of the patients in the operating room). Therefore, this type of decision should be taken at the patient flow control level and not at the department level as is done in most manufacturing systems. Table 2.5 shows an example of the decisions and control functions at the capacity scheduling level.

Decisions regarding the patient flows	Decisions regarding capacities	Control functions
expected number of patients per diagnosis group as a function of the period of time (seasonal influence) and the length of the waiting list	required capacity per time bucket	horizontal: coordination of demand and supply (expected number of patients versus required capacities); vertical: feedback regarding capacity allocation, readjustment of standards, standards for the maximum waitingtime per diagnosis group

Table 2.5: Decisions and control functions at the capacity scheduling level

2.2.5 Operational planning

Operational planning is the lowest level in our framework. This level is equivalent to the operational control level mentioned by Anthony [1965]. In his book about planning and control systems he states that this level is concerned with the processes used in facilitating the day-to-day activities of the organization. These activities consist of rules, procedures, forms and other devices which govern the performance of specific tasks. Operational control is the process of assuring that specific tasks are carried out effectively and efficiently. The day-to-day activities of a hospital include scheduling individual patients for admission. Such a schedule is made based upon a list with patients waiting for admission, an overview of the available capacity for the coming period (from one day to one week) and an outline of the required capacity to be kept on reserve for emergency patients. Table 2.6 presents an overview of the decisions and control functions at this level.

Decisions regarding the patient flows	Decisions regarding capacities	Control functions
schedule of patients to be admitted in the next period	planned capacity utilization	horizontal: coordination of demand and supply ; vertical: feedback regarding length of the waiting list, utilization of capacities and waiting times of patients

Table 2.6: Decisions and control functions at the operational planning level

2.3 Degrees of freedom

As described in Chapter 1, this research is concerned with improving the admission planning function in hospitals. The admission planning function is part of the operational planning level in a hospital. As such, admission planning takes place within the boundaries set at higher levels of control. This means that the length of the waiting list, the composition of the waiting list and available capacities are considered to be fixed. The only freedom left for the admission planner is the determination of admission dates for individual patients. By selecting specific types of patients for admission on specific days, the admission planner must try to achieve the goals regarding capacity utilization, the patient waiting time, the service level for emergency patients and the length of the waiting list.

In reality, however, it is not as simple as stated above. Although each function or specialism has its own resources, it is sometimes possible to use resources allocated to other specialisms or function. This kind of flexibility is frequently used for the treatment of emergency patients. If there is no bed available in the ward which has been assigned to the specialism in question, a bed in another ward can be used to accommodate such a patient. Also, in some hospitals, nurses are reallocated to wards on a day-to-day basis in situations where the workload is unevenly distributed between the wards. To conclude, an admission planner decides which patients are selected for admission in a given period, using the inherent flexibility which is available within the hospital.

Chapter 3
Modelling

In Chapter 1 it was stated that a scarcity of resources may lead to a change in goals. Up until now, many hospital managers have experienced difficulties in achieving these goals through admission planning. Some of these difficulties stem from the fact that a part of the information required to make admission decisions to achieve a predefined set of goals, is not available. In addition it may not be clear which type of admission policy can be used best in situations in which more than one resource is constrained.

As an initial attempt to resolve these difficulties, this chapter presents several admission policies, each designed to achieve a single, specific goal. The information required to implement each of these policies is also described. For this purpose, this chapter first describes the main goals which hospital management generally strives to achieve with admission planning. Subsequently, an analysis of the primary process is presented. This analysis demonstrates the specific difficulties of scheduling patients for admission in a situation in which more than one resource is constrained. This analysis is the starting point for describing the ways in which the process can be controlled. To conclude, an overview is given of the types of admission policies which could be used to achieve a single, specific goal and the information required to implement these policies.

3.1 Goals and objectives

To formulate policies for achieving the main goals and objectives of hospital management, the goals must first be defined. In their book on management control in non-profit organizations, Anthony and Herzlinger [1980] stated that decisions made by management in non-profit organizations generally focus on providing the best possible service given the available resources. The goals implied with this statement are the same as the revised hospital objectives described in Chapter 1. The aforementioned statement is also supported by the few goals and objectives concerning admission planning that can be found in the literature. For example:

- Sahney and Knappenberger [1977] determined that the objective of admission planning should be to keep the bed occupancy high and minimize the number of cancellations and reschedulings.
- de Vries [1984] claims that admission planning is concerned with achieving a high,

levelled occupancy of the beds, the nurses and the operating theater, given standards for patient waiting times, allocation of beds to specialisms and the available resource capacities.
- Kusters [1988] states that admission planning should a) improve the occupancy of available and expensive resources, b) reduce the time a patient stays on the waiting list, c) increase the time between a notification of admission and the actual admission, and d) reduce the time between admission and discharge.

The goals and objectives to be achieved through admission planning are not explicitly stated in most hospitals. However, if hospital managers are asked about the goals they want to achieve with admission planning, the types of goals described above are mentioned. The managers position in the organization determines to a great extent which of the previously described goals are mentioned. The goals mentioned by a specialist may differ from the goals mentioned by the head of the operating theater, or the head of the nursing personnel.
In this study it is assumed that the objectives of admission planning are:
a) improve the occupancy or utilization of available resources[1];
b) reduce the time that a patient stays on the waiting list;
c) expand the time between a notification of admission and the actual admission date;
d) reduce the time between admission and discharge;
e) achieve a predetermined service level for emergency patients.

Several of these objectives need to be explained in more detail.
With regard to b), it may be desirable to reduce the time that a patient stays on the waiting list only to a limited extent. A patient normally does not want to be admitted into the hospital immediately unless this is medically necessary. This means that there must be a certain amount of time between putting the patient on the waiting list and admitting the patient into the hospital. The desired time separating these events depends upon the medical urgency of the diagnosis or operation and the social circumstances of the patient. For a patient with a medical urgency for admission, a maximum allowable time between these events should be defined. Specialists generally use two or three categories for specifying the degree of medical urgency. Regarding the social circumstances of a patient, it can be expected that patients with children or busy jobs mostly will want to have a longer time between these events than other patients. In addition, it is important that patients with similar diagnoses are assigned similar waiting times so that there are no grounds for accusations of preferential treatment or forgotten patients on the waiting list.
With regard to c), most patients want to know the admission date several days before the actual admission. A study carried out by Valk [1983] in which he interviewed 150 elective

[1] The main resources in a hospital are the nursing personnel, the specialists, the operating theater, the beds and the ancillary departments.

patients demonstrated that 90% of the interviewed patients preferred to receive a notification for their admission one week before the actual admission. However, 90% of these patients also maintained that the time between the notification for admission and the actual admission should be at least three days.

With regard to d), a reduction in the time between admission and discharge (a reduction in the length of stay) can potentially be realized when the necessary patient treatments or processing steps are scheduled in the shortest time possible.

With regard to e), to achieve the determined service level for emergency admissions, a certain amount of capacity must be reserved for this type of patient. The amount of capacity to be reserved depends upon the number of emergency arrivals per day of the week and the use of resources by these patients (Newell [1954,1963], Swartzmann [1970], Karas [1975] and Kusters [1988]).

Most of the aforementioned goals and objectives are the same as the goals mentioned by Kusters [1988].

After determining the admission planning goals, explicit targets for these goals need to be set: which level of occupancy of beds or nursing personnel must be achieved, what the mean waiting time should be, which service level must be given to emergency patients. Setting the targets is not a simple process since the targets for different goals can conflict with each other. For example, a high service level for emergency admissions conflicts with a high occupancy of the bed capacity. When hospital management wants to reach a high service level for emergency admissions, this means that a large number of beds will need to be reserved for these patients. Since these beds will not be occupied most of the time, the occupancy of the beds will tend to decrease. In Table 3.1 the interaction between the service level for emergency admissions and the occupancy of the beds is demonstrated. In this table it is assumed that:

- 30 beds are available;
- the beds for elective patients can be occupied for 100%;
- emergency patients arrive according to a Poisson process;
- the emergency arrival rate is 1 patient per day.

The conclusion here is that insights into the conflicts between targets is necessary before feasible targets can be set. If insights into the conflicts between targets are not available then a monitoring function as described in Chapter 2 can help to gain insights into these conflicts.

Service level emergencies	Reserved beds emergencies	Occupancy emergency beds	Occupancy all beds
95.0 %	5	20 %	87 %
97.5 %	6	17 %	83 %
99.0 %	7	14 %	80 %

Table 3.1: Relationships between service level for emergency admissions and bed occupancy

3.2 The primary process

The scope of our study was defined in Chapter 1 and limited to the inpatient flows for a single surgical specialism. This section describes the throughput of these flows through such a department. This description is based upon information from interviews that were held in a number of hospitals. Subsequently, an analysis of the primary process is made using production control terminology and concepts. The process is modelled as a flow shop with a number of order categories and without intermediate buffers between the work processing steps.

3.2.1 Description of the primary process

Figure 3.1 represents the patient flows through a surgical hospital.
In Figure 3.1 it is shown that the inflow of a surgical hospital consists of two different flows. The division into these two flows has been made because the control of these flows is essentially different. The first flow consists of emergency patients. These are patients who must be admitted into the hospital immediately. It is hardly possible to control this flow. Nevertheless, it is possible to make a fairly accurate prediction of the number of emergency patients per day as demonstrated by the research carried out by Newell [1954, 1963], Swartzman [1970], Karas [1975] and Kusters [1988]. The second flow consists of elective patients. These are patients for whom the admission dates can be postponed. When their requests for admission are received,these patients are put on a waiting list. Based upon the research of Kusters [1988], this latter flow can be divided into smaller flows based upon the type of operation, age and sex of a patient. This sub-division results in a number of patient groups, each of which require the same amount of resources in hospital.

When a patient is admitted into the hospital, he may use various resources. Three types of resource capacities are relevant: operating theater capacity, wards and ancillary departments.

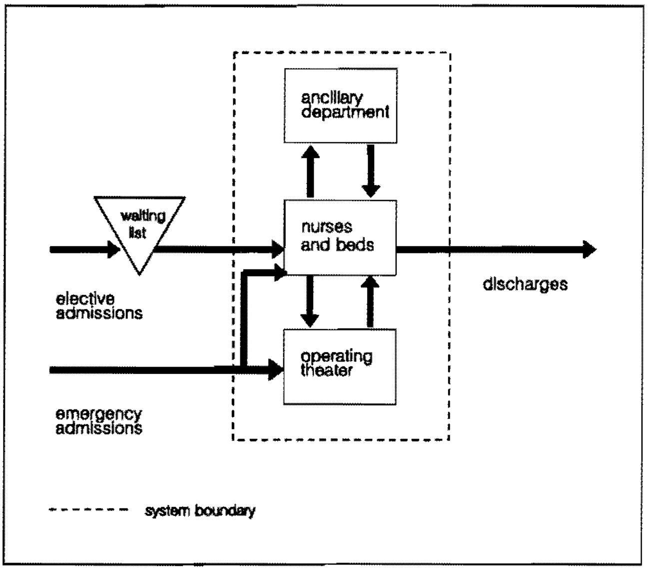

Figure 3.1: Patient flows through a surgical hospital

A patient uses operating theater capacity when he has to undergo an operation. In most cases, such an operation takes place on the first or second day of a patient's stay.
Operating theater capacity consists of four related types of capacity: specialist capacity, nursing capacity, anesthetist capacity and operating theater capacity. There is a linear relationship between the capacity requirements of each of these resources; this means that the most scarce resource determines the total available capacity. Operating theater capacity is a type of capacity which is not continuously available. According to a timetable, a specialism has access to one or more operating theaters on certain days for a certain amount of time (usually for four or eight hours).

Ward capacity is used by every patient in hospital. This capacity can be divided into two separate types of capacity: bed capacity and nursing capacity. The division into these two types of capacity is made since there is no linear relation between the number of occupied beds and the workload of the nurses. This means that these types of capacity need to be controlled separately. Nursing capacity is a resource which is continuously available, but not always in equal amounts. Bed capacity is a resource which in most hospitals is continuously available in the same amount, however.

The third resource a patient may use is an ancillary department. Use of such a department is made when a patient needs to undergo some specific examinations. The types of examinations needed differ from patient to patient and from diagnosis to diagnosis. For patients in a surgical hospital, such examinations only require a small amount of time as compared to the total time they stay in the hospital. The timing of these examinations is normally not critical with respect to the length of time they stay in the hospital. For this reason the ancillary departments are not included within the scope of this study.

3.2.2 Analysis of the primary process

The primary process in a surgical hospital is described previous as the treatment of a number of different patient groups. For the treatment of these different patient groups, operating capacity, bed capacity, nursing capacity and ancillary department capacity is required. In this section the primary process is analyzed from a production control point of view and the main features of the primary process are identified. Based upon these features, the primary process can be characterized as a flow shop with several categories of orders, without intermediate buffers between the work processing steps.

Figure 3.2 represents the flow of patients through a surgical hospital assuming that visits to the ancillary departments need not be taken into account and not every patient makes use of every processing step.

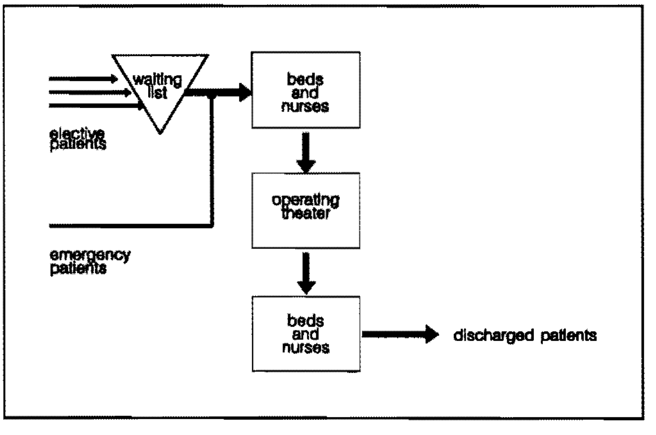

Figure 3.2: Revised representation of the patient flows through a surgical hospital

From Figure 3.2 which represents the normal flow of patients on any given day, it can be concluded that operating theater capacity and bed capacity are always used in the same order.

This is the main reason for modelling a surgical hospital at this level as a *flow shop*. This is a special kind of flow shop, however, because one resource (the operating theater capacity) is only available periodically. In this flow shop, different resources are used sequentially without any intermediate delay. A delay between the two processing steps is not possible since every patient requires a bed during the total period he is admitted in the hospital. This is the reason for modelling a surgical hospital as *a flow shop without intermediate buffers*. When the incoming patient flows are viewed in more detail, these flows cannot be represented as a single category of orders but must be represented as *a number of different categories of orders* as previously indicated in Section 3.1.1.

In conclusion, to characterize the incoming flows of patients and based upon the sequence in which the different resources are used, a surgical hospital can be modelled as a flow shop without intermediate buffers between the individual processing steps using a number of different categories of orders.

3.3 Control

It is explained in the sections above how a surgical hospital can be modelled as a flow shop with a number of different categories of orders and no buffers between the stages. This approach not only determines how such a hospital can be described, but also how such a hospital should be controlled. This section provides a description of how the primary process can be controlled on the operational level to achieve a predefined set of goals. First, the means via which the primary process can be controlled are identified. Subsequently, two different methods of control are presented. The effects of the main features of the primary process on the control are then described. Finally, the way in which the primary process can be controlled to achieve the various goals is outlined.

3.3.1 Means of control

In Chapter 2, production control in hospitals is defined as the coordination of the supply and demand for treatment in health service organizations to achieve the best possible service with the available resources. This definition shows that production control is a coordination problem. This problem can be solved by influencing:

1) the demand for treatment capacity,
2) the supply of treatment capacity, or
3) both the demand and the supply of treatment capacity.

Influencing the demand for treatment capacity at an operational level of planning means

influencing the actual configuration of patients in the hospital. The actual configuration of patients in the hospital can be influenced by the selection of patients from the waiting list. Influencing the supply of treatment capacity at an operational level of planning means influencing the actual availability of capacity.
Summarizing, it can be stated that two sources of control can be distinguished at the operational level: the selection of individual patients from the waiting list to be admitted into the hospital and the actual allocation of capacity.

3.3.2 Methods of control

In 't Veld [1988] distinguishes two basic methods which can be applied to control the patient flows in surgical hospitals of a hospital, namely: feed-forward control and feedback control. Feed-forward control is the control method in which the influence of disturbances is predicted and a correction is introduced to compensate for the effect of these disturbances. Feedback control is the control method in which a deviation from a norm is first observed and then a correction is introduced to compensate for this deviation.

When the means of control are combined with the methods of control, four alternatives can be distinguished:
1) Feedback control using patients as a means of control;
2) Feedback control using resources as a means of control;
3) Feed-forward control using patients as a means of control;
4) Feed-forward control using resources as a means of control.

The use of feedback control using patients as a means of control can be illustrated by a situation in which it is observed that there is not enough nursing capacity available to admit all of the scheduled patients on a certain day, leading to the cancellation of the admission of some of the scheduled patients. When the available nursing capacity is increased by hiring a temporary nurse instead of cancelling a number of the already scheduled patients, this becomes an example of feedback control using resources as a means of control. An example of feed-forward control using patients as a means of control can be illustrated by a situation in which patients are selected for admission on the basis of the expected availability of resources. An example of feed-forward control using resources as a means of control is the reservation of bed capacity and nursing capacity for emergency patients on the basis of the expected number of emergency patients.

To summarize, the difference between feed-forward control and feedback control lies in the fact that the first method of control calls for corrective measures to be taken on the basis of expected deviations of the process, while the latter method of control achieves this based upon observed deviations from the process.

The admission planning function makes use of both feed-forward and feedback control. In this book, however, the main emphasis is on feed-forward control. Therefore, when the word control is used, it always refers to feed-forward control unless stated otherwise.
Feed-forward control can take place using patients as a means to control the process or using resources as a means to control the process. Feed-forward control based upon resources is used mainly at the higher levels of planning as is discussed in Chapter 2. This method of control is also used at the operational level of planning specifically with regard to emergency patients. The main use of feed-forward control at the operational level is based upon influencing the admission of individual patients.

3.3.3 Effects of main features on the control

In Section 3.2.2 the primary process of a surgical hospital is modelled as a flow shop without intermediate buffers between the stages and with a number of different categories of orders. In this section the effects of the main features of the process on the control are described.

One of the main features of the primary process is the absence of a buffer between the stages. Absence of a buffer between the stages in a flow shop means that there will be a strong interference between the resources. If the first stage becomes idle, this will effect the occupancy of the successive stages at a later moment in time. In a situation in which more resources are constrained this means that the total throughput of the system is determined by the maximum occupancy of these resources at any point in time. Absence of a buffer in a flow shop in which all patients follow the exact same route means that the only point where the patient flow can be controlled (feed-forward) is at the entrance of the system. Selecting patients from the waiting list to be admitted into hospital is the only way to control the elective patient flows at an operational level in this situation. By selecting these patients from the waiting list the situation in both processing steps must be controlled (if necessary). As is described in Section 3.2.2, the emergency flow is controlled on the basis of capacity reservations.

Handling a number of different categories of orders in a flow shop means that the workload at every processing step depends upon the configuration of orders in the flow shop. Knowing that an operation may take anywhere from fifteen minutes to eight hours to complete and that beds and nursing capacity are used for anywhere from one day to several weeks, the configuration of orders at every processing step may be different. Processing times differ so widely that this automatically means that the configuration of orders at both processing steps is different. When the loads at both processing steps are not balanced, blocking can take place. In this study, blocking is defined as the phenomenon which occurs in situations in which available capacity at one stage cannot be used because the required capacity to process another order is not available at the other stage. This type of blocking resembles blocking effects which are frequently described in the flow shop literature (Pinedo, [1982]). Blocking is defined in the literature as the phenomenon which occurs in situations in which available capacity cannot be used because an order cannot be removed from or entered into the system since there is an insufficient amount of buffer storage available. In a surgical hospital, blocking occurs:

a) in cases in which operating time is available but all the beds are occupied, or

b) in cases in which there are beds available but there is no operating time left.

When blocking occurs, one stage becomes idle. If this stage is the bottleneck resource, this will cause the occupancy to decrease. The bottleneck resource is defined here as the resource which is the most scarce at the capacity allocation level. However, in a situation with several categories of orders, there is usually no specific bottleneck in the short term. Depending upon the configuration of categories in the system, the bottleneck is formed by one of the two resources.

Based upon the previous analysis of the system, the following conclusions can be made:

- the only way to control the elective patient flows at the operational level is to select patients from the waiting list to be admitted into the hospital on specified days. When using this selection process the workloads at the both processing steps must also be controlled, if necessary;
- when more than one resource is scarce (and considering that scarcity is a broad concept), blocking can take place. Blocking leads to a loss of capacity and thus a lower throughput of patients in the hospital.

3.4 Policy and information

The results of the analysis of the primary process and the consequences for the way of control derived from this analysis are used in this section to provide a general description of the way in which the primary process can be controlled in order to achieve each of the admission planning goals, separately. Subsequently, the information required to implement each of the policies is described.

Improve the occupancy or utilization of available resources
This goal can be achieved by continuously selecting a specific combination of patients such that the workload at each processing step is high at the moment of admission and is also guaranteed to remain high at each processing step in the near future. To guarantee the latter, the combination of patients must be selected in such a way as to ensure that enough capacity will be available in the near future. If this can be guaranteed, blocking will generally be minimized.
To be able to improve the occupancy of available resources, an admission planner needs information about:

- the availability of resources
- the amount of capacity needed by each patient on the waiting list
- the amount of capacity needed by each patient in the hospital
- the amount of capacity which must be reserved for emergency patients
- the time for which a patient's operation is scheduled

Regarding the availability of resources, an admission planner must have an overview of the availability of resources for a number of days into the future in terms that he is able to work with. He needs to know the total bed capacity, the total operating capacity per day and the total nursing capacity per day. These totals are known a half year to a year in advance in most hospitals. He must also know the normal variances from these totals which may be caused by illness of personnel, vacations or other circumstances. Next, he needs to know how much of each of the capacities is occupied by patients already admitted into the hospital. The research carried out by Kusters [1988] demonstrates that patients can be divided into groups according to their use of resources and based upon age, gender, diagnosis and operation. To predict the length of stay for each of these groups, information is needed about the historical length of stay for each group. This type of information is available in virtually all hospital information systems. To predict the nursing workload for each of these groups, either a workload measurement system must be implemented or the nurses must predict the workload. The duration of an operation for each of these groups can be predicted using historical data. If there is no historical data available about the durations of operations, then the specialists can generally provide reasonable estimates.

Once the planner knows the future capacity availability, he needs to select a combination of patients from the waiting list such that all of the capacities are sufficiently occupied. For this purpose he needs to know the amount of capacity needed by each patient on the waiting list and the amount of capacity that must be reserved for emergency patients. The amount of capacity needed by each patient on the waiting list can be predicted in the same way as the amount of capacity needed by each patient in the hospital as described above. The amount of capacity that must be reserved for emergency patients depends upon the expected number of emergency patients, the capacity needs of emergency patients and the service level requirements for emergency patients. The service levels to be attained in the coming period (e.g. year) are normally set by the hospital management. The expected number of emergency patients per day of the week can be predicted based upon the historical data regarding the number of emergency patients per day of the week. The capacity needs of emergency patients also can be predicted on the basis of historical data. The time at which the capacity will be needed must also be known, except for the capacity requirements of already admitted patients. This is important for determining which resources will be needed only on a specific day of the stay of a patient in the hospital. Operating theater capacity is an example of this type of capacity. An admission planner must know whether a patient is to be operated on the first, second or another day of his stay. This information can be found on the admission form in most hospitals.

Reduce the time that a patient stays on the waiting list

To reduce the amount of time that a particular patient stays on the waiting list, either the throughput must be increased or the number of patients with a medical urgency must decrease. The latter situation is relevant in case too many patients may have been assigned an urgency status. This causes a lengthening of the waiting time for patients without urgency status. If the number of patients with an urgency status can be decreased, the waiting time for elective patients could be reduced. The mean waiting time is likely to remain about the same as it was before, however.

For the throughput to be increased, the level of resource availability or the occupancy of resources must be increased (blocking must be avoided), or the capacity utilization must be decreased. These are two of the goals mentioned earlier.

To ensure that patients with a similar diagnosis are assigned the same waiting times, patients should be selected from the waiting list on a first-come, first-serve basis.
In addition to the information mentioned previously, an admission planner needs information about the amount of time a patient has already been on the waiting list and the urgency of the patient.

Expand the time between a notification of admission and the actual admission date

To expand the time between a notification of admission and the actual admission date, the selection of patients to be admitted into the hospital has to take place at an earlier stage than may currently be the case. This means that predictions about the available resources must be made more in advance. If the admission decisions are based upon these predictions, this probably will lead to a decrease in occupancy since the predictions will generally be worse.

To be able to expand the time between a notification of admission and the actual admission date, the availability of resources must be known for a couple of days in the future. The results of the study carried out by Kusters can be applied to predict the availability of resources for a couple of days into the future. It is also possible that the number of expected emergency patients per day will need to be adjusted when there are patients that need to be admitted within 24 or 48 hours. If this is the case and hospital management wants to expand the time between a notification of admission and the actual admission date to 48 hours, the expected number of emergency patients will increase by the expected number of patients per day that have to be admitted within 48 hours.

Reduce the time between admission and discharge

The only way an admission planner can influence the time between admission and discharge is by taking care that:

1) the patients who are admitted are actually suitable for admission,
2) all of the necessary materials (prosthesis, blood) are available, and
3) all of the necessary resources (beds, operating time, ancillary departments) are available at the right moment.

A patient is suitable for admission if the results of the preoperative screening are complete. Summarizing, the admission planner must select only the patients which meet the conditions mentioned above in order to influence the time a patient stays in the hospital. To be able to reduce the time between admission and discharge the admission planner must know:

1) which examinations have to be done at what time,
2) the results of the preoperative screening, and
3) whether blood or a prosthesis is needed by the patient.

Achieve a predetermined service level for emergency patients

To guarantee that a predetermined percentage of the emergency patients can be admitted in the hospital at any given time, capacity must be reserved for these patients. The reservation of capacity can take place in two ways:

1) part of the resources can be allocated to emergency patients at a higher level of planning, e.g. operating rooms reserved solely for emergency patients;
2) part of the resources for a hospital are not assigned to scheduled patients.

To achieve a predetermined service level for emergency patients, the admission planner must

know:
- how many emergency patients are expected per day of the week;
- how much capacity must be reserved for these patients.

How this information can be retrieved has already been described in this section.

To summarize, an admission planner needs information about:
- the total availability of beds, nursing capacity and operating theater capacity
- the age, sex, diagnosis, operation, specialist and ward of each patient
- the day of operation for each patient
- historical data regarding the length of stay for every group of patients
- historical data regarding the duration of an operation for every specialist and every group of patients
- historical data regarding the nursing workload for every group of patients
- the amount of time a patient has already been on the waiting list
- the urgency status for each patient
- the expected number of emergency patients per day of the week
- historical data regarding the capacity needs for emergency patients
- the prescribed service level for emergency patients
- results of the preoperative screening
- requirements for blood, a prosthesis or other facilities

The main task of the admission planner is to use this information in selecting patients from the waiting list in such a way that admission planning objectives are met as much as is possible. It will be clear that this is a hard job in practice.

Chapter 4
Decision Support for Admission Planning

One of the reasons why admission planners may not be able to achieve their targets is the lack of some of the information required to make correct admission decisions. A correct admission decision is defined here as an admission decision which contributes to the achievement of the admission planning goals. Another reason for not achieving their targets is the fact that the information processing capability of the admission planner is insufficient to copy with the amount and variety of data as described in the previous chapter.

In this chapter we describe the development and method of testing of a decision support system for admission planning which provides the admission planner with all of the information required to make correct admission decisions. The development of this system is based upon an analysis of the primary process described in Chapter 3 of this book and the prediction models designed by Kusters [1988]. In Section 4.1, a description of this decision support system is presented. The decision support system described in Section 4.1 is subsequently evaluated to determine whether:

- it provides the admission planner with all of the information required to make admission decisions;
- the prediction models designed by Kusters are useful in practice;
- the system is capable of improving the achievement of the admission planning goals.

The decision support system has been implemented in three hospitals for the purpose of evaluating this system based upon these three criteria using a case study approach. Section 4.2 describes the design of these cases in detail. Attention is paid to the main goals of these cases, evaluating the success of the implementation in each of these cases, the selection of the specific case situations and the phases that can be distinguished within each of these cases.

4.1 Decision support system

The aim of the decision support system is to provide the admission planner (whomever that may be) with all of the information required to make correct admission decisions. The most important information needed by the planner is information about:

a) the availability of beds, nurses and operating time in the future, taking the arrival of emergency patients into account, and
b) the consequences of possible admission decisions for the future availability of beds, nurses

and operating time.
Since only a limited amount of time was available for these case studies, it was decided to develop the decision support system as a prototype for only a single specialism and to assume that all patients could make use of all beds belonging to that specialism. In addition, it was assumed that the resources available to this specialism were known with complete certainty. This decision was in accordance with the decision to limit the focus of this study to only one specialism. This latter decision was based upon the fact that most hospitals make their admission planning decisions per specialism separately, whereby each specialism has its own dedicated resources. In addition, it is easier to make admission decisions per specialism. In view of this, we have assumed that a resource belonging to one specialism is not used by another specialism. It is also important to note that the decision support system was implemented on a PC with no connections to other computer systems.

The decision support system was initially developed based upon:
1) the results of Kusters's study;
2) insights into the admission planning process gained through interviews with stakeholders in the admission planning process, observations of the admission planning process and an analysis of this process (described in Chapter 3). We have identified the stakeholders in the admission planning process as being the patients, the specialists, the nursing personnel (including the head of the nursing staff), the personnel working in the operating theater (including the head of the operating theater) and the personnel of the admission planning department;
3) insights into the information required for admission planning (see Chapter 3).

In each of the hospitals in which the system was implemented, the system was presented to a group of stakeholders. The decision support system implementations were subsequently modified with respect to some points as the result of comments from the respective groups. Working with the system also led to some further adjustments.

As is described in Chapter 3 of this book, an admission planner tries to make his admission decisions in such a way that the goals of admission planning can be achieved. To support the admission planner in making admission decisions in such a way that the goals of admission planning can be achieved, the decision support system requires input information.

The decision support system has been developed to support the admission planner in achieving the following goals:
- improving the occupancy or utilization of available resources;
- reducing the time that a patient stays on the waiting list;

- expanding the time that elapses between a notification of admission and the actual admission date;
- reducing the time interval between admission and discharge;
- achieving a predetermined service level for emergency admissions.

As described in Chapter 3, to achieve these goals, information is needed about:

- the total availability of beds, nursing capacity and operating capacity;
- the age, sex, diagnosis, operation, specialist and ward of each patient;
- the day of operation for each patient;
- historical data regarding the length of stay for every group of patients;
- historical data regarding the duration of an operation for every specialist and every group of patients;
- historical data regarding the nursing workload for every group of patients;
- the amount of time a patient has already been on the waiting list;
- the urgency status for each patient;
- the expected number of emergency patients per day of the week;
- historical data regarding the capacity needs for emergency patients;
- the prescribed service level for emergency patients;
- results of the preoperative screening;
- requirements for blood, a prosthesis or other facilities.

In the decision support system three main modules can be distinguished:

1) an registrative module in which the actual situation with regard to the patient flow and the resources is registered;
2) a statistical module in which the varying capacity needs for groups of patients are recorded;
3) a planning module which provides the planner with an overview of suitable patients for admission on a given day, the capacities available on that day and for a number of days into the future and the consequences of selecting a number of patient for admission with respect to the available capacity in the future. in case some patients are selected for admission.

Each of these modules is described in more detail in the subsequent sections.

4.1.1 Registrative module

The actual situation in the hospital can be recorded in the administrative module. This module is important because it forms the basis for making predictions. This module incorporates several sets of data files. The first set of data files are used to store data about patient movements. Patients are normally placed on a waiting list which includes information about the patient (his name, address, telephone number, etc.), the admission request (name of the specialist, specialism, ward, diagnosis, operation, state of preoperative screening) and the planning (date on the waiting list, length of stay before the operation, planned admission date, etc.). It is possible to assign an admission date and to include this in the patient's record. The patient is then assigned a status of "A" (appointment). It is also possible to record the fact that the patient has been admitted into the hospital. The patient is then assigned a status of "H" (hospital). When a patient is discharged, the data referring to the patient is deleted in this set of data files.

The second set of data files contain information about the availability of capacity in time. The wards are noted to which a patient assigned to a specific specialism can be admitted. The number of beds in these wards can also be specified divided between male and female beds and distributed according to one-, two- or four-bed rooms. The specialists working in this specialism can be specified and the operating times which have been allocated to them for sixteen weeks into the future can be specified. Also, the nursing capacity available in the coming weeks can be indicated.

4.1.2 Statistical module

In this module, all of the statistical data needed to make predictions about the availability of beds, operating time and nurses is recorded. Also included is the amount of capacity needed for emergency patients and information concerning standards. Firstly, the diagnoses and operations used by the specialism can be specified. The diagnosis is used to make predictions about the length of stay and about the nursing workload expected for patients who do not undergo surgery. To be able to make these predictions, the length of stay for all patients with a given diagnosis are compiled over a period of a year or more. Using this data, the cumulative probability is calculated for each patient with a given diagnosis to determine whether he is expected to leave the hospital on day x after the admission. In Table 4.1, an example of the cumulative distribution function used in the decision support system is presented.

To predict the nursing workload associated with the patients, either workload measurements can be collected during a period of six to eight months, or the workload can be predicted by nurses.

The type of operation is used as a basis for estimating the duration of the surgery and to predict the nursing workload for patients who undergo surgery. To determine the duration of the surgery, historical data regarding the durations of operations should be gathered during a period of one year or more. The time spent in the operating theater (including anesthetics) is used as the standard definition of the duration of an operation. To predict the nursing workload for patients who undergo surgery, the same procedure is used as described above

length of stay (in days)	cumulative probability of discharge	length of stay (in days)	cumulative probability of discharge
1	0	11	88
2	8	12	90
3	12	13	93
4	20	14	93
5	29	15	93
6	35	16	95
7	55	17	95
8	68	18	98
9	75	19	100
10	84	20	100

Table 4.1: Cumulative distribution function as used in the decision support system

for patients who do not undergo surgery. For these patients, however, it is assumed that the nursing workload is constant during their stay in the hospital. For patients who do undergo surgery it is assumed that the nursing workload is variable during their stay. The stay can be divided into three periods, each with a different workload: the days before surgery, the day of surgery and the day(s) immediately after surgery (peroperative period) and, thirdly, the subsequent days after surgery.

The expected number of emergency patients per day of the week and per gender also can be registered in this module. The number of expected emergency patients can be determined by analyzing the historical data concerning the number of emergency patients arriving during the past year.

Finally, a set of standards can be maintained as data in this module. The standards used in the decision support system are:

- the workload generated by a patient in a given category;
- the length of the peroperative period;
- the time required to change between two operations;
- the probability of the number of occupied beds exceeding the total available bed capacity;
- the probability of the nursing workload exceeding the total available nursing capacity;
- the probability of the operating time exceeding the total available operating capacity.

4.1.3. Planning module

The planning module is the module which is used for making predictions about the future availability of different capacities. This module also can be used for making admission decisions. An admission decision can be made for a single day or a longer period of time in

the future. After selecting a period for which an admission decision is to be made, all patients qualifying for admission are then selected and displayed on the screen. A patient is qualified for admission if his preoperative screening is acceptable, his surgeon has operating theater time on the day of operation and the patient is available during this period. If one of these conditions is not met, the patient is not considered to be qualified for admission.
On the same screen, the availability of capacity is shown for the specified day of admission or operation along with the available capacity for the next four days. At this point it is possible to select a number of patients to be admitted on the chosen day. The amount of capacity needed by each of these patients is added to the capacity already occupied. The new capacity overview represents the expected remaining availability of capacity (using a significance level equal to a predetermined probability of exceeding the available capacity) in the event that all of the selected patients are actually admitted. In this way it is possible to compare a number of alternative admission decisions or to check if an admission decision is feasible.

4.2 Design of the cases

The common subject of all of the case studies is the implementation and testing of the prototype decision support system described in Section 4.1. The main goals of the cases are to test whether:

1) the prediction models of Kusters are applicable in practice, and
2) the decision support system is capable of supporting the admission planner in making admission decisions.

Whether the prediction models developed by Kusters can be applied in practice depends upon the availability of the information needed by these models and the reliability and accuracy of the predictions resulting from using these models. One of the criteria used in selecting the cases was the availability of the information needed by the prediction models. This means that the practical applicability of the models only depends upon their performance in the case studies presented here. Whether the decision support model is capable of supporting the admission planner in making admission decisions depends upon:

1) the performance of the prediction models in practice,
2) the correctness of <u>other</u> information presented to the planner,
3) the usability of the decision support system, and
4) the accuracy and degree of fit between reality and the models underlying the decision support system.

To achieve the main goals of the case studies, the case studies must provide insights into:

- the reliability and accuracy of the predictions made based upon the prediction models developed by Kusters;
- the organizational actions necessary for implementing the decision support system for admission planning;
- the improvement in performance that can be realized if the decision support system is used;
- external factors of the user environment which influence the actual realization of performance improvements;
- the way in which the users handle the decision support system.

Three implementation cases are examined in three separate surgical hospital situations in this study. Several cases were chosen in order to be able to compare cases and to gain insights into situations in which the implementation of the decision support system can contribute to improving the admission planning function.
The criteria for selecting these case studies were:
- availability of information needed for the prediction models;
- cooperation of the parties involved in the admission planning process;
- choice of the department in which the system would be implemented.

Our objective was to select a number of cases for which all of the information needed for the prediction models was available, the cooperation of the parties involved in the admission planning process was secured and the department in which the system was to be implemented would be different from the other cases but would also be present in almost every hospital. The latter criterium was added in order to increase the generalizability of the study.

In each of the cases, the following phases can be distinguished:
1. Description and analysis of patient flows, resources and admission planning procedures.
2. Determination of the admission planning goals and the performance indicators associated with these goals.
3. Determination of the data needed as input to the decision support system.
4. Preparation for the implementation.
5. Observation O1.
6. Implementation of the decision support system:
   - shadow system
   - actual system
7. Observation O2.
8. Evaluation.

1. Description and analysis of patient flows, resources and admission planning procedures
In this phase, a description is presented of the department where the case study takes place. This description includes the total amount of capacity in this department, the number of patients treated and the admission planning procedures used. The following questions are answered:

- how many beds are available?
- on what days the surgeons operate and how long an average operation session takes?
- how many nurses work in the ward?
- how many nurses work on the different shifts?
- how many patients are treated per year?
- what type of diagnoses the patients have?
- how many emergency patients arrive per year?
- what is the length of the waiting list?
- what is the mean waiting time for a patient?
- how are patients selected from the waiting list?
- which criteria are used for selecting patients from the waiting list?
- who takes the admission decision?
- which information related to admissions planning is available?
- what is the difference in time between the notification of admission and the actual admission date?

To gather this information and to discover problems with admission planning, the main stakeholders were interviewed. The main problem areas were identified based upon these interviews.

2. Determination of the admission planning goals and the performance indicators
The admission planning goals were defined in consultation with the main stakeholders. An operational measurement for the degree of achievement of these goals was then chosen after reaching consensus of opinion concerning the goals. This resulted in a set of performance indicators.

Minimally the following set of goals were agreed in each case:

- a consistently high occupancy rate for the resources (beds, nurses, operating room);
- a high patient throughput rate.

The latter goal can be translated into the following two goals:

- a short period of time between the notification for admission and the actual admission date;
- a short waiting time which is the same for all patients.

The degree of achievement of the first goal can be measured in terms of:

- mean occupancy rate of the operating theater;
- variance in the occupancy rate of the operating theater;
- mean bed occupancy;
- variance in the bed occupancy;
- mean nursing occupancy;
- variance in the nursing occupancy.

The translation of a goal into an operational measurement may seem simple. It must first be decided how to measure the occupancy rate, however. One also has to check if the information needed to calculate the performance indicators is available in the organization.

3. Determination of the data needed as input to the decision support system

A certain amount of input data was required in the form of initial parameters to be able to work with the decision support system. To predict the available capacity, the system needed to know the total amount of capacity. This means that the number of beds in a ward and the distribution of these beds in terms of male, female and various classes of beds (one-bed rooms, two-bed rooms and four-bed rooms) had to be entered. Also, the days of the week on which each surgeon had operating theater time and the amount of operating time on these days had to be entered. The same type of information was required for the nurses. In addition, information regarding the amount of capacity a patient needed based upon diagnosis, operation, age and gender. The following data was collected:

- age, gender, diagnosis and length of stay of patients in the past;
- age, gender, diagnosis, operation and workload for every day of the hospital stay of patients in the past;
- emergency arrivals per gender per day of the week in the past;
- duration of an operation per type of operation.

The above data had to be collected for all operations and diagnoses in order to compile a list of all of the diagnoses and operations.

Finally, the probability of predicting a higher available capacity than there actually was had to be determined.

4. Preparation for the implementation

All of the people involved in the project had to be informed about what was going to happen. The person or persons working with the system needed to learn how to handle the system. It also had to be determined whether the information necessary to plan the admissions would be available in time. In situations where this information would not be available in time, the method of information processing needed to be changed. Also, it was necessary to determine in which way the decision support system would be used to make an admission plan and by whom the system would be used.

5. Observation O1

Observation O1 involved measuring the performance of the admission planning function in the period before the decision support system was implemented. The performance indicators determined in phase 2 were measured during a period of a month.

6. Implementation of the decision support system

The implementation of the decision support system was divided into two phases. During the first phase the system was used as a "shadow" system: All of the information needed to make predictions about the consequences of admission decisions was entered into the system, but the system was not actually used to make admission decisions. The admission decisions were made in the traditional way while the system showed the consequences of this decision. During this period it was possible to test the accuracy and reliability of the predictions using a simulation program. This program was able to recreate the situation in the past and compare the predictions with the reality. When the predictions were not good enough, it was possible to make adjustments after analyzing the reasons why the predictions were not good enough.

When the predictions became reliable enough, the system was then used to evaluate the admission decisions and to change these decisions when they appeared to be infeasible. The decisions of the user were recorded by the computer program. This made it possible to see how often the planner had made admission proposals, how often proposal were changed and what the predicted occupancy of the resources was. In addition, each planner kept a log-book. In this book he noted what went wrong, why plans were changed and how admission decisions where made.

7. Observation O2

Observation O2 involved measuring the performance measurement of the admission planning function after implementing the decision support system during a period of a month. In addition, observation O2 involved interviews with the main stakeholders in the admission planning process. The subject of these interviews was their reactions and comments regarding the design of the decision support system and the use of this system in practice.

8. Evaluation

In the evaluation, the measured values of the performance indicators were compared and analyzed. In addition, the results of analyses based upon the notes in the log-book and the reactions and comments of the main stakeholders were taken into account in the evaluation.

Chapter 5
Orthopedics 1

This chapter presents the results of the first case study. This case study was carried out in an orthopedic department of a large hospital. The management of this hospital was interested in implementing a decision support system for admission planning since some departments were not able to achieve an adequate utilization of their resources.
First, a description of the situation in which the decision support system for admission planning was implemented is presented in this chapter. Second, the predictions regarding the availability of beds and operating time in the future made by the decision support system are evaluated. Third, the implementation of the decision support system is described. Attention is then paid to comparing the performance of the admission planning function in the old and in the new situation. Subsequently, a qualitative evaluation of the decision support system is presented. Finally, a summary of the main conclusions derived from this case study is presented.

5.1 Description of the situation

This section describes the environment in which the decision support system is implemented. First, the orthopedic department is described in terms of patient flows and resources. Second, the way in which admission planning takes place in this department is described. To conclude, the problem areas regarding admission planning are identified.

5.1.1 The orthopedic department

Three specialists are employed in the orthopedic department. Each of these specialists has his own waiting list of patients. The fact that each specialist has his own waiting list influences the choices that can be made regarding the admission of patients. It is not possible to admit a patient for one specialist if this patient has already been placed on the waiting list for another specialist. The waiting list of every specialist differs in length as well as in type and number of diagnoses.
Yearly about 1500 patients are treated. More then 90% of these patients undergo one or more operations. Most of these patients are admitted into the hospital for the implantation of a hip prosthesis or an arthroscopy of the knee. In this hospital, back operations are performed primarily by the neurosurgeons.

The orthopedic department has 35 beds, divided over two wards. One ward with 30 beds is used solely by the orthopedic department. Five beds in another ward are also used by the orthopedic department. Any of the patients may be placed in either ward.
Each specialist is provided with a certain amount of operating time per week. In Table 5.1 the operating schedule for all three of the specialists is presented.

Specialist	Monday	Tuesday	Wednesday	Thursday	Friday
1	480	-	480*	240	-
2	-	480	480*	-	240
3	-	-	480*	480	240

Table 5.1: Operating time in minutes per day per specialist

* on Wednesday two operating rooms are available, each for 480 minutes. The operating schedule depends on the number of the week. For example, in week 1 specialist 1 and specialist 2 have an operating session on Wednesday and in week 2 specialist 2 and specialist 3 have a session on Wednesday.

5.1.2 Admission planning

In this section it is described in which way the admission planning was done before the start of the project. This knowledge of the way in which the admission planning was done was gained via structured interviews with one of the specialists, the head of the admission planning department, the head of the operating department and the head of the nursing department. In a later phase, the secretaries of the orthopedic specialists and the head of the orthopedic wards also were interviewed. In addition, the activities at the admission planning department were observed for several days.

Traditional admission procedure

The selection of patients to be admitted into hospital was performed primarily by the secretaries of the specialists. Firstly, the appointments with individual patients which were made in an earlier stage were included in the initial admission proposal for the coming week. Subsequently, patients who had indicated that they preferred short term treatment were added to this admission proposal. If operating time was still available, the initial admission proposal was completed with patients with a high urgency or patients that already had waited for a long time.
Two to four days before the day of the operation (most of the time equivalent to one to three

days before the day of admission), the initial admission proposal was checked against the availability of beds and operating time and the preferences of the orthopedic specialists. The check against the availability of beds was done on the basis of a list of expected available beds in the near future which was prepared by the head of the ward. The check against the availability of operating time was performed by the specialists based upon their knowledge about the time they need for an operation.

Emergency admissions

To be able to admit emergency patients, an effort was made to keep (reserve) two beds available: one bed for males and one bed for females. In practice, however, these beds were often occupied by elective patients. In the operating theater, two rooms were available for the admission of emergency patients after four o'clock. Capacity was also available during the day to admit emergency patients without disturbing the current operating schedule.

Consultation with stakeholders

On a daily basis, the secretaries consulted with the specialists to translate the initial schedule into a final schedule. This final schedule was passed to the head of the admission planning department on a daily basis. The head of the admission planning department then consulted with the heads of the orthopedic wards to check whether the schedule would cause any problems with the workload of the nurses. If there were problems with the final schedule in the sense that selected patients were not available for admission or the workload of the nurses in the wards was too heavy, the head of the admission planning department consulted with the specialists. In consultation with the specialists, other patients were then selected for admission.

If a patient was expected to need extra blood during surgery, the specialist ordered the required amount of blood. If a prosthesis was needed, the specialist ordered this prosthesis via the head of the operating theater.

The head of the operating theater was not consulted about the available operating time.

Information used in the admission planning process

The following information was used during the course of this admission planning procedure:

- a list of the expected available beds in the near future, produced on a daily basis by the head of each ward;
- the admission registration form. This is a form which is completed at the time a patient is placed on the waiting list. This form includes patient information and information

regarding the specific admission, such as the diagnosis and the operation;
- an estimation of the nursing workload, made by the head of the ward;
- an estimation of the required operating time, made by the specialist.

5.1.3 Problem areas

Occassional problems arose due to the way in which the admission planning was performed before the decision support system was implemented. From the structured interviews, the following problem areas could be identified:

- the available operating time often could not be used efficiently at the end of the week because all of the beds were occupied. It is assumed that this problem occurred because it was not known how many emergency patients would arrive on a specific day and there was a lack of insight into the availability of beds in the future;
- patients were notified of their admission only one day before the actual admission date. Because of this, not all patients were available on the scheduled date. This resulted in a number of cancellations and *ad hoc* adjustments to the final schedule;
- a final schedule often had to be revised because the workload in the ward was too heavy. According to most of the stakeholders, a main cause of this problem was the fact that the workload of the nurses could not be measured resulting in a situation in which the feasibility of the schedule could not be verified in terms of the workload of the nurses.

Our attention was focused primarily on the first two problem areas in this case study.

5.2 Predictions

The decision support model developed for admission planning provides predictions about the availability of bed capacity, nursing capacity and operating theater capacity in the future using the prediction models developed by Kusters [1988]. Before the decision support model could be used, it was necessary to verify that:

- the assumptions on which the prediction models rely were valid in this particular situation, and
- the predictions made on the basis of these models were accurate and reliable enough to use for admission planning purposes.

In this section, we first identify the assumptions which were not valid in this particular situation and we describe the necessary adjustments made to the models developed by Kusters. Second, the results of the evaluation of the predictions are presented.

5.2.1 Adjustments to Kusters's models

In this case study, two adjustments to Kusters's model were made.

The first adjustment was that the prediction of the length of stay is not based upon the diagnosis of the patient but on the type of operation. This adjustment was made because the type of operation is registered on the waiting list form while the diagnosis is not noted. It proved to be very difficult in practice to translate a given operation into the corresponding diagnosis since the same operation may be used for different diagnoses and one diagnosis may lead to different operations. In addition, it appeared that the prediction of the length of stay based upon the type of operation seemed to be more reliable than the prediction which was based upon the diagnosis. Initial analyses of the variance of the length of stay based upon the type of operation and based upon the diagnosis showed no significant difference between the two approaches. The mean weighted variance per patient (over a total of 1107 patients) for predictions on the basis of diagnosis was 56.804. The mean weighted variance per patient for predictions on the basis of operation was 55.086. However, when the upper and lower 5% of the data samples in each group were removed, the mean weighted variance of the length of stay for the predictions based upon the type of operation and the gender of the patient was considerably smaller (14.415) than the mean weighted variance of the length of stay for the predictions based upon the diagnosis and the gender (18.705). For these last calculations we used the data for 991 patients out of the total number of 1107 patients.

A second adjustment to Kusters's model was that the prediction of the duration of an operation was based not only upon the type of operation on the patient, but also upon the particular specialist. In his study, Kusters assumed that it often was not known which specialist would operate on a patient. However, in this department it was always known which specialist was scheduled to operate on a specific patient. In addition, an analysis of the duration of operations in the past showed that the time required to perform an operation not only depended upon the type of operation, but also upon the specialist.

5.2.2 Performance of the prediction models

All of the changes in the patient data and the capacity data were registered by the decision support system to provide a basis for evaluating the performance of the prediction models. Using this data and a computer simulation model, it was possible to compare the actual utilization of the resources with the predictions of the resource utilization. In this section we will show the results of the evaluation of the prediction model for the future bed availability.

Prediction model for the future bed availability

The future bed availability model of Kusters [1988] predicts the number of beds available at

some time in the future. Starting with the number of available beds on day t one can find the expected number of available beds on day t+y by predicting the changes. These changes are:
a) the number of waiting list admissions on the days t+1,...,t+y-1;
b) the number of emergency admissions on the days t+1,...,t+y;
c) the number of discharges on the days t+1,...,t+y.
This latter term is composed of the following factors:
1) the number of discharges out of the patients present on day t;
2) the number of discharges out of the emergency patients admitted on day t+1,...,t+y;
3) the number of discharges out of the waiting list patients admitted on day t+1,...,t+y-1.

Depending upon the purpose for which the decision support system for admission planning is used, the patients may or may not be known who will be admitted during the period from the time at which the prediction is made to the day in the future for which the prediction is being made. If the decision support model is used to support the planner in making admission decisions for a long period in advance, it is assumed that the admissions for the coming days are already known. If the decision support model is used only to gain insights into the consequences of admission decisions for the next couple of days, however, it can be assumed that the admissions for these days are not yet known. In this section we will evaluate the performance of the prediction models in both situations.

First, the expected number of occupied beds must be determined in order to predict the number of available beds in the future. The expected number of occupied beds is then subtracted from the total number of beds. A comparison of the actual number of available beds with the predicted number of available beds provides a measure of the "fit" between prediction and reality. The prediction of the number of available beds in the future is carried out separately for male and female beds. Since the number of male and female beds in this department is not fixed, the expected number of occupied beds (instead of available beds) for each gender are compared with the actual number of occupied beds for each gender.
To measure the "fit" between the predictions and the actual data we calculated the correlation coefficient, the determination coefficient, the average prediction error (APE) and the standard deviation of the prediction error (SDPE). The results of these calculations for males are presented in Table 5.2 for the predictions made 1 to 7 days in advance, assuming that the admissions for the coming period are not known. Table 5.3 presents the results of these calculations for females, also assuming that the admissions for the coming period are not known. Tables 5.4 and 5.5 present the same type of data for the situation in which the admissions for the coming period are known. The data on which Tables 5.2 through 5.5 are based can be found in Appendix A.

x	R	R^2	APE	SDPE
1	0.86	0.74	0.067	1.233
2	0.72	0.52	0.149	1.555
3	0.61	0.37	0.299	1.683
4	0.49	0.24	0.284	1.776
5	0.41	0.17	0.233	1.787
6	0.25	0.06	0.193	1.885
7	0.02	0.01	0.004	2.038

Table 5.2: "Fit" between the predictions and the actual situation for males when the admissions in the coming period were not known

x	R	R^2	APE	SDPE
1	0.74	0.55	0.342	1.412
2	0.64	0.41	0.576	1.611
3	0.64	0.40	0.857	1.586
4	0.64	0.40	1.002	1.566
5	0.64	0.41	1.176	1.465
6	0.64	0.42	1.370	1.401
7	0.74	0.55	1.315	1.154

Table 5.3: "Fit" between the predictions and the actual situation for females when the admissions in the coming period were not known

x	R	R^2	APE	SDPE
1	0.90	0.82	0.067	1.233
2	0.83	0.69	0.041	1.604
3	0.77	0.59	0.082	1.825
4	0.70	0.48	0.044	2.050
5	0.65	0.43	0.015	2.143
6	0.57	0.32	-0.024	2.344
7	0.31	0.09	-0.247	2.453

Table 5.4: "Fit" between the predictions and the actual situation for males when the admissions for the coming period were known

x	R	R^2	APE	SDPE
1	0.80	0.64	0.342	1.412
2	0.73	0.53	0.483	1.612
3	0.74	0.55	0.700	1.590
4	0.75	0.56	0.734	1.587
5	0.76	0.58	0.759	1.540
6	0.76	0.58	0.834	1.579
7	0.75	0.57	0.644	1.506

Table 5.5: "Fit" between the predictions and the actual situation for females when the admissions for the coming period were known

In the Tables 5.2 through 5.5:

x = number of days in advance for the prediction of the number of occupied beds
R = correlation coefficient
R^2 = coefficient of determination
APE = average prediction error
SDPE = standard deviation prediction error

From Tables 5.2 through 5.5 it can be concluded that the "fit" between the predictions and the actual data is:

- moderate for predictions made for males for 1 to 2 days in advance when the admissions in the coming period were not known,
- moderate for predictions made for females for 1 or 7 days in advance when the admissions in the coming period were nog known,
- quite good for predictions made for males for 1 to 3 days in advance when the admission in the coming period were known, and
- moderate for predictions made for females for 1 to 7 days in advance when the admissions in the coming period were known.

The "fit" between prediction and actual data is, both for females and for males, better in the situation in which the admissions in the coming period are known. The reason for this is that when the admissions in the coming period are known, the prediction of the occupancy of the beds is based upon more patients whereby individual patient variances from the average length of stay are more likely to be smoothed out. The "fit" between predictions and actual data for males is very poor for predictions made four or more days in advance. This is probably due to the small number of beds (6-10) occupied by males and the relatively short mean length of stay. We can also conclude that the prediction error for females is quit large. The reason for this is that the predictions of the length of stay are based upon statistical data which is two years old. Since the average length of stay tends to decrease each year, it can be expected that the predictions made using these data will generally show a higher bed occupancy than the actual value. Although we tried to adjust this data in such a way as to reduce the average prediction error, this was not completely successful. A better solution would have been to collect up-to-date statistical data regarding the length of stay of patients. However, in this hospital it was very difficult to collect this type of information since statistical data about the length of stay of patients was only available once a year for the previous year.

To test whether the predictions for the bed occupancy for a period of 1 to 7 days in advance were sufficiently reliable to use as a basis for admission planning, we used the same measures as Kusters used in his thesis [1988]. To calculate these measures the number of occupied beds was predicted using a theoretical overflow possibility of 5%. This means that the probability predicting more available beds than actually available is 5%.

Measure 1 was used to test the accuracy of the predictions. This was defined as the standard deviation of the prediction error divided by the mean occupancy of the beds. The standard deviation of the prediction error is a measure for the variance of an individual prediction from the actual value. By dividing the standard deviation of the prediction error by the mean occupancy, an indication of the relative magnitude of the deviation was obtained. In addition to the accuracy of the predictions, the reliability of the predictions is also of importance.

Measure 2 represents the frequency of which the actual number of occupied beds exceeded the predicted number of occupied beds (realized overflow possibility).

Measure 3 is a measure of the efficiency of the predictions. Efficiency is defined here as the fraction of the predicted number of available beds which were actually available. In this calculation it is assumed that the total number of beds is equal to the number of occupied beds on day 0. As compared to the efficiency calculated by Kusters [1988], the efficiency calculated here will tend to be lower.

In Tables 5.6 and 5.7 the value of the measures was calculated based upon a simulation of 61 days for which the predictions made by the system are compared with the actual situation. The predictions were made assuming that the admissions are known for the period from the time at which the prediction is made to the day in the future for which the occupancy is predicted. A theoretical overflow possibility of 5% was used.

x	Measure 1	Measure 2	Measure 3
1	0.19	0.06	0.94
2	0.23	0.07	0.93
3	0.26	0.07	0.93
4	0.28	0.08	0.92
5	0.27	0.08	0.92
6	0.29	0.11	0.90
7	0.31	0.13	0.87

Table 5.6: Results of a simulation of 61 days during which the predictions of the number of occupied beds for males were compared with the actual situation

x	Measure 1	Measure 2	Measure 3
1	0.15	0.00	1.00
2	0.18	0.05	0.95
3	0.19	0.02	0.98
4	0.19	0.02	0.98
5	0.20	0.00	1.00
6	0.20	0.00	1.00
7	0.19	0.00	1.00

Table 5.7: Results of a simulation of 61 days during which the predictions of the number of occupied beds for females were compared with the actual situation

From the Tables 5.6 and 5.7 we can conclude that the predictions for males are less reliable than the predictions for females. The efficiency of the predictions for males was lower, the variances of these predictions were larger (Measure 1) and the predicted number of beds for males exceeded the actual number of available beds more frequently. Recalling the results summarized in Tables 5.4 and 5.5, the "fit" of the predictions for males for 1 to 3 days in advance is better than the fit of the predictions for females. This does not necessarily mean that the reliability of the predictions for males was also higher, however. There are two explanations for this phenomenon. Firstly, the number of beds used for males is much smaller than the number of beds used for females, increasing the likelihood of a larger variance due to a smaller sample size. Secondly, the average prediction error for females was positive. This means that the number of available beds for females was mostly underestimated. This explains the higher efficiency and the lower value of Measure 2 for the female bed predictions. The value of Measure 1 for females, however, is quit high. This means that often a much higher bed occupancy is predicted than there actually is. Using these predictions, this will result in a decrease in the bed occupancy. Whether such a decrease in bed occupancy is acceptable is to be decided by hospital management.

Prediction model for the required operating time
We have made predictions of the required operating time for thirty operating sessions and compared them with the actual required time. The average prediction error was -4 minutes. The standard deviation of the prediction error was 38.5 minutes. The coefficient of correlation was 0.94. We can conclude that this prediction model performs quite well.

5.3 Implementation

In this section the implementation of the decision support system in the orthopedic department is described. Firstly, we describe the changes in procedures which were necessary to guarantee that the information required as input for the decision support system was available at the right place and time. Secondly, the way in which the decision support system was used in the admission planning process is described.

5.3.1 Changes in procedures

Before an admission schedule is made, the information in the decision support system must be up-to-date in order to be able to work effectively. In practice, this means that the history of admissions and discharges that have taken place must be known in the system before an admission schedule is made. In most hospitals the information about the discharge of patients is passed to other departments after the discharge has occurred. This means that:

a) an admission schedule can be made only after the discharges have been passed on to the admission planning department, or
b) the decision support model must be able to make use of additional information which is currently entered on a special form. This form is filled in by the nurses and shows the available beds on a specific day.

Information regarding patients was gathered at two different locations, namely, at the admission planning department and at the office of the specialists. To guarantee that all of the necessary patient information was available at a central location, it was necessary to make agreements about the transferring of information from one location to another. At the start of the project, this information was not passed from the admission planning department to the office of the specialists and vice versa. This often resulted in admission schedules that could not be implemented because the patient either was not available or still had to undergo some tests before he could be admitted.

5.3.2 Admission planning

Almost all the information required by the decision support model was available within the admission planning department. Therefore, it was decided to install the decision support system in this department even though the admission planning department personnel were not responsible for making the admission decisions. This meant that the admission planning procedure had to be revised in order to make an admission schedule using the decision support model. In the project group in which the main stakeholders of the admission planning process in the orthopedic department were involved, three alternative procedures for admission planning were developed. The basic idea underlying all of these procedures was that the specialist was the person responsible for the admission decisions and thus must approve an admission schedule. These three alternatives were:

1) for a representative of the specialists to visit the admission planning department every day and use the decision support model to prepare an admission schedule for a few days in advance;
2) for one of the secretaries to visit the admission planning department every day with a preliminary admission schedule which she has prepared herself, then using the decision support model to revise this schedule. She would subsequently pass the revised schedule to the specialists for their approval;
3) for the head of the admission planning department to make an admission schedule for a few days in advance and then to pass this schedule on to the specialists. Each specialist would subsequently decide whether to accept or change the admission schedule. When the specialists have already made certain appointments with patients or prefer to admit certain patients ahead of others, they can relay this information to the head of the admission planning department so that he can take their preferences into account.

Initially, the project group chose to implement alternative 1. All three of the specialists agreed. In a consultation between the head of the admission planning department and the representative of the specialists it was agreed that one of the specialists would visit the admission planning department daily between one and two o'clock. In practice, however, the specialist was almost never able to visit the admission planning department. As a result, this alternative did not work out. Next, it was recommended that alternative 2 be implemented since this alternative was almost the same as the traditional admission planning procedure. However, in consultation with the secretaries of the specialists, it was decided not to implement this alternative because they would not have the time to visit the admission planning department. Finally, the decision was made to implement alternative 3. In the beginning, this alternative also failed because the specialists and the secretaries had already made so many appointments with patients that the head of the admission planning department could evaluate only the consequences of the schedule. He could not make adjustments to the schedule to ensure that the admission planning goals could be achieved. Nevertheless, after an initial period, the number of appointments made by the specialists decreased and the head of the admission planning department had more freedom to make admission recommendations. The admission recommendations made by the head of the admission planning department on the basis of the decision support system were, in most instances, approved by the specialists and implemented without changes.

5.4 Performance measurement

One of the main objectives of the cases was to determine whether the use of the decision support system could lead to an improvement in the performance of the admission planning function. To be able to draw conclusions about the effects of the implementation of the decision support model, the admission planning objectives were defined, first. Next, these objectives were translated into operational performance indicators. These performance indicators then could be measured during a period prior to the implementation of the decision support system and subsequently during a period after the decision support system was implemented. Ideally, this would result in differences which could be attributed to the implementation. However, because admission planning is part of a real-life process, many other changes occurred at the same time within this department. Some of these changes also affected the performance of the admission planning process. It was necessary to record all of these changes in order to be able to make an objective evaluation of the differences in performance between the two measurements.

In the next sections, the determined performance indicators are described first. Second, the results of the two measurements of these performance indicators are presented. Subsequently, the changes that took place between the first and the second measurements and the effects of these changes on the performance are described. To conclude, the differences in performance between the first and the second performance measurements are analyzed and conclusions are drawn.

5.4.1 Performance indicators

In a project group in which the heads of the nursing department, admission planning department, operating theater, medical department, one of the specialists and a staff employee of the nursing department participated, the admission planning objectives were defined. First, the main factors determining what is meant by a good admission planning were identified. The following factors were identified by the project group:

- planning the admissions on a weekly basis instead of planning on a daily basis (long

range planning);
- reserving enough capacity for emergency patients;
- taking the configuration of patients in the hospital into account. The configuration of patients in the hospital determines the future occupancy of the beds and the future nursing workload. If the configuration of patients in the hospital is not taken into account this can lead to problems with the occupancy of the operating theater and problems with the admission of emergency patients;
- optimalization instead of suboptimalization. Instead of planning on the basis of one resource, the schedule must contribute to a consistently high occupancy of all the potentially scarce resources.

These factors were subsequently translated into objectives. The project group determined that admission planning should contribute to achieving the following objectives:
- a consistently high occupancy of beds, operating time, nurses and specialists;
- a high service rate for emergency patients;
- a high throughput of patients.

From the last objective the following sub-objectives were derived:
- a limited and equal waiting time for patients in accordance with their diagnosis and urgency;
- a limited time between a notification of admission and the actual admission date;
- a high, balanced number of treated patients per period. A balanced number of patients treated per period means that the frequency of diagnoses for treated patients must equal the frequency of diagnoses for patients on the waiting list.

These objectives were translated into performance indicators. Table 5.8 provides a summary of the performance indicators used to measure the achievement of the objectives described above.

The starting point for calculating the occupancy rate of the operating theater time was the available operating time allocated to the specialists on the basis of the operating schedule (see Table 5.1). This schedule was made once per eight weeks and took planned absence of specialists or operating personnel into account. However, absence due to illness was not taken into account. The starting point for calculating the occupancy rate of the beds was a list on which the occupied beds for every specialism and every ward were noted each day at midnight.

<u>5.4.2 Measurement of the performance indicators</u>

This section summarizes the results of the two performance measurements.
The first performance measurement took place in June, 1991. The head of the admission

Objectives	Performance indicators
A consistently high occupancy of the beds	- mean occupancy rate of the beds - standard deviation of the occupancy rate of the beds
A consistently high occupancy of the operating room	- mean occupancy rate of the operating time - standard deviation of the occupancy rate of the operating time
A high service rate for emergency patients	- # emergency patients admitted in a orthopedic ward - # emergency patients admitted in a ward belonging to another specialism
A limited and equal patient waiting time	- mean patient waiting time (per diagnosis and total) - standard deviation patient waiting time (per diagnosis and total)
A limited time between a notification of admission and the actual admission date	- # patients with an appointment made three or more days prior to the admission date - # patients with an appointment made less than three days prior to the admission date - # patients without an appointment receiving a notification of admission three or more days prior to their admission date - # patients without an appointment receiving a notification of admission less than three days prior to their admission date
A high, balanced number of treated patients per period	- # admitted patients per period

Table 5.8: Admission planning objectives and the associated performance indicators

planning department kept track of the number of patients admitted during this month on a form developed for this purpose. Forms were also designed for keeping track of:

a) the waiting time of patients admitted during this month,

b) whether a patient admitted in this month had an appointment or not, and

c) the placement of emergency patients.

For the calculation of the occupancy of the operating time, the operation registration forms used in the operating department were used. For the calculation of the occupancy of the beds the so-called "STAT6" list was used.The second measurement of the performance indicators was carried out a year later in June, 1992. The logging facility of the decision support system was used to determine the waiting time of the patients admitted in this month and to count

the number of patients admitted during this month who had an appointment for this admission which had been made three or more days prior to the actual admission date. For the calculation of the mean value and variance of the occupancy of the operating time the operation registration forms were used as before. For the calculation of the mean value and variance of the occupancy of the beds, the "STAT6" list was used together with data from the logging facility of the decision support system.
The data on which the calculations of the mean occupancy of the operation time and the mean occupancy of the beds are based, can be found in Appendix A.
The results of the performance measurements can be found in Tables 5.9 and 5.10. In these Tables we did not include the performance indicators for a limited and equal patient waiting time since the patient waiting times differed enormously between specialists. During the first measurement we did not register which patient belonged to which specialist, so an analysis of the patient waiting times per specialist could not be made. In Table 5.9 the occupancy of the beds is represented in two ways. The first figure gives the occupancy of the beds taking all of the data into account. The second figure represents the occupancy of the beds only for weekdays (i.e., excluding weekends). The same types of calculations have been made for the standard deviation of the occupancy of the beds. The two values for the operation room occupancy for the second measurement represent two different methods of calculation. Each Friday, the operating schedule provides an opportunity for using more operating time than the time which was allocated to the specialist. During the period in which the second measurement took place, the specialists made use of this opportunity to schedule additional operating time on several occasions. The first figure in Table 5.9 represents the result of calculating the occupancy of the operating time using the time allocated to each specialist. The second figure represents the result of calculating the operating theater occupancy on the basis of the allocated time plus the extra time which was available on Friday. The number of patients with an appointment are also included in Table 5.9. It is apparent that the number of patients with an appointment was significantly higher during the second measuring period. The number of patients with an appointment did increase, but not to the extent shown in this table. This is due to the fact that the registration in the decision support system did not distinguish between patients with an appointment and patients which were given notice of their admission date three or more days prior to the actual admission date.

5.4.3 Changes

Hospital organizations change continually. To ensure the validity of comparing the results of the performance measurements, it was necessary to keep track of the other changes which took place during the period between the two measurements and to estimate the effect of these changes on the performance of the admission planning function.

Performance indicator	First measurement	Second measurement
Mean occupancy of the operating time	81.3 %	99.0 % / 95.3 %
Standard deviation of the occupancy of the operating time	18.9 %	22.5 % / 12.0 %
Mean occupancy of the beds	76.2 % / 80.1 %	73.2 % / 76.1 %
Standard deviation of the occupancy of the beds	9.1 % / 6.9 %	13.4 % / 14.1 %
# emergency patients admitted in the orthopedic ward	2	13
# emergency patients admitted in a ward belonging to another specialism	1	0
# patients with an appointment made three or more days in advance	3	84
# patients with an appointment made less than three days in advance	6	
# patients without an appointment given notice of their admission three or more days prior to the actual admission date	0	
# patients without an appointment given notice of their admission less than three days prior to the actual admission date	103	55

Table 5.9: Results of the performance measurements

Four significant changes took place in the orthopedic department during the period between the two measurements.

The first change that took place was that the five orthopedic beds used in another ward were no longer available for use by all of the orthopedic patients, but only for patients who could be admitted **O**n the **D**ay of the **O**peration (so-called "odo" patients) and for whom the length of stay was five days or less. This change had a number of effects. Firstly, this change led to an increase in the number of patients admitted on the day of the operation and, thus, to a reduction of the occupancy of the beds used by these patients. Every "odo" patient needs one less bed-day than a similar non-"odo"-patient. Secondly, this change meant that there was less capacity available for the patients with more severe diagnoses since they only could make use of the 30 beds in the other ward. This also meant that it was more difficult to fully occupy the operating time on some occassions since most of the patients with a length of stay of less

Operation	First measurement	Second measurement
Arthroscopy of the knee	48	56
Arthroscopy of the wrist	1	2
Arthroscopy of the shoulder	1	0
Prosthesis of the hip (including fractures of the hip)	13	25
Hammer toe	8	4
Spondylodesis	2	3
Cross ligament plastic	2	0
Prosthesis of the knee	1	2
Prosthesis of the ankle ligament	1	1
Other (mostly small) operations (osteotomies, arthrotomies)	40	46

Table 5.10: Number of patients treated during each measuring period

than five days only needed half an hour of operating time.

The second change that took place was an expansion of the nursing capacity in the orthopedic ward which had 30 beds. We estimate that the effect of this change was very small since the workload in this ward also increased due to the fact that only the more severe patients were admitted to this ward as stated above.The third change that took place was that the heads of the wards became responsible for maintaining a satisfactory utilization of their own resources. This change led to an increase in the willingness of the heads of the wards to admit patients from other departments. This especially affected the service rate for emergency patients since they were generally the only patients admitted to other wards. However, sometimes it also happened that elective patients were admitted to other wards. In such cases, the occupancy of the operating room was also affected.

The fourth change was the increased use of "oda" patients (One-Day-Admission patients). These are patients who are operated and discharged on the day they are admitted. The effect of the increase in the number of "oda" patients was similar to the effect of the increase in "odo" patients.

5.4.4 Conclusions

When the first measurement of the performance indicators is compared with the second measurement of the performance indicators, it can be concluded that the occupancy of the operating time increased by 17,2 % (from 81,3 % to 95,3 %). This difference in performance proved to be significant with a probability of more than 99 %, since the outcome of the "Two-sample" test of Wilcoxon was 413 for T_1 (n_1 = 22 and n_2).

The increase in the occupancy of the operating time was accompanied by a 5% decrease in the occupancy of the beds (weekends excluded from the calculation) and an increase of 19 % in the number of treated patients, however. The difference in the occupancy of the beds proved to be insignificant. The outcome of the "Two-sample" test of Wilcoxon was 982 for T_1 (n_1 = 30 and n_2 = 30).

The increase in occupancy of the operating time is due, to a large extent, to a better planning of the admissions. However, the fact that the long-stay ward was given extra personnel also could have had a slight influence on this increase. In addition, the addition of five beds to the short-stay unit in the other ward resolved the problems with personnel in this ward.

It is striking to see that a relatively large increase in the occupancy of the operating time is accompanied by a smaller decrease in the occupancy of the beds. An initial explanation for this phenomenon could be that a change in the mix of patients has occurred. A comparison of the mix of patients in both periods does not substantiate this fact, however. A further explanation of this phenomenon could be that the occupancy of the beds at the beginning of the period in which the performance indicators were measured was so poor that this significantly influenced the reliability of the mean occupancy of the beds in the total period. The data regarding the occupancy of the beds in the period indeed supports this hypothesis (see Appendix A). We can make the conclusion from this data that the length of stay of patients decreased somewhat. In addition, the introduction of one-day admissions and admissions on the day of operation have also reduced the mean length of stay of patients. During the period in which the second measurement of the performance indicators took place, 58 patients were admitted on the same day as the day on which they were operated. The admission of these patients required 58 bed-days less than would have been required during the period in which the first measurement took place. This is equivalent to a decrease in the occupancy of the beds of 58/30 = 2 beds during the whole month. This explains a difference of 5.7% in the occupancy of the beds. In addition, also the average length of stay for all the patients taken together is decreased.

5.5 Evaluation of the system design

In this section the decision support system is evaluated based upon a number of qualitative criteria. Attention is paid to the user friendliness of the system, the information provided by the system, the flexibility of the system, the ease-of-use and the "fit" of the system to the user environment.

User friendliness

The user friendliness of the system was not completely satisfactory. This can be attributed partly to the fact that the decision support system was implemented as a stand-alone system. Since there was no link between the decision support system for admission planning and the hospital information system, a certain amount of data had to be entered twice. This was a time-consuming process, taking between one to two hours each day.

Another factor that restricted the user friendliness of the system was the fact that a patient in the system could only be identified on the basis of his patient number. The patient numbers were not always known in practice and, thus, had to be looked up in the hospital information system. The users would have preferred identifying a patient on the basis of his/her last name and birth date.

Also the response time of the system was poor when the list of patients to be admitted into the hospital on a specific day was generated. This meant that the system was used primarily to establish an initial admission schedule and generally not used to take a quick look at the consequences of changes subsequently made to this initial schedule.

Information provided by the system

The information provided by the system represented the complete set of information considered to be necessary for making an admission decision. The way in which the information was presented to the user was also found to be satisfactory.

Flexibility

The flexilibility of the system was seen as being satisfactory. One situation could be identified in which the flexibility of the system appeared to be insufficient. This was the case when one patient was put on the waiting list by two specialists. In this version of the system it is not possible to put a patient on the waiting list more than once. When the system is used for only one specialism, this is not a serious drawback since it seldom happens that a patient needs to be put on the waiting list twice for the same specialism.

Ease-of-use
The admission planner could work quite well with the decision support system for admission planning. For some of the other employees within the admission planning department it was sometimes difficult to interpret the predictions of the occupancy of the beds and the operating theater.

The "fit" of the system in the user environment
During the project some modifications were made to the decision support system to ensure that there was a good "fit" between the system and the user environment.

5.6 Conclusions

This chapter has described how the implementation and testing of a decision support system for admission planning was carried out in an orthopedic department of a large hospital.
This case study illustrates that the fit between the predicted bed occupancy and the actual bed occupancy was quite good for males for predictions made 1 to 3 days in advance. The fit between the predicted bed occupancy and the actual bed occupancy for females was moderate for predictions made 1 to 7 days in advance when the admissions in the coming period were known. The average prediction error for females was quite large, however. In this respect we stated that the predictions of the bed occupancy for females probably could be improved by using more up-to-date data.
This case study also shows that the performance of the admission planner can be improved through the use of this decision support system. Nevertheless, it remains difficult to prove whether this improvement can be attributed fully to the introduction of the system in view of the other changes which also took place.
Regarding the qualitative aspect of the system, the user friendliness of the system appeared to be the only factor which needed significant improvement. Improving the user friendliness of the system could be achieved by linking the system with the hospital information system, running the program on a mainframe (to improve the response time) and making it possible to identify a patient using his last name and birth date.

Chapter 6
Orthopedics 2

Case 2 was also carried out in an orthopedic department. However, in contrast with the orthopedic department in Case 1, this situation involved an orthopedic department in a small hospital. Although we only used the decision support system as a shadow system for a short period of time, a description of the case is still useful because it illustrates a situation in which use of the system probably would not contribute significantly to a better performance of the admission planning function. In addition, this case study also shows that Kusters's prediction models can also be used in a small hospital.

6.1 Description of the situation

In this section a description of the orthopedic department in which the decision support system was implemented is presented. Special attention is paid to the way in which the admissions were planned and to the main problem areas with respect to this process.

6.1.1 The orthopedic department

Three specialists are employed in the orthopedic department. Approximately 900 patients are treated yearly.

The patients in the orthopedic department make use of beds in five different wards. A ward on the sixth floor of the hospital is used for long-stay patients of the orthopedic, surgical and urological departments. In this ward, thirty-nine beds are available. Nineteen of these beds can be used by orthopedic patients.

A ward on the fourth floor is used for patients with a length of stay of less than five days. This ward is used by every specialism in the hospital and is closed during the weekends. There is no allocation of beds among specialisms in this ward. In practice, patients of the orthopedic department occupy an average of approximately nine beds a day. The number of occupied beds, however, varies enormously from day to day.

Patients of the orthopedic department sometimes make use of beds on the fifth floor. The fifth floor beds are used for patients with an infection. The beds used on the fifth floor are subtracted from the beds available on the sixth floor.

Children admitted to the orthopedic department make use of a special ward for children on the second floor of the hospital.

Nursing capacity is not allocated to patients according to their specific department. A certain

amount of nursing capacity is allocated to each ward, instead. This capacity is used for all of the patients in the ward.
A block schedule is used in this hospital to allocate operating time to the individual specialists. This schedule provides an overview of which specialist is assigned to which operating room and for which sessions. Two sessions per operating room are scheduled in this hospital: a morning session from 8:00 a.m. - 11:45 a.m. and an afternoon session from 12:45 p.m. - 4:30 p.m.. The operating times assigned to each of the orthopedic specialists are presented in Table 6.1.

Specialist	Monday	Tuesday	Wednesday	Thursday	Friday
1	225	-	225	225	-
2	-	225	225	-	285
3	225	225	-	225	-

Table 6.1: Operating time per specialist

6.1.2 Admission planning

This section describes the way in which the admission planning was done in the orthopedic department at the start of the project. Insights into the admission planning process were gained by holding structured interviews with the secretary of the specialists, the specialists themselves and the heads of one of the wards, the admission planning department and the operating theater.

Traditional admission procedure

A patient was put on the waiting list at the moment a specialist decided that this patient needed to be admitted into the hospital. At that moment an admission form was completed. This form contained the personal data of the patient, his diagnosis, any peculiarities or abnormalities and patient preferences regarding his admission. The urgency status of the patient was also entered on this form. The urgency of a patient dictated in which period the patient had to be admitted into the hospital and, thus, determined the degrees of freedom an admission planner had.

Using this information on the admission forms, the secretary of the specialists then prepared cards which were placed on a planning board. She noted the name, diagnosis and date on which the patient was put at the waiting list on these cards. Each specialist had his own waiting list. Waiting lists for children, day-admissions or short-stay admissions and long-stay

admissions were maintained per specialist on the planning board. Also, a list of urgent patients was kept.
Once each week (on Wednesday), the secretary of one of the orthopedic specialists prepared an admission recommendation for the coming week. In making this recommendation she took into account the waiting time of patients, the ward in which they should be admitted, a global estimate of the operating time on the patients and a number of restrictions with respect to the operating schedule. Patients with the longest time on the waiting list were admitted first. The primary objective was to keep the beds occupied in the long-stay ward. Patients to be admitted in the long-stay ward (sixth floor), therefore, formed the basis of an admission schedule. A maximum of fifteen patients with a hip prosthesis may be admitted to the long-stay ward. Generally only one back operation was performed in each week. The remaining operating time was filled up with patients who could be admitted to the short-stay ward. The secretary tried to balance the number of patients admitted to the short-stay ward and the long-stay ward. For every block of operating time, usually one patient was admitted to the long-stay unit and one or two patients to the short-stay unit.
The secretary also scheduled the outpatients who needed to undergo an operation. The operations for outpatients were also performed in the operating theater belonging to the inpatient department of the hospital. The number of outpatients treated per operating session was reported to the head of the admission planning department. The head of the admission planning department assumed that each outpatient operation took half an hour.

In making an admission recommendation a number of restrictions needed to be taken into account. For example, it was not possible to perform more than three arthroscopies during one operating session since only a limited number of instruments were available. When short-stay patients were admitted, a sufficient number of beds had to be available for them in the short-stay unit. The secretary assumed that 5 short-stay patients could be admitted each day.

The scheduling of patients who had to undergo a discography was discussed with the X-ray department. In practice, three patients with a discography were admitted on every second Tuesday. However, this was not treated as a regular appointment.

Major back operations were scheduled more than a week in advance since they require a long preparation time.

When the admission recommendation for the coming week was prepared, it was passed to the head of the admission planning department. A check was made to determine whether the necessary beds were actually available a day prior to the admission of the patients. The final decision of whether to admit a patient depended on the availability of a bed. When the admission of a patient needed to be cancelled or a patient could be added to the admission recommendation, the secretary was consulted. If a patient could be admitted, the data on his admission form were checked. The patient was then called in for admission, when all of the data was approved.

Emergency admissions
The head of the admission planning department tried to reserve two beds per ward for emergency admissions. These beds were often occupied by scheduled patients, however, since specialists feared that patients of other specialisms might occupy their beds. When no beds were available in the hospital, emergency patients were not accepted.
There was no special room for emergency operations within the operating theater. Emergency operations were performed during the normal schedule. Nevertheless, there was one room available for emergency operations during the night.

Consultation with stakeholders
The secretary of one of the specialists contacted the head of the admission planning department on a daily basis to discuss changes in the admission recommendation. There was also communication between the secretary and the head of the admission planning department in the case of emergency arrivals.

The secretary contacted the heads of the wards once each week to find out how many patients were still in the ward. The secretary also consulted with the specialists. The specialists notified her of any special wishes regarding the admission recommendation for the coming week. Most of the time, however, there were no special requirements.
Once a week (on Thursday) the head of the admission planning department consulted with the head of the operating theater to evaluate the admission recommendation for the coming week. The admission recommendation was evaluated based upon the following criteria:
- the number of arthroscopied during each operating session;
- the number of patients with leg fractures, since there was only one operating table available for this type of patient;
- the availability of operating supplies;
- the probability of exceeding the available time;
- the distribution of operations over the days of the week. The head of the operating theater tried to achieve an even distribution of operations over the days of the week.

If the admission recommendation was rejected, the head of the admission planning department then made changes as necessary to this recommendation.

Each day, the head of the admission planning department reported to the heads of the wards the patients to be admitted to the wards on the next day. The heads of the wards informed the head of the admission planning department regarding the expected discharges in the coming three to four days.

Information used in the admission planning process
The following information was used to prepare an admission schedule:
- restrictions regarding the configuration of an operation schedule;
- data from the admission form;
- an estimation of the availability of beds in the near future made by the heads of the wards;
- an estimation of the required operating time made by the head of the operating theater.

6.1.3 Problem areas
During the interviews, all of the stakeholders admitted that there were practically no problems regarding the admission planning function. However, the secretary of the specialists who prepared the admission recommendation stated that the admission recommendation was subject to many changes in practice. These changes occurred, because:
- patients did not want to be admitted on the day they were scheduled for admission;
- patients could not be reached by phone;
- some data regarding patient preferences were not known to the secretary;
- there were not enough beds available;
- patients did not show up for admission.

The fact that data regarding the patient preferences was not known to the secretary was due to the fact that this information was kept by the admission planning department. This information was not passed to the secretary of the specialists.
The fact that an insufficient number of beds were available on some occassions was caused by the fact that the secretary did not take the available beds into account when she prepared an admission recommendation. Emergency admissions could also disrupt the schedule. An addition problem was that admission recommendations were prepared about a week in advance, but the patients were notified of their admission only one day before the actual admission date. The heads of the wards also knew just one day before the admission day which patients they could expect. In the future it would be preferable to make appointments with patients more frequently.
Another problem was the fact that there was no information included on the waiting list form regarding whether infection was to be expected. This was important information since patients with an infection needed more operating time and could not be admitted to the regular long-stay ward.

6.2 Predictions

In this department all of the required input data was entered into the decision support system. Subsequently, the decision support system was used as a shadow system for a period of six months. Carrying out these two activities provided us with enough insights and data to determine whether:

1) the prediction models developed by Kusters [1988] could be adjusted to this particular situation, and
2) the predictions of the length of stay confirmed with the actual situation and would be reliable enough to use for admission planning purposes.

6.2.1 Adjustments to Kusters's models

Three adjustments to Kusters's model were made in this case.
The first adjustment made to Kusters's model was the fact that a prediction of the length of stay was based upon the type of operation instead of the patient's diagnosis. The reason for this was that the diagnosis was not entered on the admission form and the personnel of the admission planning department had difficulties translating types of operation into diagnoses since the same type of operation may be used for different diagnoses and one diagnosis may lead to different types of operation.

A second adjustment was that the prediction of the required operating time per operation schedule was not only based upon the types of operations that had to be performed but also upon the specialist scheduled to perform the operation. In this situation it was always known which specialist operated on which patient and, therefore, it was possible to make allowances for the specialist who was scheduled to perform the operation.

The thirth and last adjustment was that we not only made separate predictions for males and females, but also for the different wards. The ward in which a patient was admitted depended upon the type of operation and the age of the patient. Not every patient could be admitted in every ward, so the type of ward in which a patient could be admitted had to be determined.

6.2.2 Performance of the prediction models

Only the prediction model for the future bed availability is evaluated in this section since this is the only model for which sufficient data was available. The evaluation of this prediction model took place in the same way as described in Section 5.2.2, except that emergency admissions were not taken into account.
Tables 6.2 and 6.3 show the coefficients of correlation for the prediction of the bed

availability for males and females for the situation in which the admissions in the coming period are unknown. Tables 6.4 and 6.5 show the same results for the situation in which the admissions in the coming period are known (and taken into account). The data on which Tables 6.2 through 6.5 rely can be found in appendix B.

Tables 6.6 and 6.7 show the values of the three measures described in Section 5.2.2. These values were calculated using a 60-days simulation in which the predictions of the number of occupied beds were compared with the actual situation.

x	R	R^2	APE	SDPE
1	0.85	0.72	-0.059	0.609
2	0.74	0.55	-0.098	0.744
3	0.69	0.47	-0.099	0.775
4	0.65	0.42	-0.084	0.830
5	0.57	0.32	-0.037	0.926
6	0.53	0.28	-0.017	0.950
7	0.37	0.14	0.072	1.060

Table 6.2: "Fit" between predictions and actual data for males when the admissions in the coming period are not known

x	R	R^2	APE	SDPE
1	0.95	0.90	0.063	0.965
2	0.79	0.63	-0.048	2.002
3	0.85	0.73	0.249	1.563
4	0.82	0.68	0.315	1.669
5	0.80	0.63	0.410	1.743
6	0.77	0.59	0.513	1.772
7	0.74	0.54	0.739	1.900

Table 6.3: "Fit" between predictions and actual data for females when the admissions in the coming period are not known

x	R	R^2	APE	SDPE
1	0.84	0.71	-0.043	0.641
2	0.74	0.55	-0.118	0.799
3	0.68	0.47	-0.160	0.862
4	0.58	0.33	-0.187	0.956
5	0.42	0.18	-0.189	1.098
6	0.32	0.10	-0.219	1.192
7	0.18	0.03	-0.181	1.401

Table 6.4: "Fit" between predictions and actual data for males when the admissions in the coming period are known

x	R	R^2	APE	SDPE
1	0.95	0.91	0.063	0.965
2	0.92	0.85	0.125	1.268
3	0.88	0.78	0.213	1.565
4	0.87	0.76	0.260	1.663
5	0.86	0.74	0.349	1.761
6	0.85	0.74	0.446	1.825
7	0.84	0.70	0.680	1.964

Table 6.5: "Fit" between predictions and actual data for females when the admissions in the coming period are known

x	Measure 1	Measure 2	Measure 3
1	0.14	0.05	0.96
2	0.17	0.05	0.96
3	0.18	0.05	0.95
4	0.19	0.08	0.93
5	0.22	0.12	0.89
6	0.23	0.14	0.86
7	0.28	0.15	0.86

Table 6.6: Results of a simulation of 60 days during which the predictions of the number of occupied beds for males were compared with the actual situation

Orthopedics 2

x	Measure 1	Measure 2	Measure 3
1	0.09	0.00	1.00
2	0.12	0.01	0.99
3	0.15	0.03	0.97
4	0.16	0.03	0.97
5	0.17	0.00	1.00
6	0.18	0.00	1.00
7	0.19	0.00	1.00

Table 6.7: Results of a simulation of 60 days during which the predictions of the number of occupied beds for females were compared with the actual situation

From the Tables 6.2 through 6.5 it can be concluded that the fit between the predictions and the actual data is:
- moderate for predictions for males made 1 to 2 days in advance, and
- good for predictions for females made 1 to 7 days in advance.

Seventy percent of the variance in the number of occupied beds for females was still explained by the model when predictions were made 7 days in advance in a situation in which the admissions in the coming period were known.

6.3 Implementation

Although the predictions made by the decision support system were found to be satisfactory (by the head of the admission planning department), it was decided not to implement the decision support system. The reasons for this decision were:
- the waiting list was very short. This made it extremely difficult to achieve the main objective of providing patients with an earlier notification of their respective admission dates;
- the decision support system was not able to provide the same flexibility as in the current situation. It provided no insights into the total occupancy of the short-stay ward. It was similarly not designed to represent the occupancy of the beds for other specialisms. In this hospital, however, the admission planner used the beds in a very flexible manner. Although the long-stay beds were distributed among the specialisms, the beds allocated to a specialism often were used for other specialisms (when the beds were not required for patients of the own specialism). The decision support system assumed that a specialism had a fixed allocation of beds and was, thus, not able to support the planner in situations in which beds of other specialisms could be used;

- working with the decision support system was very time-consuming and it was not clear whether improvements could be expected, since:
  1) the system did not support the planner in the flexible use of available beds,
  2) the performance was already relatively high. A performance measurement during one month showed us that the occupancy of the operating time in this department was 91%. An average of 19.5 beds per day were occupied in the long-stay ward, resulting in a bed occupancy of almost 103%, and
  3) much of the information provided by the system was already collected in other ways.

6.4 Evaluation of the system design

Although the system was not used in this case, a number of useful observations could still be made during the period in which the required data was maintained in the system.
Firstly, it was found to be very time-consuming to keep the system up-to-date with respect to maintaining all of the changes in patient data. This took about one and a half hours per day. Secondly, the system was found to be inflexible with respect to the use of the bed capacity allocated to other specialisms and the variances in the average operating time or average length of stay. Thirdly, there were some minor problems with the interpretation of the predictions regarding the availability of bed capacity and operating capacity in the future. These problems concerned the use of a significance level of 5%.

6.5 Conclusions

This case illustrated that the prediction model for the future bed availability also can be used in situations in which there are only a small number of beds.
However, this case has also showed us that the way in which the decision support system is designed is not useful in situations in which bed capacity is used in a flexible way and when a network of information exchange already exists and functions satisfactorily.

Chapter 7
Gynecology

The third case study is described in this chapter. This case study was carried out by a student within a gynecology department of a medium-sized hospital. The management of this hospital decided to take part in this project since it supported their ongoing efforts in this area. The correspondence between this project and the efforts of the hospital management in this area can be illustrated by the fact that the hospital management had already decided to initiate a project for admission planning at the end of 1988. The project group's task was to evaluate the way in which admission planning is done in the hospital and to generate proposals to improve the performance of admission planning. Improvement of the admission planning performance was necessary in their opinion, because:

- there was a need to use the available resources more efficiently (because of bed reductions and the introduction of budget financing);
- some problems were evident in the area of admission planning.

The management of this hospital found the results of this case study to be so encouraging that they decided to implement the decision support system for all of the surgical specialisms in the hospital. They also linked the decision support system with the existing hospital information system and are currently developing a new module in the hospital information system to replace the stand-alone decision support prototype system.

In this chapter the same format is used as in Chapters 5 and 6. First, the department is described in which the decision support system was implemented. Then, the predictions made by the model are evaluated. Next, the implementation of the decision support system in this department is described. Subsequently, the results of the performance measurement are presented and discussed. Finally, an evaluation of the total system is presented and the main conclusions of this case study are summarized.

7.1 Description of the situation

In this section the gynecology department is described in which the decision support system was implemented. First, the patient flows and the resources in this department are described. Then, the admission planning procedures in this department are described as they were before the introduction of the decision support system. In conclusion, an overview is provided of the main problem areas regarding the admission planning in this department.

7.1.1 The gynecology department

Five gynaecologist work in the gynecology department. On a yearly basis, approximately 1000 patients are treated in the clinic. In 1990, 531 patient were admitted into the gynecology department for a stay of longer than one day. The mean length of stay for these patients was 8.2 days. Twenty-six percent of these patients were admitted into the hospital as emergency cases. In 1990, 484 patients were admitted to the gynecology department for a stay of one day.

The gynecology department officially has 15 beds in a medium-care ward (B1). However, the medium-care gynecology patients can also make use of an overflow unit with a capacity of four beds. These beds are additionally used by the obstetrics department and, therefore, are not included as a part of the normal capacity of the gynecology department. The nursing capacity in the ward amounts to seven day-shifts. Three or four of these shifts are filled by students[1], while the other three or four shifts are filled by qualified nurses.

The operating capacity of the gynaecologists is presented in Table 7.1.

	Monday	Tuesday	Wednesday	Thursday	Friday
g1	210	-	150*	-	-
g2	120	-	-	-	240
g3	-	300	150*	-	-
g4	-	-	240	-	-
g5	-	-	-	300	150

Table 7.1: Operating capacity (minutes) assigned to the gynecologists

*= A session of 150 minutes was available every Wednesday. This session was used by either gynaecologist g1 or by gynaecologist g3.

7.1.2 Admission planning

The admission planning procedure for an elective patient starts at the moment a specialist decides that a patient needs to be admitted into the hospital. At that moment the specialist fills in an admission form. On the basis of this form the patient is placed on a waiting list. The admission planning procedure for an emergency patient also starts at the moment the specialist decides that a patient must be admitted into the hospital. However, an emergency

[1] In the Netherlands there is a so-called in-service training of nurses which takes place in the hospital

patient is not placed on a waiting list. An employee of the admission planning department checks whether there is a bed available for the emergency patient. For this check he uses an overview of the empty beds which is prepared twice a day. When he finds an empty bed, he contacts the head of the ward on which the empty bed is located and notifies him of the arrival of the emergency patient.

Traditional admission procedure

Every Wednesday an admission recommendation is prepared for the coming week by the heads of the operating theater, ward B1 and the admission planning department. To prepare this recommendation, patients are selected from the waiting list on the basis of the following two criteria:

1. urgency of the patient;
2. waiting time of the patient.

The waiting list is sorted per gynecologist to these two criteria.

The starting point for the admission recommendation is the operating schedule since the operating theater is considered to be the critical resource.

The head of the operating theater estimates the operating time for each patient. On the basis of these estimates, the available operating time is allocated to the greatest extent by selecting patients in a different sequence than the sequence on the waiting list, whenever necessary. For example, if a block of thirty minutes of operating time is still available, a patient with a short operation time will be admitted instead of the next patient on the list if this patient happens to need more than thirty minutes of operating time. The scheduling efficiency is, thus, more important than the total waiting time in some instances.

The patients admitted for gynecology may be placed in two different wards:

1) one ward for day admissions whereby the patients are admitted in the morning and return home in the afternoon;
2) one ward for medium-stay and long-stay patients whereby the patients are admitted for more than one day.

Based upon experience, the head of the ward for medium-care patients knows how many beds will be available in the coming week. The ward for day admissions is used by various specialisms. In this ward the beds are not allocated to specialisms. The head of the admission planning department estimates how many beds can be used for gynecology in this ward. Most of the time, however, the bed capacity poses no restriction for the admission recommendation. The same approach is used for allocating the nursing capacity. The head of the medium-care ward is able to estimate the workload associated with each of the patients and can determine whether the workload is within acceptable limits based upon her knowledge of the nursing schedule.

When a patient is included in the admission recommendation for the coming week, she is notified of this admission two days (for patients admitted to ward B1) or three days (for day admissions) ahead of the actual admission date.

Emergency admissions

In making the admission recommendation emergency patients are not explicitly taken into account. Neither bed capacity nor operating capacity is reserved for emergency patients. One session in the operating theater is reserved for emergency admissions. If the beds in the regular ward are all occupied, the beds in the overflow unit can be used to accommodate emergency patients.

Information used in the admission planning process

The following information is used to prepare an admission schedule:
- information about the patient which has been entered on the admission form;
- estimates of the required operating time made by the planner for the operating theater;
- estimates of the number of available beds in the coming week made by the head of the ward;
- estimates of the nursing workload in the coming week made by the head of the ward;
- estimates of the number of patients to be admitted at the day centre, made by the head of the admission planning department.

7.1.3 Problem areas

The main problem areas of admission planning in this hospital identified by the project group for admission planning, were:
- large fluctuations in the workload in the wards;
- admission of emergency patients;
- coordination of the admission activities between stakeholders;
- the level of service provided to the patients.

A low utilization of the operating time, the admission of emergency patients and, to a lesser extent, the level of service provided to the patients were the main problem areas of admission planning in the department in which the decision support system was implemented.

7.2 Predictions

This section provides an overview of the evaluation of the prediction models developed by Kusters. First, it is described which adjustments were required to be able to use these prediction models in this case. Second, the results are presented of a comparison between the predictions made using these models and the actual data.

7.2.1 Adjustments to Kusters's models

In this hospital, three adjustments were made to the prediction models developed by Kusters. A first adjustment was that the prediction of the length of stay of patients took place on the basis of the type of operation instead of the diagnosis. This adjustment was necessary since the diagnosis of a patient was not entered on the admission form.

A second adjustment to the prediction models of Kusters was the fact that the prediction of the operating time was based not only upon the type of operation, but also upon the surgeon who performed the operation.

The third and final adjustment was necessary because the prediction of the workload of the nurses was not based upon statistical data for the workload category in which a patient with a given diagnosis or operation could be placed. Instead, estimates of the workload for a given diagnosis or operation were made by the nurses.

7.2.2 Performance of the prediction models

In this section, a comparison is made between the results based upon the prediction models and the actual data. First, the results are presented of comparing the predictions made on the basis of the prediction model for the future bed availability and the actual bed availability. Then, the results of the evaluation of the prediction model for operating time are described. Finally, an overview is provided of the evaluation of the prediction model for the nursing workload.

Prediction model for the future bed availability

The evaluation of this prediction model was carried out in the same way as described in Section 5.2.2, except that emergency patients are not taken into account in this case. Table 7.2 presents the correlation coefficient for females in a situation in which the admissions in the coming period are not taken into account. Table 7.3 presents the same results for the situation in which the admissions in the coming period are taken into account. The data on which Tables 7.2 and 7.3 rely can be found in Appendix C.
Finally, Table 7.4 presents the results of simulating 61 days in which the predictions of the number of occupied beds are compared with the actual situation using three types of performance measurement. The predictions made for this simulation were based on a theoretical overflow possibility of 5% (see Section 5.2.2).

x	R	R^2	APE	SDPE
1	0.97	0.95	-0.127	1.010
2	0.95	0.91	-0.169	1.288
3	0.93	0.87	-0.150	1.438
4	0.91	0.84	-0.119	1.499
5	0.89	0.79	-0.099	1.573
6	0.87	0.76	-0.059	1.531
7	0.81	0.66	0.069	1.643

Table 7.2: "Fit" between the predictions and the actual data for females when the admission in the coming period are not known

x	R	R^2	APE	SDPE
1	0.98	0.95	-0.094	1.022
2	0.96	0.92	-0.149	1.385
3	0.94	0.89	-0.130	1.622
4	0.93	0.87	-0.111	1.778
5	0.91	0.84	-0.112	1.915
6	0.91	0.83	-0.110	1.926
7	0.89	0.79	-0.044	2.055

Table 7.3: "Fit" between the predictions and the actual data for females when the admissions in the coming period are known

x	Measure 1	Measure 2	Measure 3
1	0.12	0.07	0.93
2	0.14	0.07	0.93
3	0.16	0.05	0.95
4	0.19	0.12	0.89
5	0.19	0.12	0.91
6	0.20	0.10	0.91
7	0.22	0.11	0.94

Table 7.4: Results of simulating 61 days in which the predictions of the number of occupied beds for females are compared with the actual situation

From the results presented in Tables 7.2 and 7.3 it can be stated that the fit between the predictions and the actual data is quite good. This shows that 66% (Table 7.2) or 79% (Table 7.3) of the variance can be explained when the predictions are made seven days in advance. If the results in these Tables are compared with the same type of results as described in the previous chapters, it can be concluded that the results presented in this chapter show a much better fit than the results presented previously. This is probably due to the fact that the gynecologists perform only a small number of operations and the length of stay associated with a specific type of operation is very predictable.

Prediction model for the required operating time

During a period of 56 days, the predictions made by the system regarding the required operating time were compared with the actual required operating time. During this period the system made 51 predictions of the length of an operation schedule. On the basis of this data, we were able to calculate the average prediction error and the standard deviation of the prediction error. The average prediction error was 8.65 minutes per operating program. The standard deviation of the prediction error was 33.08 minutes. From these calculations it can be concluded that the accuracy of the prediction model is good.

Prediction model for the nursing workload

It was very difficult to compare the predicted nursing workload with the actual nursing workload since the actual nursing workload was not measured. However, in order to be able to test the prediction model for the nursing capacity, the head of the ward was confronted with the predictions made by the system and was asked to classify each prediction in one of five categories ranging from excessively high to excessively low. The results of this classification are presented in Table 7.5.

N=49	excessively high	too high	good	too low	excessively low
%	0	10	76	14	0

Table 7.5: Distribution of the predictions of the nursing capacity over the five categories

7.3 Implementation

To test the performance of the decision support system for admission planning, the system was used to generate the admission recommendations. The system had to be integrated into the admission planning procedure in order to achieve this. In this section, it is described how the system was integrated into the admission planning procedure in this particular department. Firstly, it is described which changes in procedures had to take place in order to implement the system to support the admission planners. Secondly, it is described how admission planning was achieved using the decision support model.

7.3.1 Changes in procedures

To work with the decision support system, data had to be entered into the system to establish the required capacity per diagnosis or type of operation and the characteristics of the patients in the hospital and the patients on the waiting list. During the implementation of the decision support system, a student kept the data in the system up-to-date using information collected from the admission planning department.

7.3.2 Admission planning

The admission planning procedures did not change significantly. The admission recommendation was still prepared in collaboration with the planner of the operating theater, the head of the ward and the head of the admission planning department. However, the decisions they made regarding the admission of patients for the coming week currently were based upon the information presented (produced) by the decision support system instead of upon estimates made by hospital personnel.

7.4 Performance measurement

In order to test whether using the decision support system could lead to an improvement in the admission planning performance, it was necessary to determine admission planning objectives and to translate these objectives into performance indicators. These performance indicators were then measured before and after the implementation of the decision support system.

This section describes these performance measurements. First, the objectives and the associated performance indicators are presented. Second, the results of the two measurements of these performance indicators are described. Finally, the conclusions derived from an analysis of these performance measurements are presented.

7.4.1 Performance indicators

The student who prepared this case study was assisted by a project group. This project group decided that admission planning should achieve the following objectives:

1) a maximal patient service level,
2) an optimal processing of emergency patients, and
3) control of the occupancy of gynecologists in the operating theater and beds and nurses in the long-stay ward.

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In order to determine whether admission planning based upon the information provided by the decision support model actually leads to an improvement in achieving the above mentioned objectives, these objectives had to be translated into measurable performance indicators. The project group decided that the objectives should be measured in the following way:

1) the patient service level in terms of the average patient waiting time,
2) the processing of emergency patients in terms of the percentage of the emergency admissions placed in their own ward and the number of patient transfers require, and
3) control of the occupancy of gynecologists in the operating theater and beds and nurses in the long-stay ward in terms of the average and standard deviation of the occupancy of operating theater time, bed capacity and nurse capacity.

7.4.2 Measurement of the performance indicators

The performance indicators were measured during two periods of time. The first measurement of the performance indicators took place before the implementation of the decision support system for admission planning. The second measurement was performed after the system was implemented. The results of both measurements are presented in Table 7.6.

7.4.3 Conclusions

Table 7.6 shows that the occupancy of the operating capacity increased by more than 15% after the implementation of the decision support system. This was associated with a decrease in the standard deviation of the operating time and a slight decrease of the bed occupancy in the long-stay ward. The decrease in the bed occupancy in the long-stay ward can be explained by the fact that the number of single day admissions increased. These patients were not admitted in the long-stay ward, however. The large increase in the occupancy of the operating time is surprising since the waiting lists of the specialists were generally quite short. It was normal for the waiting list to be nearly empty after preparing the admission recommendation for the coming week.

7.5 Evaluation of the system design

In this section the system is evaluated based upon a number of qualitative criteria. Attention is paid to the user friendliness of the system, the information provided by the system, the flexibility, the ease-of-use and the "fit" of the system in the user environment.

Performance indicator	First measurement	Second measurement
Average occupancy of the operating capacity	67.5 %	77.9 %
Standard deviation of the occupancy of the operating capacity	49.0 %	36.4 %
Average occupancy of the beds	83.6 %	81.0 %
Standard deviation of the occupancy of the beds	18.0 %	22.1 %
Percentage emergency admissions admitted in their own ward	100 %	100 %
Number of patient transfers required	1	2

Table 7.6: Results of the measurements of the performance indicators

User friendliness

In general, the users were satisfied with the simplicity of the control of the system, the layout of the screens in the system and the system response times. Regarding the control of the system, however, they would have preferred the use of pull-down menus. The main disadvantage of the system was the large amount of time that had to be invested in maintaining the data in the system. This significant investment of time was necessary due to the fact that the system functioned as a stand-alone system without any links to other systems. This means that every admission and discharge had to be entered into the decision support system even though it had already been entered into the hospital information system.

Information provided by the system

The information provided by the system was satisfactory. The system provided the admission planner with the information he needed to prepare an admission recommendation. Nevertheless, it was recommended to continue using the old admission form since all of the required information about a patient could not be entered via the admission planning screen.

Flexibility

The system turned out to be inflexible with respect to changes in the required operating time, the length of stay and the nursing capacity for any particular patient. It is not possible to temporarily change this information for a particular patient.

Ease-of-use
The ease-of-use of the system was judged to be satisfactory. The personnel working with the system understood the way in which the predictions were made and were able to use this information for admission planning purposes.

The "fit" of the system in the user environment
Initially, the system was not able to accomodate a situation in which patients in the same department could be admitted to more than one ward. In the gynecology department patients could be distributed across three different wards, depending on the type of ailment.

7.6 Conclusions

This case study describes the implementation and testing of a decision support system for admission planning in a gynecology department.
This case illustrates that the fit between the prediction model for the future bed availability and the actual situation was quite good. The performance of the other prediction models was also good. We can conclude that estimations made by hospital personnel can be used as input for the decision support system.
Using the system in this case led to an increase in the occupancy of the operation time even though the waiting list decreased during the period in which the system was implemented.
Some qualitative aspects of the system were found to be unsatisfactory. Too much time was required to maintain the data in the system. Because of this, hospital management decided to make a link between the decision support system and the hospital information system. Also, the system was found to be too inflexible with regard to accepting temporary changes in the required amount of capacity for a patient. The system did not offer a possibility for changing the required amount of capacity for a particular patient.

Chapter 8
Comparison of the Cases

This chapter presents a comparison of the cases described in Chapters 5, 6 and 7. Four different aspects of the cases are compared, namely:
1) the performance of the prediction models,
2) the implementation of the decision support system in the organization,
3) the changes in the performance after the implementation of the decision support system, and
4) the evaluation of the system design.

For all four aspects, the differences and similarities between the cases are described. Where possible, the reasons for the differences between the cases with respect to a certain subject are indicated.

8.1 Performance of the prediction models

The performance of the prediction models is evaluated using two criteria. Firstly, it is evaluated whether the assumptions underlying the prediction models are valid in the organizations in which the cases have been carried out. Secondly, it is evaluated whether the predictions made by the adapted prediction models correlate sufficiently with the actual data and are sufficiently reliable to use in admission planning.

With respect to the first criterion, we can conclude that:
- in all three cases the prediction of the length of stay of the patients is based upon the type of operation instead of the diagnosis. The reason for this adjustment was the same in all three cases, namely, that the type of operation was entered on the admission form and/or the waiting list form and the patient's diagnosis was not. In addition, in all three cases it proved to be difficult to translate a given type of operation into the corresponding diagnosis.
- in all three cases the prediction of the duration of an operation is not only based upon the type of operation, but also upon the surgeon who performs the operation. This adjustment to Kusters's model could be made in all three cases since it was always known which surgeon would perform a scheduled operation.
- in the the cases orthopedics 2 and gynecology, no beds were reserved for emergency patients. In the case orthopedics 2 it was decided to make no bed reservations for

emergency patients since an admission stop for emergency patients was declared whenever all beds were occupied or already reserved for elective patients. In case gynecology it was decided to make no bed reservations due to the fact that extra beds were available on some occassions since they were not taken into account in the calculation of the available bed capacity.

- in the case orthopedics 2 and, in a later stage, in the cases orthopedics 1 and gynecology, predictions of the number of occupied beds were not only made separately for males and females, but also for a number of different wards in which the patients could be admitted. This adjustment to Kusters's model was necessary since the introduction of short-stay and long-stay units created a situation in which there was insufficient capacity in the wards of certain specialisms to admit all of the patients for that specialism.

As indicated above, the need for adjusting the prediction models is dependent upon the way in which the specialism is organized. The factors which led to a need for adapting the prediction models in these cases, were:

- the capacity reservation for emergency patients,
- the allocation of the operations to the surgeons,
- the allocation of the patients to the various wards, and
- the registration of patient data concerning their admission.

With respect to the second factor, we can conclude that there was generally a good correlation between the predictions and the actual data. When we compare the results of the cases it is apparent that the correlation for females is much higher in cases orthopedics 2 and gynecology than in the case orthopedics 1. This difference can be explained by several facts. Firstly, in the case orthopedics 1 the prediction of the number of emergency patients is included in the prediction of the number of occupied beds. This is not true for the cases orthopedics 2 and gynecology, however. Secondly, in the case orthopedics 1 the predictions are made for an orthopedic department and in the case gynecology the same predictions are made for a gynecology department. It is known that the standard deviation of the length of stay for orthopedic patients is greater than the standard deviation for gynecology patients. In addition, the orthopedic specialism performs more different types of operations, than the gynecology specialism. This means that for the orthopedic specialism the group of patients with the same type of operation, staying in the hospital at a specific period of time is probably smaller and the differences in the length of stay are more pronounced. Thirdly, we have stated that the standard deviation of the length of stay of the patients in the case orthopedics 1 is greater than the standard deviation of the length of stay of patients in the case orthopedics 2. This is probably due to the fact that in orthopedics 2 the treatment for patients with the most common types of operations has been standardized. A standard

treatment is used less frequently in orthopedics 1. Finally, the data used to make the predictions in orthopedics 1 were older than the data used in orthopedics 2 and gynecology. Considering the fact that the average length of stay still decreases each year, this means that the use of older data leads to deviations in the predictions.
No additional comments are relevant with respect to the degree to which the predictions are suitable for use for admission planning.

8.2 Implementation of the decision support system

As mentioned in the literature [Mintzberg and Quinn, 1991], the implementation of an organizational change is often more difficult as the change has more impact on the organization. Most people have problems adapting to changes. It is important to analyze the reasons for these problems since the reasons for problems determine which intervention strategy should be used (Zaltman and Duncan). This is also clear from the cases.
In orthopedics 1, the implementation of the decision support system met with a number of problems. These problems were likely due to the fact that:

1) the implementation of the decision support system required changes in the admission planning procedure,
2) the intervention strategy used did not correspond with the type of situation. The differences in interest of each party formed the main problem, and
3) the hospital manager was not directly involved in the implementation process.

In the gynecology case, however, the implementation did not cause significatn problems. In this case the implementation of the decision support system was not accompanied by a major change in the admission planning procedure. In addition, the student that supported the implementation process was continually present.
Comparing orthopedics 1 and gynecology from an implementation point of view, it can be concluded that a successful implementation process is apparently associated with choosing the right intervention strategy and a limited number of procedural changes.

8.3 Changes in the performance

In the case orthopedics 1 as well as gynecology, the implementation of the decision support system is accompanied with a large increase in the operation theater occupancy. The introduction of the decision support system obviously has had a positive influence on the admission planning process. This positive influence could have resulted from either the fact

that the information provided by the decision support system has helped the admission planner(s) in making better admission decisions or the fact that the introduction of the system has helped the planners to focus on managing additional resources.
In the case orthopedics 2, the decision support system was not implemented. One of the reasons for this decision was the fact that the admission planner questionned the added value for the admission planning function which would have resulted from the introduction of the system. She argued that she already had access to the information which the system would provide. In this hospital a significant amount of information was already available.
Summarizing, we can conclude that the extent to which the information required for admission planning is already available in the organization is probably a factor which determines whether the implementation of the decision support system will lead to an improvement in performance.

8.4 Evaluation of the design of the system

In Chapters 5, 6 and 7, the design of the system is evaluated based upon user friendliness, the information provided by the system, flexibility, ease-of-use and the "fit" of the system to the situation. These same criteria will be used in this section to compare the opinions of the users in the three cases.

User friendliness
In all three cases the user friendliness of the experimental system was evaluated as being poor with respect to the user's time investment. The large amount of time needed to maintain the data in the system is caused by the fact that the system operates in a stand-alone mode with no links to other systems. In orthopedics 1 and 2 the response time of the system's admission planning screen was poor. The reason for this poorer response time in cases 1 and 2 as compared with the gynecology case is due to the fact that the waiting lists in orthopedics 1 and 2 contained approximately three hundred to four hundred patients while in the gynecology case there were only approximately fifty patients.

Information provided by the system
The information provided by the system was determined to be satisfactory in both cases in which the system was implemented.

Flexibility
One remark was made in each case with respect to the flexibility of the system. In the case

orthopedics 1, the users mentioned that it should be possible to place a patient on more than one waiting list. In the case gynecology, the users requested the possibility for changing the specified operating time, length of stay and/or nursing capacity for any given patient.

Ease-of-use

In both case orthopedics 1 as well as case gynecology, the ease-of-use of the system was found to be satisfactory. In orthopedics 1, some users had occassional problems with the interpretation of the predictions of the occupancy of beds and the operating time.

The "fit" of the system in the user environment

For the initial design of the decision support system (in which all beds could be used for any patient), the "fit" to the situation was not good enough for using the system for admission planning purposes. After adjusting the system in this respect, the "fit" of the system to the situation was found to be satisfactory in both cases orthopedics 1 and gynecology. In orthopedics 2, however, the "fit" of the system to the situation was still considered to be poor since the system was not able to make use of the bed capacity in a flexible way.

8.5 Conclusions

In the sections above, four aspects of the decision support system for admission planning are discussed. Briefly, the outcome is that:

- once some adjustments to the prediction models are made, depending upon the situation in which these models are used, the correlation of these models with the actual data is good,
- the implementation of the system must be accompanied by a significant investment of time,
- when sufficient information to make admission decisions is not available in the organization, a better performance of the admission planning function can be expected by implementing the decision support system, and
- the design of the system needs to be adjusted in some areas. The two most important points were that the system must be able to use data derived from the hospital information system and that the response time of the system needed to be improved.

Chapter 9
Admission Policies

Most hospitals currently operate in a situation in which more than one resource is scarce. Interviews in eight Dutch hospitals revealed that hospital managers have problems with achieving the admission planning goals in this type of situation. These problems are mainly due to a lack of knowledge and information about:

1) the capacity needs of an individual patient for the individual processing steps,
2) the availability of resources in the future, and
3) the type of policies that have to be used in this type of situation to achieve the admission planning goals.

A decision support system has been developed to provide the admission planner with information about the capacity needs of an individual patient for the individual processing steps and the availability of resources in the future. Using the decision support system has led to an improvement in the occupancy of the operating theater and the throughput of patients in two surgical departments of two different hospitals. From these two situation we have learned that it is possible to improve the achievement of the admission planning goals by providing an admission planner only with the information described previously.

The study described in this chapter determines:

- whether using a different type of admission policy actually can improve the achievement of the admission planning goals in a situation in which more than one resource is scarce, and
- which requirements have to be met by an admission policy which is able to improve the achievement of the admission planning goals.

In Chapter 3, it was explained that blocking can occur in situations in which more than one resources is scarce. Blocking may cause a decrease in the occupancy of the bottleneck resource. To be able to achieve a high occupancy of the bottleneck resource in situations in which more than one resource is scarce, it is important to reduce the occurrence of blocking. The subject of this chapter is the development of admission policies which, in the first place, are able to achieve a high occupancy of the bottleneck resource and thus a high throughput of patients in the hospital. The performance of such rules will be tested in a number of different situations. In connection with this it is assumed that the operating theater is the bottleneck resource, even though beds may also be scarce. This assumption is made since the operating theater is seen as the bottleneck resource in most Dutch hospitals.

We will evaluate two types of admission policies. The first type is called the Look-Ahead Procedure. It uses predictions of the future resource availability and the future mix of patients on the waiting list to develop a schedule which aims at maximizing the occupancy of the operating theater over two periods. A period is defined in this context as one operating session. The second type of admission policy is called the Balancing Procedure. It tries to balance the availability of future operating time and future beds in order to minimize the probability of an occurrence of blocking.
The performance of the two aforementioned policies are compared with the performance of two rules which are assumed to represent decision behavior in practice. These two rules are called the First-Come First-Serve Procedure (FCFS) and the Myopic Procedure. The Myopic Procedure maximizes the occupancy of the operating theater during the first period, thereby ignoring the possibility of future occurrences of blocking.
A simulation study is used to test the performance of all four of the admission policies. The design of this simulation study is described in Section 9.1. Section 9.2 provides an overview of the admission policies used in the simulation study. Section 9.3 presents the results of the simulation study. To conclude, the conclusions drawn from the simulation study are reviewed in Section 9.4 and the influence of uncertainty and emergency admissions on the performance of the admission policies is discussed.

9.1 Design of the simulation study

The main objectives of the simulation study are:
1) to gain insights into the performance and the problems of the admission policies which represent current decision behavior. These insights are used to develop new admission policies. These new admission policies must be able to achieve a higher occupancy of operating capacity and, thus, bed capacity by minimizing the occurrence of blocking;
2) to evaluate the performance of the new admission policies in a number of relevant situations and compare them with the performance of the old admission policies.

This section describes the simulation model and the experimental parameters used in the simulation study.

9.1.1. Simulation model

The simulation study focuses on the throughput of patients in a surgical hospital. This type of department was described in Section 3.2.2. This description is used as a starting point for describing the simulation model. However, as can be seen in Figure 9.1, we made some changes to the aforementioned description:

1) there are two waiting lists instead of one;
2) there is no flow of emergency patients;
3) all patients are operated on the day of their admission whereby it is assumed that each patient first makes use of the operating resource and then requires a bed;
4) nursing capacity is not taken into account;
5) the capacity needs of a patient are assumed to be deterministic.

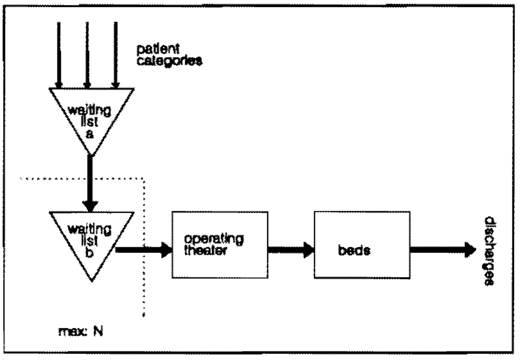

Figure 9.1: Simulation model

These changes were required for a number of reasons.
The arrival (demand) of elective patients at the waiting list (B) in our model is seen as a controlled process since it is assumed that a specialist wants to keep a relatively constant number of patients on the waiting list. A specialist can keep a constant number of patients on the waiting list by either changing his criteria for admission or by refering his patients to other specialists or hospitals. In practice, both methods are used. In our simulation model, however, we assume that a specialist refers the patients to another hospital. The arrival of patients at the outpatient department of a hospital is not seen as a controlled process, however. It is assumed that neither the specialist nor the hospital management can directly influence the number of patients visiting the outpatient department.

In the simulation model the aforementioned process is modelled as follows: elective patients arrive at waiting list A according to a class-dependent inter-arrival rate. A class is defined here as a group of patients needing the same amount of capacity. As soon as a patient from waiting list B is admitted into the hospital, the first patient from waiting list A is transferred to waiting list B. The waiting time of a patient starts at the moment he arrives at waiting list B and ends at the moment the patient is admitted into the hospital. The inter-arrival rate for each class of patients at waiting list A is much larger than the throughput of this class of patients in the hospital in order to prevent that waiting list B becomes empty. The number of patients at waiting list B is constant in order to be able to compare the waiting times of patients in the different simulation runs.

The arrival of elective patients at the hospital can also be seen as a controlled process since the admission planning function determines when a certain patient is admitted into the hospital. The admission planning function makes use of an admission policy to achieve this. In this simulation study it is assumed that the objective of admission planning is to achieve a high occupancy of the resources.

The demand for care in a surgical hospital (surgical department) stems from the flow of emergency patients and the flow of elective patients. In the simulation studies the flow of emergency patients is not taken into account. The decision to not take the flow of emergency patients into account was made since we were interested in observing the pure effects of admission policies. As described in Chapter 2 of this thesis, the flow of emergency patients cannot be controlled at the operational level (by using an admission policy) even though the arrival of these patients can disturb the activities on this level to a great extent. Control of this patient flow takes place at a higher level in the organization (by reserving capacity for these patients). In Section 4 of this chapter, the effect of this flow on the performance of an admission policy is discussed in detail.

Surgical patients in a hospital need operating theater capacity, bed capacity and nursing capacity. However, in our simulation study we have assumed that nursing capacity does not have to be taken into account. We have made this assumption because nursing capacity is the most flexible resource. Also, the case studies showed that nursing capacity could not always be allocated to the separate specialisms. In addition, it is difficult enough to take two possible bottlenecks into account. Once a satisfactory solution has been found for the two-resource problem, the effects of this solution on the nursing capacity can be investigated. This will not be covered by research here.
When a patient is admitted into the hospital, he requires operating time and a number of bed-days. The need for operating time and bed-days depends upon the class (category) to which the patient belongs and is assumed to be deterministic. The need for operating time and bed-days in practice, however, is stochastic. We have assumed that the needs for resources are deterministic since it is then easier to:
1) develop a simulation model,
2) make some calculations, and
3) use a mathematical programming approach.

In addition, the influence of uncertainty on the performance of the admission policies is assumed to be insignificant. We will discuss the influence of uncertainty on the performance of the admission policies in Section 4 of this chapter. The effects of emergency arrivals on the performance of the admission policies will also be discussed in this section. The operating theater is a resource which is not constantly available. A specialism has access to one or more operation rooms on certain days for a certain amount of time according to a specific timetable. The bed capacity is a resource which is constant and also constantly available.

The simulation program was written in Turbo Pascal and runs on a IBM PS/2 model 70 computer. To verify that the simulation program performed according to the simulation model, the detailed output of the simulation program was reviewed. Furthermore, the simulation results for one of the admission policies were compared with some analytical results.

9.1.2 Experimental parameters

This paragraph describes the experimental parameter settings we used in our simulation studies. We first made some assumptions about the phenomenon of blocking in order to develop a set of experimental situations which:

1) provide insights into the phenomenon of blocking and the effect of this phenomenon on the occupancy of the resources in a surgical hospital, and
2) could be used to evaluate the applicability of the decision rules which were developed.

Based upon these assumptions, a number of variables were identified which influence the occurrence of blocking. To conclude, the parameter settings used in our simulation study are described.

Blocking

In Chapter 3 it was assumed that the occurrence of blocking is the main factor influencing the occupancy of the resources at the operational level of control. We can identify two situations in which blocking occurs, namely:

1) operating time is available, but all of the beds are occupied;
2) beds are available, but there is no operating time available or remaining.

The stage in which blocking occurs determines whether the occurrence of blocking will actually lead to a loss of capacity in the sense that the throughput of patients in a surgical hospital decreases. If blocking occurs during the stage in which the bottleneck (most scarce) resource is not a critical resource, this always leads to a decrease in the patient throughput. If blocking occurs during the stage in which the bottleneck capacity is a critical resource and the average occupancy of the other capacity is not affected to the extent that this capacity becomes the bottleneck capacity, then blocking does not lead to a decrease in the patient throughput.

The situations in which blocking occurs can be caused by decisions taken at a higher level of control or at the same level of control (the operational planning level). This can be called structural blocking when the blocking is caused by decisions taken at a higher level of control and cannot be prevented by decisions taken at the operational planning level. The type of blocking which is caused by decisions taken at the operational planning level is called incidental blocking.

Both structural blocking and incidental blocking can occur in the surgical hospital. To be able to minimize the occurrence of both types of blocking, the causes of these types of blocking first need to be identified. Structural blocking can occur when the length of stay of certain patients does not correspond with the distribution of operating time over the days of the week. This leads to a situation in which beds become available when operating time is not available. The occurrence of this type of blocking depends upon the average length of stay for each patient category and the distribution of operating time over the days of the week. Incidental blocking can occur when patients in the hospital (= previous admission decisions) are discharged and there is no combination of patients on the waiting list to replace them and to fully occupy the bottleneck capacity. This type of blocking depends upon the type of admission policy used, in addition to other variables.

We have focused primarily on the occurrence of incidental blocking in this study, although we have to take the occurrence of structural blocking into account when comparing different situations.

Two underlying causes of the occurrence of incidental blocking can be identified:
1) the existence of a temporary imbalance between the average required capacity and the average available capacity caused by admission decisions made in the past, and/or
2) the stochastical behavior of the patient arrivals on the waiting list.

The stochastical behavior of the waiting list arrival process of patients cannot be influenced. Although we stated previously that the specialist could influence the length of the waiting list, it is assumed that he is not able to influence the number of patients on the waiting list which belong to a given class. If we assume that there is an adequate coordination between the aggregate patient flow and the resources and also between the individual resources at the capacity allocation level in a hospital, then an imbalance between required capacity and available capacity can only occur when the occupancy of the operating theater and the occupancy of the beds deviates from the average occupancy calculated at the capacity allocation level. Deviations from the average occupancy can occur when the ratio between the required operating time and the required number of bed-days differs from patient category to patient category. The consequence of a difference in ratios between the required operating time and the required number of bed-days is that implementing some admission decisions (= combination of patients to be admitted into hospital) requires more bed capacity than operating capacity or vice versa. Deviations from the average occupancy have a stronger impact on the occupancy of the bottleneck resource when:

- the average occupancy of the other resource is nearly equal to the occupancy of the bottleneck resource. In this case an imbalance may lead more quickly to a loss of capacity and, thus, to a decrease in occupancy;
- the operating theater capacity is distributed over a small number of days of the week resulting in a large amount of operating theater capacity per day. A distribution of operating theater capacity over a small number of days in the week means that new operation patients can only be admitted a few times per week. The number of times per week that new patients can be admitted determines the variance in the occupancy of the bed capacity. When the variance in the occupancy of the bed capacity is relatively large, this also means that an imbalance will lead to a loss of capacity more quickly.

Variables

In the previous paragraph, we made some assumptions about the occurrence of incidental blocking and the occurrence of structural blocking. Based upon these assumptions, we identified which variables need to be taken into account in the simulation study. The selected variables can be divided into two groups: one group of variables which can be influenced by the specialism or the hospital management and a different group of variables which characterize a certain specialism.

The first group of variables consists of:

- the distribution of operating capacity over the days of the week;
- the available number of beds in a department;
- the length of the waiting list.

The second group of variables consists of the differences in the ratio of required bed capacity and required operating time between the various categories.

Analysis of the simulations using different values for the variables in the first group can provide an indication of the way in which production control problems at higher levels in the organization need to be solved to guarantee the best possible performance at the admission planning level of the hospital. Analysis of the simulations using different values for the variables in the second group, on the other hand, can provide an answer to the question of whether a certain admission policy is generally applicable.

Experimental design of the simulations

We have investigated the three situations presented in Tables 9.1 to 9.3. in our simulation study. These situations are simplifications of the configuration of patient categories in hospitals.

Category	Operating time (in hours)	Length of stay (in days)	Ratio operating time : bed	Relative frequency
1	0.5	2	1 : 4	5/11
2	1.0	5	1 : 5	3/11
3	2.0	8	1 : 4	3/11

Table 9.1: Situation 1

Category	Operating time (in hours)	Length of stay (in days)	Ratio operating time : bed	Relative frequency
1	0.5	2	1 : 4	5/11
2	1.0	6	1 : 6	3/11
3	2.0	14	1 : 7	3/11

Table 9.2: Situation 2

Category	Operation time (in hours)	Length of stay (in days)	Ratio operating time: bed	Relative frequency
1	0.5	4	1 : 8	5/11
2	1.0	2	1 : 2	3/11
3	2.0	10	1 : 5	3/11

Table 9.3: Situation 3

As can be seen, these situations differed only with respect to length of stay per category and, thus, the ratio of the required operating time to the required number of bed-days. We chose to change only the length of stay per category since this would then ensure that there were no other factors which might affect the performance. The change in length of stay per category affected the number of required beds and the occurrence of structural blocking (in combination with a given distribution of operating time over the days of the week). When the occurrence of structural blocking is not taken into account, at least 14 beds were required in Situation 1 to treat 22 patients a week (10 patients in Category 1, 6 patients in Category 2 and 6 patients in Category 3). At least 20 beds were required in Situation 2 to treat the same number of patients per week. In Situation 3 we needed at least 16 beds. In each of these situations, the available amount of operating theater capacity was assumed to be 24 hours a week. This equaled the average capacity needed to treat 22 patients a week. This throughput resulted in an operating theater occupancy of 95.8%. Each of the situations was simulated in combination with a distribution of the operating time over two, three and six days of the week. The operating time was respectively 12, 8 and 4 hours per day. The length of the waiting list used for all the simulations was either 16 or 32.

Situation 1 was simulated using a bed capacity of 14 to 21 beds. Situation 2 was simulated using a bed capacity varying from 20 to 27 beds and situation 3 was simulated using a bed capacity of 16 to 23 beds.

For each combination of variables, simulations were run with five different sets of random numbers. Each simulation run consisted of a startup phase of 42 days and a simulation phase of 350 days.

We have assumed in the simulation study that the information required to make admission decisions was always available and that the admission decisions were all made at the beginning of the day on which the patients were admitted.

9.2 Admission policies

In order to develop admission policies to achieve a higher utilization of resources than the currently used policies by preventing the occurrence of blocking, we first needed to know more about the performance of the policies currently used. First, a description of these policies is provided in this section. Next, the results of several simulations based upon these policies are presented. New admission policies are then proposed based upon the insights gained through these simulations.

9.2.1 Currently used admission policies

We can draw the conclusion that patient flow control by means of admission planning is done both in practice and in the literature based upon a single resource while one or more of the other resources are considered as restrictions. This conclusion is based upon interviews we took in eight Dutch hospitals [Groot, 1990], and upon literature research (Amladi, Bliven and Butler [1985], Barrick [1985], Elmore and Zimmerman [?], Hancock and Walter [1983] and Rubenstein [1977]). The admission policies used to control the patient flows at the operational level vary from hospital to hospital. The policies used in most Dutch hospitals are variations of the two extreme admission policies described below, however.

The first admission policy is called the First-Come First-Serve (FCFS) Procedure. This admission policy represents an extreme form of the simplest admission policy used in practice. The other policy is called the Myopic Procedure. This admission policy represents an extreme form of the most complex admission policies used in practice.

A description of both of these policies is presented first. Subsequently, the results of several simulations using these policies are presented. To conclude, the weak points of each policy are described using detailed insights provided by the simulations.

The FCFS Procedure

The FCFS Procedure selects patients from the waiting list in a first-come, first-serve sequence. This selection process continues as long as the capacity of neither of the two resources is exceeded. When the capacity of one of the two resources is exceeded, then the patient causing this is not admitted into the hospital and the selection process stops.

Table 9.4 presents an example of the performance of the FCFS Procedure for Situation 1 with a distribution of operating time over three days of the week.

Bed capacity	Operating occupancy	Bed occupancy	Maximum operating occupancy	Incidental congestion (percentages)
14	0.7927	0.8267	0.8289	4.4
15	0.8342	0.8110	0.8881	6.1
16	0.8739	0.7966	0.9473	7.7
17	0.8978	0.7712	1.0000	10.2
18	0.9217	0.7483	1.0000	7.8

Table 9.4: Performance of the FCFS Procedure in Situation 1 with a distribution of operating time over three days of the week

Table 9.4 shows the maximum attainable operating occupancy for a situation in which the occurrence of structural blocking is taken into account. The occurrence of structural blocking is calculated by counting the number of bed-days which will be lost due to a shortage of operating time, assuming that the probability of being admitted on a certain operating day is the inverse of the number of days per week on which operating time is available.

The Myopic Procedure

The Myopic Procedure represents the traditional method of planning in which it is assumed that only one resource, the bottleneck, needs to be taken into account. We assumed that the operating theater was the bottleneck resource (although we will see later that this is not always the case).

The only way to realize a high operating theater occupancy is to select a combination of patients from the waiting list which leads to a maximum occupancy of the operating theater. When the categories of patients on the waiting list are known it is possible to determine all of the possible combinations of patients in order to choose the combinations which results in a full occupancy of the operating theater.

By selecting one of these combinations, full occupancy of the operating theater can be attained. However, some of the theoretical combinations of patients may not be feasible in practice. The choice of a combination in a given situation is restricted both by the number of available beds and the actual number of patients per category on the waiting list. The first restriction determines the maximum number of patients which can be selected for admission in a given situation. After applying both restrictions, it is also possible that several different combinations could lead to a full occupation of the operating theater. The choice of a specific combination in this case can be made on the basis of a second criterion. Using the Myopic Procedure, the final choice of a specific combination is made based upon the average patient waiting time already incurred for all of the possible combinations. The combination with the longest average patient waiting time already incurred is implemented.

If there are no combinations left after applying the restriction, then the operating theater will not be fully occupied. Use of the following policy guarantees an occupancy of the operating theater which is as high as possible, however. This policy selects patients from the waiting list according to the longest operating time. When more than one patient has the same operating time, the final choice is made based upon longest patient waiting time already incurred. This policy is optimal only for situations in which the operating time of each patient category is a multiple of the smallest operating time and the operation room capacity per day is a multiple of the largest operation time. Applying this policy results in the selection of as many patients as there are beds available or are available on the waiting list. In Table 9.5, the Myopic Procedure is summarized.

To gain insights into the occurrence of blocking when the Myopic Procedure is used, we ran several simulations and studied the output of these simulations in detail. In Table 9.6, the resulting operating occupancy and bed occupancy are given for a simulation of Situation 1 with a distribution of the operating capacity over three days of the week and a bed capacity varying from 14 to 18.

1. Make a list of all possible combinations which lead to a full occupancy of the operating theater;
2. Determine the number of available beds. Select the combinations from the list which do not lead to an overflow with respect to the occupancy of the beds. Call this set of combinations Subset A;
3. Determine the number of patients in each category on the waiting list. Select from Subset A the combinations which do not need more patients from a certain category than the number of patients of this category which are on the waiting list. Call this set of combinations Subset B;
4. If Subset B is empty then proceed to step 5.
   Otherwise determine the average waiting time for each combination. Implement the combination in B with the longest average waiting time;
5. Order the waiting list according to the longest operating time and the longest waiting time already incurred within the same operating time. Select patients in the order in which they appear on the waiting list until all of the beds are occupied or the waiting list is empty.

Table 9.5: Summary of the Myopic Procedure

Bed capacity	Operating occupancy	Bed occupancy	Maximum operating occupancy	Incidental blocking (percentages)
14	0.8133	0.8484	0.8289	1.9
15	0.8679	0.8453	0.8881	2.3
16	0.9143	0.8347	0.9473	3.3
17	0.9562	0.8224	1.0000	4.4
18	0.9849	0.7994	1.0000	1.5

Table 9.6: Performance of the Myopic Procedure in Situation 1 with a distribution of operating time over three days of the week

Comparing the results of the Myopic Procedure with the results of the FCFS Procedure (Table 9.4) we can conclude that the performance of the Myopic Procedure is much better than the performance of the FCFS Procedure. This means that not admitting patients in a first-come first-serve order already can improve the patient throughput significantly. As can be seen in Table 9.6, however, the Myopic Procedure also leads to the occurrence of incidental blocking. Studying the detailed output of the simulation runs shows us that the Myopic Procedure has a tendency to admit the patients with the largest operating time first. This can be illustrated by Table 9.7 in which the waiting time of each patient category for the different amounts of bed capacity is given.

Bed capacity	Waiting time category 1	Waiting time category 2	Waiting time category 3
14	7.22	2.76	1.74
15	6.29	2.86	1.72
16	5.77	2.98	1.98
17	5.16	3.24	2.22
18	4.82	3.58	2.54

Table 9.7: Waiting time per patient category using the Myopic Procedure in Situation 1 with a distribution of operating time over three days of the week

In Table 9.7 it can be seen that the waiting time of patients in Category 1 is much larger than the waiting time of patients in Categories 2 and 3. Since there is a difference in the ratio of operating time and bed-days between patients in Category 1 and Category 2, an imbalance occurs frequently between the required operating time and the required number of beds. Using a linear programming model to maximize the occupancy of the operating theater during the phases of the simulation run in which such an imbalance occurs, it is clear that it is sometimes better to accept a small loss of capacity at a given moment in order to avoid a larger loss of capacity in a later phase. This premise was used to develop the new admission policies.

9.2.2 Newly developed admission policies

In this section we describe two new admission policies which have been developed using insights gained by simulating the currently used admission policies and analyzing the primary process described in Chapter 3.
Firstly, the Look-Ahead Procedure will be described. Simulations with this procedure demonstrated that the procedure could not be used for all of the situations described in Section 9.1. For this reason, the Balancing Procedure was developed. This procedure is also described in this section.

The Look-Ahead Procedure

This policy is designed to avoid the possible occurrence of blocking by looking one period ahead to determine whether sufficient possibilities will be available to fully utilize the operating theater at that time. To be more precise, this policy tries to maximize the expected occupancy of the operating room for two successive periods of time. The idea behind the Look-Ahead Procedure is that blockings mainly occur because the effect of an admission decision on the future availability of resources is not taken into account. Not taking the effect of an admission decision into account can lead to the use of an admission schedule which may maximize the utilization of the operating theater at a given moment, but then leads to a loss of operating capacity in the near future. Before describing the Look-Ahead Procedure in detail, the mathematical relationship between an admission decision taken at time t and an admission decision taken at time t+1 is described first.

The admission decision taken at time t consists of a number of patients selected from the waiting list. The admission decision at time t can be described as:

(1) $A(t)=A_1(t)+A_2(t)+A_3(t),\qquad A_i(t)\geq 0$

$A(t)$= *number of patients admitted at time t*

$A_i(t)$= *number of patients category i selected for admission at time t*

The admission decision must satisfy restrictions concerning the number of patients selected and the amount of operating time needed by these patients. The maximum number of patients which can be selected at time t equals the number of available beds:

(2) $N(t)\geq A(t)$

$N(t)$= *number of available beds at time t*

The restriction concerning the amount of operating time needed by the selected patients can be described as follows:

(3) $P(t)=p_1*A_1(t)+p_2*A_2(t)+p_3*A_3(t)$

$P(t)$= *the amount of opeating time needed at time t*

p_i = *the amount of operating time needed by a patient of category i*

(4) $P(t) \leq P$

P= total available operating theater capacity

As a result of an admission decision taken at time t, the configuration of the waiting list changes. The number of patients in category i on the waiting list at time t+1 can be described as follows:

(5) $E(X_i(t+1) = X_i(t) - A_i(t) + E(WA_i(t))$

$X_i(t)$ = *the number of patients of category i on the waiting list at time t*

$E(X_i(t+1))$ = *the expected number of patients of category i on the waiting list at time t-*

$E(WA_i(t))$ = *the expected number of patients of category i arriving*

at the waiting list at time t

(6) $E(WA_i(t)) = \sum_{j=1}^{A(t)} \binom{A(t)}{j} * j * (f_i)^j * (1 - f_i)^{(A(t)-j)}$

f_i = *relative frequency of patients of category i*

In Section 9.1 it was assumed that the length of the waiting list is constant. This means that if A(t) patients are selected, A(t) new patients will be added to the waiting list. To which category these patients belong is unknown, but the probabilities are assumed to be known.

The admission decision taken at time t partly influences the number of available beds at time t+1. This relationship can be described as follows:

(7) $N(t+1)=N(t)-A(t)+D(t+1)$

$D(t+1)$= *the number of discharges at time* $t+1$

The number of patients discharged is assumed to be a deterministic function of the patients previously admitted.

To maximize the expected occupancy of the operating room for time t and time t+1, we need to know the number of empty beds and the configuration of the waiting list at time t. With this information it is possible to describe all of the possible admission decisions at time t. The occupancy of the operating theater, the number of empty beds at time t+1 and the possible configurations of the waiting list at time t+1 can be determined for each of these possible admission decisions. Next, all possible admission decisions for time t+1, including their probability of occurrence, are listed. On the basis of these possible admission decisions the expected occupancy of the operating room at time t+1 is calculated. Finally the occupancy at time t is added to the occupancy at time t+1. The admission decision alternative at time t which has the highest sum of occupancies should then be used according to this procedure.

Bed capacity	Myopic Procedure	Incidental congestion (percentages)	Look-Ahead Procedure	Maximum operating occupancy	Incidental congestion (percentages)
14	0.8133	1.9	0.8273	0.8289	0.2
15	0.8679	2.3	0.8835	0.8881	0.5
16	0.9143	3.3	0.9239	0.9473	2.5
17	0.9562	4.4	0.9328	1.0000	6.7
18	0.9849	1.5	0.9837	1.0000	1.6

Table 9.8: Performance of the Look-ahead Procedure compared with the Myopic Procedure in Situation 1 with a distribution of operating time over three days of the week

Although the results of the simulations presented in Table 9.8 show us that the Look-Ahead Procedure performs slightly better than the Myopic Procedure, we have chosen to develop an alternative admission policy. The reason for this decision was the fact that the simulation of the Look-Ahead Procedure was very time-consuming and could only be used for situations in which there where patient categories with a length of stay smaller than or equal to the number of days between two operating sessions. When the lengths of stay for all of the categories of patients were longer than the number of days between two operating sessions,

the Look-Ahead Procedure was not able to take the length of stay of patients into account since all of the patients admitted at day t would still be in the hospital on day t + 1.
This means that in all of the situations described in Section 9.1.2 with a distribution of operating time over two or three days of the week, the Look-Ahead Procedure can only make a distinction between the lengths of stay of Category 1 (Situations 1 and 2) and the other categories and Category 2 (Situation 3) and the other categories. Since this policy maximizes the operating theater occupancy over two periods, this means that Category 3 patients are

preferred above Category 1 or 2 patients in all instances. This preference may lead to blocking in some circumstances as is shown in Table 9.8. In the situations with a distribution of operating time over six days of the week, the length of stay is not taken into account at all.

Summarizing, the simulations using the Look-Ahead Procedure show that it is important to keep the mix of patients in the hospital and on the waiting list about the same (balancing the bed occupancy and the operating occupancy). If the mix of patients in the hospital is not kept more or less constant in a situation in which the resources are scarce, it is likely that a situation will occur in which only a few beds are available on the day when operating capacity is available. In order to keep the operating occupancy at a high level, patients with a requirement for a large amount of operating capacity are admitted. For most operations, however, a large operating capacity requirement is accompanied by a large requirement for bed capacity. This will then result in a situation in which only a few beds will be available for the next operating session. This again results in admitting only a few patients with a large operating capacity requirement. Eventually, all of the patients with a large operating capacity requirement will have disappeared from the waiting list, leaving the patients with a smaller operating capacity requirement on the waiting list. This way of making decisions not only results in a large loss of operating capacity, but also in an imbalance of patient categories on the waiting list.
To investigate whether the decisions made by the Look-Ahead procedure can be improved, an integer programming model was used to optimize parts of these simulations. The objective of the integer programming model was to maximize the operating theater occupancy over three or four periods. To be able the use an integer programming model, the arrival of patients at the waiting list had to be known. Information from the simulation runs was used to ensure that the arrival process was modelled as good as was possible. The outcomes of these runs demonstrated that it is often better to accept a minor loss of capacity in order to maintain the mix of patients in the hospital, than to maximize the short term operating theater

occupancy at the cost of a balanced mix of patients in the hospital.
The previously described findings led to the development of the Balancing Procedure.

The Balancing Procedure
The idea behind the development of this procedure is the hypothesis that blocking will occur less frequently if it is possible to keep the occupancy of both resources in balance with each other. In practice this means that we define certain boundaries between which the occupancies of both resources must lie. The Balancing Procedure uses minimum and maximum values for the occupancy of the resources. The procedure selects patients from the waiting list on a first-come, first-serve basis until:
1) the maximum value for the bed capacity is reached,
2) all of the available patients on the waiting list are selected, or
3) the maximum value of the occupancy of the operating theater is exceeded.
The patient which would cause the maximum value for the operating theater to be exceeded is not added to the admission list. If the maximum value of the occupancy of the beds has not yet been reached, or all of the patients on the waiting list have not yet been evaluated, then the next waiting list patient is evaluated for selection. If the maximum value of the bed occupancy is reached or all of the patients on the waiting list have been evaluated, the occupancies of the resources are then evaluated. This evaluation has one of the following outcomes:
1) both occupancies are within the preset boundaries;
2) one of the occupancies is below the minimum value;
If the evaluation results in Outcome 1, the selection process stops and all of the patients from the admission list are admitted into the hospital. If the evaluation results in Outcome 2, the action that is undertaken depends upon the resource which is below the minimum occupancy. When the bed occupancy is below the minimum, patients at the admission list with a large need for operating theater time are exchanged with two or more patients at the waiting list with a smaller need for operating theater capacity. When the operating theater occupancy is below the minimum occupancy patients at the admission list with a small need for operating theater time are exchanged for patients at the waiting list with a large need for operating theater time.

To determine whether the Balancing Procedure is capable of achieving a higher utilization of the resources, Situation 1 was simulated with a distribution of operating time over three days of the week. In Table 9.9, the occupancy of the operating theater is presented for each situation. This table also shows the boundaries set for both bed occupancy and operating theater occupancy.

Bed capacity	Occupancy operating room	Maximum operating occupancy	Incidental congestion (percentages)	Boundaries operating occupancy	Boundaries bed occupancy
14	0.8324	0.8289	0.00	6.0 - 8.0	14 - 14
15	0.8877	0.8881	0.05	6.5 - 8.0	15 - 15
16	0.9415	0.9473	0.60	7.5 - 8.0	16 - 16
17	0.9762	1.0000	2.40	8.0 - 8.0	16 - 17
18	0.9878	1.0000	1.20	8.0 - 8.0	16 - 18

Table 9.9: Performance of the Balancing Procedure in Situation 1 with a distribution of operating time over three days of the week

When we compare the results of the Balancing Procedure from Table 9.9 with the results from the Myopic Procedure and the Look-Ahead Procedure, we can conclude that the Balancing Procedure performs better than either the Myopic Procedure or the Look-Ahead Procedure for any number of beds in this situation. As the number of beds increases, the difference between results of the Balancing Procedure and the Myopic Procedure first increases and then decreases, however. This suggests that the Balancing Procedure may only perform better in a situation in which both resources are scarce.

9.3 Results

In this section, we describe the most significant results of the simulation study. The other data gained from the simulation study can be found in Appendix D.
Subsequently, the impact of the distribution of operating capacity over the days of the week, the impact of the situation and the impact of the length of the waiting list on the performance of the admission policies are described.

9.3.1 Impact of the distribution of operating capacity

In the first experiment we investigated the influence of the distribution of operating capacity over the days of the week on the performance of the various admission policies.

Expectations

As we discussed in Section 9.1.2, we expect that the distribution of operating capacity over the days of the week influences the amount of structural blocking and the variance in the number of occupied beds. To be more precise, we expect that the influence of structural blocking on the performance of the admission policies is greater when the operating capacity is distributed over fewer days in the week. Also, we expect that more beds are needed to achieve the same performance since there is an increased variance in the bed occupancy as the operating capacity is distributed over fewer days in the week.

Results

Tables 9.10 through 9.12 present the results of simulations using the three admission policies and three different ways of distributing the operating capacity over the days of the week.

Beds	Realized occupancy x = 2	Maximum obtainable occupancy x = 2	Realized occupancy x = 3	Maximum obtainable occupancy x = 3	Realized occupancy x = 6	Maximum obtainable occupancy x = 6
14	0.6671	0.6708	0.7927	0.8289	0.8125	0.9238
15	0.7135	0.7188	0.8342	0.8881	0.8457	0.9898
16	0.7570	0.7667	0.8739	0.9473	0.8630	1.0000
17	0.7955	0.8146	0.8978	1.0000	0.8745	1.0000
18	0.8327	0.8625	0.9217	1.0000	0.8813	1.0000
19	0.8707	0.9104	0.9297	1.0000	0.8846	1.0000
20	0.9007	0.9583	0.9371	1.0000	0.8853	1.0000
21	0.9233	1.0000	0.9402	1.0000	0.8862	1.0000

Table 9.10: Performance of the FCFS Procedure in Situation 1

Tentative conclusions

From Tables 9.10 through 9.12 the following conclusions can be drawn:

- In a situation with a distribution of operating capacity over two or three days of the week, the Balancing Procedure performs the best, provided that the maximum obtainable occupancy is smaller than 100%. When the maximum obtainable occupancy becomes 100% the Myopic Procedure performs best.
  Explanation: When the maximum obtainable occupancy is 100%, the beds are less scarce. This means that it is less likely that all of the beds will be occupied while operation time is still available. It is logical that the Myopic Procedure performs well in such a situation, since this rule maximizes the operation theater occupancy and does not create an imbalance in the configuration of the patients on the waiting list. This is because a combination of

Beds	Realized occupancy x = 2	Maximum obtainable occupancy x = 2	Realized occupancy x = 3	Maximum obtainable occupancy x = 3	Realized occupancy x = 6	Maximum obtainable occupancy x = 6
14	0.6713	0.6708	0.8133	0.8289	0.8832	0.9238
15	0.7151	0.7188	0.8679	0.8881	0.9259	0.9898
16	0.7611	0.7667	0.9143	0.9473	0.9678	1.0000
17	0.8037	0.8146	0.9562	1.0000	0.9919	1.0000
18	0.8425	0.8625	0.9849	1.0000	0.9988	1.0000
19	0.8831	0.9104	0.9943	1.0000	0.9993	1.0000
20	0.9149	0.9583	0.9979	1.0000	0.9999	1.0000
21	0.9377	1.0000	0.9988	1.0000	1.0000	1.0000

Table 9.11: Performance of the Myopic Procedure in Situation 1

Beds	Realized occupancy x = 2	Maximum obtainable occupancy x = 2	Realized occupancy x = 3	Maximum obtainable occupancy x = 3	Realized occupancy x = 6	Maximum obtainable occupancy x = 6
14	0.6714	0.6708	0.8324	0.8289	0.8217	0.9238
15	0.7188	0.7188	0.8877	0.8881	0.8952	0.9898
16	0.7673	0.7667	0.9415	0.9473	0.9366	1.0000
17	0.8114	0.8146	0.9762	1.0000	0.9404	1.0000
18	0.8559	0.8625	0.9878	1.0000	0.9479	1.0000
19	0.9078	0.9104	0.9891	1.0000	0.9473	1.0000
20	0.9339	0.9583	0.9899	1.0000	0.9517	1.0000
21	0.9620	1.0000	0.9904	1.0000	0.9524	1.0000

Table 9.12: Performance of the Balancing Procedure in Situation 1

In the Tables 9.10 through 9.12:
x = number of days of the week on which operating theater capacity is available

patients which fully occupies the operating theater capacity is chosen which has the longest average waiting time already incurred. The Balancing Procedure tends to perform worse in such a situation because it tries to keep the occupancy of the beds at a predetermined level. This can lead to an imbalanced composition of the waiting list.

- In a situation with a distribution of operating capacity over six days of the week, the Myopic Procedure performs best in all of the cases.
  Explanation: Since the operating theater capacity per session is small, only a limited number of patient combinations can be found which fully occupy the operating capacity (Myopic Procedure). The combinations found do not vary widely with respect to the required bed-days and, thus, the mix of patients in the hospital is not likely to be disrupted. The Balancing Procedure does not perform well in this situation. This is probably due to the fact that the difference between maximum occupancy and minimum occupancy of the operating theater time is only half an hour (time needed to operate a patient of Category 1). The exact reason, however, is not clear.
- The effect of structural blocking using the Myopic Procedure and the Balancing Procedure is most signigicant in the situation in which the operating capacity is distributed over two days of the week. This means that more bed capacity is needed to achieve the same occupancy in the operating theater (and thus the same throughput) when the operating capacity is distributed over fewer days of the week, regardless of whether the Myopic Procedure or the Balancing Procedure is used. When the FCFS Procedure is used, it is not always necessary to have more capacity when the operating capacity is distributed over fewer days of the week. In fact, the simulation results demonstrate that the largest amount of bed capacity is needed when the operating theater capacity is distributed over six days of the week (assuming a goal of 90% operating time occupancy). Figure 9.2 shows the performance of the FCFS Procedure for the various ways of distributing the operating time over the days of the week.
- Incidental blocking affects the throughput of the patients in cases in which both resources are scarce. The effect of incidental blocking can be shown by comparing the average maximum obtainable occupancy with the realized occupancy (see Figure 9.3)

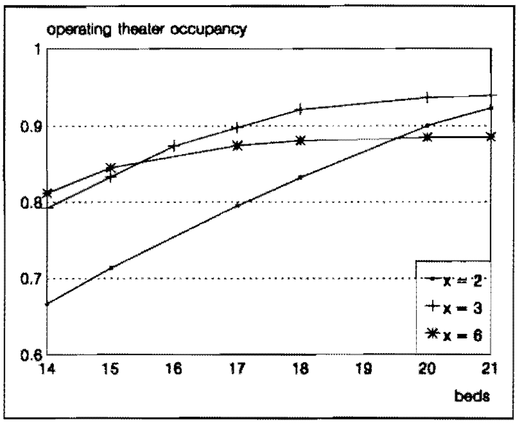

Figure 9.2: Performance of the FCFS Procedure with various distributions of operating time over the days of the week

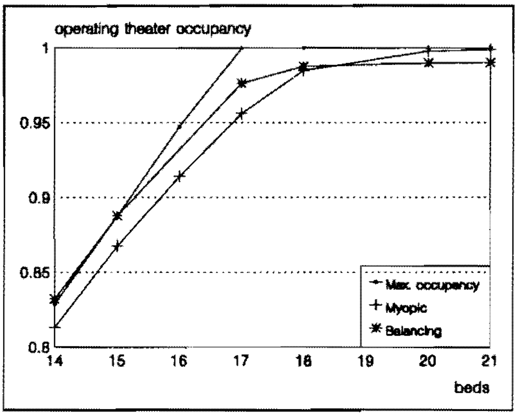

Figure 9.3 : The effect of incidental blocking on the performance of the admission policies

9.3.2 Relevance of the situation on the performance of the admission policies

In these experiments we will investigate the influence of the situation (ratio between required operating theater capacity and required number of beds of each patient category) on the performance of the various admission policies.

Expectations

As discussed in Section 9.1.2, we expect that incidental blocking will occur more frequently as the differences of the ratio between required bed capacity and required operating time become larger. This means that we expect that the occurrence of incidental blocking will be the highest in Situation 3 and the lowest in Situation 1.

Results

Tables 9.13 through 9.15 present some results from the simulation study for Sitation 1, 2 and 3 with a distribution of operating capacity over three days of the week.

Beds	FCFS	Myopic	Balancing	F-value	Maximum occupancy
14	0.7927	0.8133	0.8324	6.46	0.8289
15	0.8342	0.8679	0.8877	35.67	0.8881
16	0.8739	0.9143	0.9415	27.18	0.9473
17	0.8978	0.9562	0.9762	5.13	1.0000
18	0.9217	0.9849	0.9878	0.48	1.0000
19	0.9297	0.9943	0.9891	17.22	1.0000
20	0.9371	0.9979	0.9899	26.74	1.0000
21	0.9402	0.9988	0.9904	19.45	1.0000

Table 9.13: Results of all of the admission policies for Situation 1 with a distribution of operating time over three days of the week

Beds	FCFS	Myopic	Balancing	F-value	Maximum occupancy
20	0.8506	0.8640	0.8677	0.06	0.8986
21	0.8811	0.8987	0.9209	8.97	0.9209
22	0.8995	0.9318	0.9488	6.77	0.9885
23	0.9179	0.9579	0.9736	4.95	1.0000
24	0.9286	0.9819	0.9775	0.58	1.0000
25	0.9341	0.9922	0.9829	5.26	1.0000
26	0.9385	0.9983	0.9813	42.38	1.0000
27	0.9433	0.9992	0.9823	37.07	1.0000

Table 9.14: Results of all of the admission policies for Situation 2 with a distribution of the operating time over three days of the week

Beds	FCFS	Myopic	Balancing	F-value	Maximum occupancy
16	0.8039	0.8346	0.8265	0.55	0.8474
17	0.8370	0.8761	0.8703	3.17	0.9003
18	0.8657	0.9183	0.9121	0.45	0.9533
19	0.8858	0.9520	0.9478	0.13	1.0000
20	0.9112	0.9781	0.9655	28.18	1.0000
21	0.9239	0.9913	0.9815	0.28	1.0000
22	0.9313	0.9970	0.9850	12.39	1.0000
23	0.9368	0.9981	0.9862	9.34	1.0000

Table 9.15: Results of all of the admission policies for Situation 3 with a distribution of the operating time over three days of the week

In Tables 9.13 through 9.15 the F-value is calculated using a randomized block design (5 observations for two different admission policies).

Conclusions

From Tables 9.13 through 9.15 the following conclusions can be drawn:

- the Balancing Procedure performs significantly better in:
  - situation 1 for a number of 15 or 16 beds (alpha=0.01);
  - situation 2 for a number of 21 beds (alpha=0.05);
- the Myopic Procedure performs significantly better in:
  - situation 1 for a number of 19, 20 or 21 beds (alpha=0.01);
  - situation 2 for a number 26 and 27 beds (alpha=0.01);
  - situation 3 for a number of 20, 22 or 23 beds (alpha=0.05)

We can conclude that the Balancing Procedure performs better in situation 1 and situation 2 when both capacity resources are scarce. When the operating theater capacity is less scarce both procedures perform equally well. When the bed capacity is less scarce the Myopic Procedure performs better.

Figure 9.4 presents the occurrence of incidental blocking using the Balancing Procedure in each of the three situation. This figure demonstrates that the occurrence of incidental blocking is the lowest in Situation 1 and the highest in Situation 3. A low occurrence of blocking means a high occupancy of the resources and thus a need for less beds in order to achieve the same occupancy as in a situation in which the occurrence of blocking is higher.

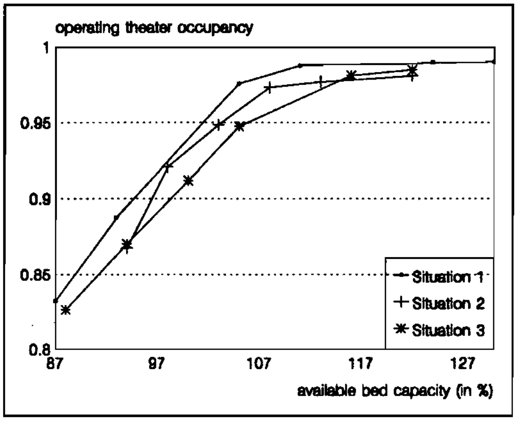

Figure 9.4: The occurrence of incidental blocking in each of the three situations

4.3.3 Impact of the length of the waiting list

The influence of the length of the waiting list on the performance of the various admission policies is investigated here.

Expectations

We expect that the performance of the Myopic Procedure and the Balancing Procedure will initially improve as the length of the waiting list increases. A longer waiting list in this context means that more patients are on the waiting list and, thus, more alternative admission proposals can be made.

Results

Tables 9.16 and 9.17 present the results of simulations using the Myopic and the Balancing Procedure for Situation 1 with a distribution of operating capacity over three days of the week and a waiting list length of 16, 24 and 32 patients.

Conclusions

From Tables 9.16 and 9.17 we can conclude that the performance of the Myopic Procedure improves as the length of the waiting list increases. This is exactly what we expected since the number of combinations of patients which can fully occupy the operating theater increases. The performance of the Balancing Procedure sometimes increases (especially when the number of available beds is high) and sometimes decreases. The explanation for this

Beds	Waiting list : 16	Waiting list: 24	Waiting list: 32
14	0.8133	0.8187	0.8229
15	0.8679	0.8737	0.8787
16	0.9143	0.9203	0.9247
17	0.9562	0.9729	0.9803
18	0.9849	0.9947	0.9982
19	0.9943	0.9983	1.0000
20	0.9979	0.9998	1.0000
21	0.9988	0.9998	1.0000

Table 9.16: Influence of the length of the waiting list using the Myopic Procedure for Situation 1 with a distribution of the operating time over three days of the week

Beds	Waiting list : 16	Waiting list: 24	Waiting list: 32
14	0.8324	0.8240	0.8332
15	0.8877	0.8575	0.8607
16	0.9415	0.8971	0.8960
17	0.9762	0.9553	0.9550
18	0.9878	0.9849	0.9602
19	0.9891	0.9959	0.9931
20	0.9899	0.9979	0.9995
21	0.9904	0.9991	0.9997

Table 9.17: Influence of the length of the waiting list using the Balancing Procedure for Situation 1 with a distribution of the operating time over three days of the week

behavior when the Balancing Procedure is used is that when the number of available beds is low, this procedure tends to select patients which require a small number of bed-days. When the waiting list size increases, more patients in this category can be found and the occupancy decreases. However, when the number of available beds is high, this procedure selects patients in equal quantities from all categories. When the waiting list size increases, it is easier to smooth the effect of the Poission arrival of each patient category on the waiting list. This means that it is easier to select patients at a rate equal to their average arrival rate.

9.4 Discussion

In the sections above we have gained some insights into the way in which an admission policy must be developed to achieve a high occupancy of the operating theater. We have seen that an admission policy which is able to achieve a high occupancy of the operating theater does not admit the patients from the waiting list in a first-come first-serve order. In addition we have concluded that such a policy must balance both the configuration of patients in the hospital and the configuration of patients at the waiting-list.
With respect to choosing an admission policy which is suitable for a given situation we have demonstrated that the situation in which the admission policy is used, the distribution of operating capacity over the days of the week, the available capacity and the length of the waiting list are all factors which determine which type of policy should be used.

We have seen that hospital management can minimize the occurrence of structural blocking by distributing the available operating capacity over as many days of the week as possible. The number of days over which the operating capacity can be distributed depends partly upon the operating time which is required for each patient category. It is of no use to distribute the operating capacity in such a way that it is no longer possible to complete the operation on a patient during a single session.
We also have seen that provided that the both bed capacity and operating capacity are scarce, the Balancing Procedure performs best in both situation 1 and situation 2 in case the operating theater capacity is distributed over two or three days in the week.
In case only the operating theater capacity is scarce or the operating theater capacity is distributed over six days a week the Myopic Procedure performs best.
To conclude, we have demonstrated that the occurrence of incidental blocking is the highest in a situation in which the ratios between required amount of operating theater capacity and required amount of bed capacity differ the most between the patient categories. In such a situation more capacity needs to be allocated to a specialism in order to achieve the same occupancy as a specialism for which the ratios between required amount of operating theater capacity and required amount of bed capacity do not differ much per patient category.

The results summarized above are based upon a simulation study in which it is assumed that there are no emergency patients, the capacity needs are deterministic and the admission decision is taken at the beginning of the day on which a patient is admitted. In the paragraph below we consider what might happen with the performance of the admission policies if the above assumptions are no longer valid.

As described in Chapter 3, the flow of emergency patients is a patient flow which cannot be controlled at the operational level. The only way in which it can be assured that emergency patients can be admitted into the hospital is by reserving capacity for these patients. A large amount of capacity must be reserved to ensure that all emergency patients can be admitted into the hospital without cancelling elective patients. The reservations must be large since emergency patients arrive according to a Poisson process and need to be admitted into the hospital immediately. When hospital management does not want to reserve this much capacity, the alternative is to cancel the scheduled admissions of elective patients. This means that by including emergency patients in the patient flow control, the performance of the admission policies will decrease since either capacity reservations need to be made for emergency patients or the number of cancellations of elective patients will increase. In addition, admitting emergency patients will also affect the occurrence of incidental blocking. Whether this would be a positive or negative effect is not directly obvious.

The assumption that the capacity needs for patients are deterministic does not affect the performance of the admission policies, provided that the information about the availability of resources at the time new patients can be admitted is accurate. Also, it must be assumed that there are possibilities for lengthening an operating session. If it is not possible to lengthen an operating session and it turns out that the scheduled operations take longer than scheduled, one or more patients will need to be cancelled. Otherwise, this also means that the operations may take less time than planned, thus reducing the occupancy of the operating theater. When the information about the availability of the resources is not accurate (for example, in the situation that an admission decision is made several days before the actual admission date) there will be a risk that some patients will need to be cancelled or the occupancy of the beds will decrease.

Chapter 10
Conclusions and Recommendations

This last chapter presents an overview of the main conclusions of our research. This includes:
- the model of the primary process,
- the development and evaluation of the decision support system for admission planning, and
- the development and evaluation of an admission policy.

Where required, the need for further research will be indicated.

10.1 Model of the primary process

The subject of our study was the improvement of the patient flow control by means of admission planning in a surgical hospital in a situation with multiple resource constraints.
In our study we have modelled this type of a department as a flow shop which processes several different types of orders and without an intermediate buffer between the stages. This way of modelling has made it obvious that blocking can occur in this type of situation. Blocking is defined here as the phenomenon which occurs in situations in which the available capacity at one stage cannot be used because the capacity required to process another order is not available at a different stage. Blocking can lead to a loss of capacity utilization in this case. In order to achieve a high utilization of the resources, the occurrence of blocking has to be minimized.
To be able to minimize the occurrence of blocking, information is required about the utilization of the resources in the future and the capacity requirements for each individual patient on the waiting list. To minimize the occurrence of blocking, an admission policy must take all of the scarce resources into account, contrary to many of the admission policies proposed in the literature.

10.2 Decision support system

The decision support system for admission planning was developed to provide the admission planner with all of the information required to achieve the admission planning objectives. It is assumed that admission planning should contribute to the achievement of the following objectives:
- a high, balanced utilization of the available resources,

- a reduction in the time a patient stays on the waiting list,
- an increased period of time between a notification of admission and the actual admission date,
- a reduction of the time between admission and discharge,
- an improvement in the service provided to emergency patients.

To achieve the aforementioned objectives, the decision support system needs to provide the admission planner with information about:
- the availability of beds, nursing capacity and operating capacity for a few days into the future,
- the need for beds, nursing capacity and operating capacity for an individual patient,
- the diagnosis, operation, specialist and ward of a patient,
- the waiting time of a patient,
- the urgency status of a patient,
- the capacity reservations for emergency patients,
- the results of the pre-operative screening,
- the need for blood, a prosthesis or other facilities.

The prediction models developed by Kusters [1988] are used to calculate the future resource availability, the capacity needs for an individual patient and the capacity to be reserved for emergency patients.

The decision support system was implemented in three surgical departments in three different hospitals. These implementation cases demonstrated that the prediction models developed by Kusters need to be adjusted to the specific situation of each department. The adjustments which were required in these cases depended upon the way in which:
- capacity reservations were made for emergency patients,
- operations were allocated to specialists,
- patients were allocated to wards, and
- patient data was registered.

When operation time for emergency patients is reserved at a central location in the organization, it is not necessary to reserve operation time for these patients at the department level. The same conclusion can be made for bed reservations for emergency patients.

When it is always known which specialist operates on a patient, better predictions of the duration of an operation can be made when they are based upon both the type of operation performed and the specialist who performs the operation.

When all of the patients of one specialist cannot be admitted to the same ward, it is necessary to make separate predictions for each ward in which the patients can be admitted.

When the type of operation of a patient is known, but not his diagnosis, predictions of the length of stay need to be based upon the type of operation.

More research is required to determine whether other types of situations may also require adjustments to the prediction models.

We have stated that the fit between the prediction model for the future bed availability and the actual data was quite good in all three cases. Nevertheless, differences in the fit between the prediction model and the actual situation still occurred. These differences probably were due to:
- differences in patient categories (other specialisms),
- differences in the standard deviation of the length of stay,
- differences in the types of patients included in the prediction (elective and emergency patients versus only elective patients),
- differences in the age of the historical data.

Definitive statements about the fit between the prediction models and the actual situations in the case of the other two prediction models are difficult to make since only limited data is available. Further research is recommended in this area.

It has also become clear that the success of the implementation of the decision support system depends upon a number of factors. Case 2 has shown us that implementing the decision support system is not likely to be successful in a situation in which most of the information provided by the decision support system is already available or when the available capacity of a specialism cannot be determined (e.g. when the capacity is used flexible). In addition, Cases 1 and 3 have demonstrated that the implementation of the system introduces more problems as more procedural changes are required.

Performance measurements in Cases 1 and 3 have shown that working with the decision support system can significantly improve the throughput of patients and the occupancy of the operating theater.

To conclude, we have indicated that the users evaluated the system as being satisfactory except for two points. It was argued that the system must be linked with the hospital information system in order to eliminate the need for duplicate entry of data. The system should also provide possibilities for noting the capacity requirements for individual patients when these requirements are different from the capacity requirements assumed by the system.

10.3 Admission policy

In Chapter 3 of this book it was stated that the occurrence of blocking must be minimized for an admission policy to be able to achieve a high utilization of resources in a situation with multiple resource constraints.

In Chapter 9, two types of blocking, namely, structural blocking and incidental blocking, were identified. Structural blocking is defined as the type of blocking which is caused by decisions made at a higher level of control. This means that structural blocking cannot be prevented by decisions made at the operational planning level (admission planning). Nevertheless, structural blocking can be minimized at a higher planning level by matching the lengths of stay of the patient categories with the distribution of operating time over the days of the week. In practice, this means that each specialism (or group of specialisms using beds in the same ward) must be allocated operating theater time over as many days of the week as possible in order to guarantee the achievement of a high utilization of the resources at the operational planning level. Incidental blocking is defined as the type of blocking which is caused by decisions made at the operational planning level (admission decisions). The occurrence of incidental blocking depends upon:

- the type of admission policy used;
- the number of available beds;
- the length of the waiting list;
- differences in the ratios of the required bed capacity and the required operating time between the various categories.

The Balancing Procedure was developed as an example of an admission policy designed to minimize the occurrence of blocking. The Balancing Procedure tries to minimize the occurrence of blocking by balancing the future availability of beds and operation time. Balancing the future availability of beds and operation time is done by keeping the occupancy of both resources within preset boundaries.

To investigate whether the Balancing Procedure is capable of minimizing the occurrence of blocking, the performance of this procedure was determined using a number of situations in a simulation study. The results of this study were compared with the results of simulations with two other admission policies currently used in practice (the FCFS Procedure and the Myopic Procedure).

Main results of this comparison were that:

- the Balancing Procedure performs best in situations in which:
  - a relation exists between the required amount of operation time and the required amount of bed-days for each patient category (Situations 1 and 2);
  - the operating theater time is distributed over two or three days of the week; and
  - the number of available beds is limited;
- the Myopic Procedure tends to perform best when:
  - the maximum obtainable operating theater occupancy approaches 100%,
  - the operating theater time is distributed over six days of the week, and
  - no relation exists between the required amount of operation time and the required

amount of bed-days (Situation 3);
- blocking has the strongest effects in cases in which the ratio of the required operation time and the required number of bed-days is different for each patient categorie (Situation 3);
- an increase in the length of the waiting list leads to an improvement in the performance of the Myopic Procedure;
- an increase in the length of the waiting list sometimes increases and sometimes decreases the performance of the Balancing Procedure.

The simulation study provided valuable insights into the performance of the admission policies and, thus, into the way in which admission decisions should be made. A number of questions remain unanswered, however. For example, the factor which causes instability in the performance of the Balancing Procedure when the length of the waiting list increases is still unknown. The effect of changing the boundaries of the Balancing Procedure should also be evaluated in more detail. Since the Balancing Procedure can improve the performance of admission planning in a number of situations, it is recommended that more research be carried out on this subject. Special attention must be paid to setting the boundaries for the bed occupancy and the operating theater occupancy, the effect of stochastic lengths of stays on the performance of this procedure and the unbalanced mix of patients which can occur on the waiting list.

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Appendix A
Raw Data Orthopedics 1

This appendix presents the raw data of the orthopedics 1 case. These data have been used to determine the fit between the predictions of the future availability of the beds and the real availability of the beds and to calculate the mean and standard deviation of the operating theater occupancy and the bed occupancy.
Tables A.1 and A.2 present the predicted availability of the beds and the actual availability of the beds for males or females for predictions made 1 to 7 days in advance for a situation in which the admissions in the coming period are not known. Tables A.3 and A.4 present the same type of data for a situation in which the admissions in the coming period are known. Tables A.1 through A.4 each consist of fourteen columns. These columns can be divided in seven sets of two colums. The first of these columns always shows the predicted number of available beds. The second column shows the actual number of available beds. The data of the first set of columns represent the predicted and actual number of occupied beds for predictions made one day in advance, the second set of columns represents the same data for predictions made two days in advance etc.
Tables A.5 and A.6 present the measurements of the use of the available operating time. Table A.5 presents the use of the operation time before implementing the decision support system en Table A.6 after implementing the system. To conclude, Tables A.7 and A.8 give an overview of the number of occupied beds on each day during both measurement periods. Table A.7 gives an overview of the bed occupancy during the first measurement period and Table A.8 during the second measurement period.

7.575	9	6.068	9	5.803	5	5.407	5	5.051	4	5.131	3	4.555	3
7.303	9	6.797	5	6.143	5	5.52	4	5.455	3	4.982	3	4.888	2
8.806	6	7.629	6	6.985	5	6.818	3	6.185	3	5.922	2	5.689	2
6.416	7	5.917	6	5.728	3	5.082	3	4.803	2	4.57	2	4.115	1
9.463	9	8.984	5	7.818	5	7.19	3	6.587	3	6.34	2	5.904	2
9.585	6	7.961	6	7.245	3	6.514	3	5.941	2	5.523	2	4.667	2
5.167	6	4.99	3	4.595	3	4.317	2	3.931	2	3.17	2	2.88	3
5.993	3	5.609	3	5.448	2	5.048	2	4.197	2	4.406	3	4.162	3
2.708	3	2.875	2	2.603	2	1.977	2	2.186	3	2.17	3	2.076	3
3.133	2	2.792	2	2.094	2	2.287	3	2.272	3	2.178	3	2.095	3
3.384	3	3.428	3	3.794	3	3.778	3	3.685	3	3.602	3	3.345	3
3.354	4	3.617	3	3.71	3	3.546	3	3.463	3	3.536	3	3.261	3
3.83	3	3.93	3	3.513	3	3.43	3	3.503	3	3.307	3	3.204	3
4.647	4	4.586	4	4.38	4	4.442	3	4.116	3	4.083	3	3.836	3
4.138	4	3.975	4	4.216	3	3.889	3	3.856	3	4.149	3	3.983	3
3.85	4	4.103	3	3.826	3	3.793	3	4.086	3	4.07	3	3.603	3
4.253	3	3.958	3	3.925	3	4.218	3	4.203	3	3.718	3	3.375	4
5.134	5	5.094	5	5.231	5	5.215	5	4.735	5	4.392	6	3.915	6
6.442	8	6.318	6	6.411	5	5.735	5	5.392	6	5.19	6	4.744	7
6.939	6	6.938	5	5.621	5	5.208	6	4.998	6	4.882	7	4.476	8
6.536	5	4.85	5	4.441	6	4.184	6	4.068	7	3.724	8	3.421	7
4.485	5	4.091	6	3.998	6	3.883	7	3.539	8	3.776	7	3.235	7
4.437	6	4.5	6	4.234	7	3.674	8	3.954	7	3.522	7	3.148	7
5.969	6	5.662	7	5.061	8	5.312	7	4.759	7	4.366	7	4.077	7
7.176	9	6.137	10	6.344	8	5.577	8	5.035	8	4.645	8	3.366	8
8.276	11	7.954	9	6.695	8	6.062	8	5.668	8	4.542	8	3.964	9
11.725	12	9.392	11	8.73	10	8.266	9	6.925	8	6.188	9	5.783	7
10.651	11	9.875	10	9.431	9	7.878	8	7.132	9	6.805	7	5.919	7
10.718	10	10.301	9	8.853	8	8.083	9	7.751	7	7.232	7	6.793	4
10.409	10	8.724	9	7.658	10	7.11	8	6.469	8	6.18	5	5.956	3
8.098	9	6.818	10	6.223	8	5.548	8	5.245	5	5.022	3	4.319	3
7.892	10	7.157	8	5.662	8	5.204	5	4.831	3	3.806	3	2.953	3
10.277	9	8.749	9	8.372	6	7.999	4	6.946	4	6.382	4	5.639	4
10.732	11	9.83	8	8.937	6	7.573	6	6.842	6	6.018	6	5.69	5
12.734	10	11.619	8	9.661	8	8.646	8	7.617	8	7.344	7	6.831	6
9.213	8	7.104	8	6.866	8	6.013	8	5.684	7	5.711	6	5.105	5
6.25	8	5.997	8	5.092	8	4.963	7	4.989	6	4.833	5	4.475	5
7.663	8	6.217	8	6.088	7	6.114	6	5.958	5	5.558	5	4.992	5
6.8	8	6.671	7	6.531	6	6.375	5	5.892	5	5.159	5	4.678	4
10.794	10	10.25	8	9.913	7	9.216	7	7.993	7	7.683	6	6.384	4
9.222	8	8.753	7	8.076	7	7.261	7	6.943	6	5.707	4	4.815	4
8.175	8	7.162	8	6.444	8	6.163	7	5.333	5	4.759	4	4.007	4
6.912	8	6.56	8	6.207	7	5.344	5	4.716	4	4.437	4	3.59	5
7.636	8	6.628	7	5.599	5	4.925	4	4.595	4	3.677	5	3.259	5
6.938	7	5.828	5	5.08	4	4.718	4	3.778	5	3.361	5	3.278	5
6.685	5	5.693	4	5.242	4	4.778	5	4.361	5	4.278	5	4.021	5
5.176	5	5.015	5	4.7	5	4.222	5	4.139	5	4.212	5	3.936	5
4.262	5	3.853	5	3.189	5	3.105	5	3.179	5	2.983	5	2.88	4
5.647	6	4.262	6	3.935	6	3.718	5	3.221	5	3.098	4	2.981	5
5.714	6	5.33	6	5.091	5	4.395	5	4.172	4	4.595	5	3.988	4
5.619	6	5.37	5	4.7	5	4.466	4	4.889	5	4.264	4	3.536	4
5.62	5	4.822	5	4.541	4	4.964	5	4.305	4	3.578	4	3.37	4
4.8	5	4.594	4	5.011	5	4.475	4	3.735	4	3.485	4	3.128	3
5.792	5	6.208	6	5.781	5	4.985	5	4.652	5	4.57	4	4.494	3
6.514	7	5.993	6	5.246	6	4.63	6	4.67	5	4.674	4	4.304	3
6.016	6	5.253	6	4.641	6	4.669	5	4.673	4	4.384	3	4.204	3
4.888	6	4.291	6	4.484	5	4.488	4	4.199	3	4.559	3	4.268	1
5.333	6	5.497	5	5.55	4	5.261	3	5.621	3	5.438	1	5.012	3
6.08	5	6.134	4	5.678	3	6.038	3	5.772	1	5.178	3	4.945	3
5.584	5	5.498	4	5.858	4	5.438	2	5.345	4	5.112	4	4.448	4
5.504	5	5.89	5	5.3	3	5.206	5	4.973	5	4.64	5	4.284	4

Table A.1: predicted and real number of occupied beds for males in a situation in which the admissions in the coming period are not known

14.18	14	13.332	13	12.822	12	12.604	12	12.385	12	11.707	9	10.055	9
14.345	14	13.85	13	13.391	12	12.885	12	11.937	9	10.525	9	9.68	11
13.092	13	12.487	12	12.13	12	11.182	9	9.77	9	9.245	11	7.879	9
13.791	12	12.933	12	11.989	9	10.465	9	10.014	11	8.859	9	7.792	9
12.628	12	11.643	9	10.341	9	10.05	11	9.14	9	8.251	9	7.747	8
12.438	10	11.143	10	11.004	12	10.08	10	9.183	10	9.009	9	8.734	8
9.161	10	9.481	12	8.945	10	7.911	10	7.791	9	7.686	8	7.103	8
10.666	12	10.143	10	8.996	10	8.877	9	8.771	8	8.359	8	7.772	7
12.209	11	10.859	11	10.808	10	10.567	9	10.154	9	9.767	8	9.038	8
12.41	14	12.149	13	11.808	12	11.237	12	10.849	11	10.434	10	9.914	9
15.759	15	14.881	14	14.202	14	13.675	12	13.24	11	12.7	10	12.189	10
15.09	14	14.353	14	13.888	12	13.453	11	12.886	10	12.574	10	11.989	9
13.615	14	13.174	12	13.177	11	12.681	10	12.412	10	12.287	9	11.916	9
14.662	13	14.65	12	14.174	11	13.748	11	13.577	10	13.352	10	13.229	11
13.634	12	13.154	11	12.808	11	12.638	10	12.413	10	12.46	11	11.933	10
14.595	14	14.058	14	13.956	12	13.522	12	13.569	13	13.372	12	12.185	12
13.165	15	12.984	12	12.579	12	12.626	13	12.383	12	11.632	12	10.107	9
16.756	14	15.98	14	15.806	15	15.203	13	14.136	13	12.59	10	11.588	10
14.373	15	14.218	16	13.825	14	12.931	14	11.339	10	10.543	10	9.949	9
15.056	16	13.9	14	13.158	14	11.566	10	10.769	10	10.636	9	10.069	9
16.595	16	15.437	16	13.528	12	12.651	11	12.484	10	11.957	10	11.108	10
16.13	17	14.262	12	13.402	11	13.362	10	12.835	10	12.157	10	11.428	8
16.085	15	14.723	12	14.59	11	13.878	11	13.199	11	12.8	9	11.377	9
15.695	15	15.096	14	13.804	14	12.695	14	11.776	9	10.723	9	9.891	6
14.646	14	13.524	14	12.15	14	11.194	9	10.141	9	9.459	6	8.693	6
12.652	14	11.134	14	10.018	9	8.905	9	8.223	6	7.546	6	6.623	6
12.41	14	11.068	9	10.06	9	9.372	6	8.662	6	8.168	6	7.562	6
13.682	10	12.598	10	11.787	7	10.453	7	9.693	7	9.086	7	7.814	7
9.825	10	9.51	7	8.801	7	8.158	7	7.676	7	6.725	7	5.863	5
9.88	7	9.198	7	8.569	7	8.087	7	7.136	7	6.435	5	5.207	5
14.69	16	12.582	16	10.41	8	10.143	8	9.824	8	9.918	9	9.65	7
13.523	16	10.345	8	10.147	8	9.751	8	9.845	9	10.037	7	9.679	8
12.07	9	11.715	9	11.041	9	11.056	10	11.215	8	10.97	9	10.593	8
10.164	10	9.819	10	9.859	11	9.822	9	9.56	10	9.478	9	8.951	9
9.845	10	9.912	11	9.683	9	9.422	10	9.339	9	9.142	9	8.34	7
13.005	14	12.171	12	11.791	13	11.291	12	11.048	12	10.682	10	10.224	8
15.232	14	14.652	14	13.716	13	12.823	13	11.937	11	11.539	9	11.199	10
13.776	14	12.756	13	11.982	13	11.504	11	11.378	9	11.262	10	9.712	9
12.033	12	11.721	12	11.683	10	11.556	8	11.426	9	10.189	8	9.81	7
13.103	13	13.061	11	12.925	9	12.655	10	10.489	9	10.206	8	9.457	8
15.074	13	14.874	11	14.661	12	12.417	11	12.135	10	11.555	10	10.954	10
14.04	12	14.022	13	11.62	12	11.314	11	10.916	11	10.645	11	10.242	11
14.079	15	12.026	14	11.589	13	10.931	13	10.57	13	10.627	13	9.171	9
13.131	14	12.666	13	12.039	13	11.657	13	11.714	13	10.247	9	9.296	8
13.905	13	13.247	13	12.902	13	12.96	13	11.434	9	10.664	8	10.295	8
12.352	13	11.938	13	12.147	13	10.531	9	9.676	8	9.767	8	9.437	7
12.344	13	12.566	13	10.814	9	9.826	8	9.917	8	9.757	7	9.351	7
14.428	14	12.484	10	10.988	9	10.41	8	10.03	7	9.654	7	9.18	7
13.424	11	11.862	10	11.382	9	10.874	8	10.498	8	10.354	8	9.272	9
12.826	13	12.347	12	11.638	11	10.332	11	9.749	11	8.823	12	7.419	6
13.394	12	11.761	11	10.466	11	9.873	11	8.881	12	7.615	6	6.966	6
11.288	11	10.012	11	9.494	11	8.643	12	7.33	6	6.888	6	6.626	6
10.043	11	9.519	11	9.069	12	7.882	6	7.509	6	7.703	6	7.427	6
11.114	12	10.406	13	9.143	7	8.673	7	8.842	7	8.736	7	8.613	7
12.212	14	10.749	8	10.321	8	10.462	8	10.356	8	10.403	8	10.11	8
13.251	9	12.773	9	12.895	9	12.703	9	12.751	9	12.741	9	11.993	9
10.121	10	10.299	10	10.32	10	10.287	10	10.211	10	10.018	10	9.36	9
11.372	11	11.404	11	11.421	11	11.231	11	11.039	11	10.481	10	10.145	9
11.513	11	11.548	11	11.349	11	11.156	11	10.47	10	10.278	9	10.046	9
11.246	11	11.084	11	11.043	11	10.356	10	10.165	9	10.393	9	10.074	9
12.023	12	11.906	12	11.245	11	10.933	10	10.952	10	10.732	10	10.164	7

Table A.2: Predicted and real number of occupied beds for females in a situation in which the admissions in the coming period are not known

7.575	9	7.068	10	7.723	7	9.827	10	11.441	11	10.5	6	9.075	6
8.303	10	8.717	7	10.563	10	11.91	11	10.825	6	9.502	6	8.998	3
9.806	7	11.629	10	12.955	11	11.858	6	10.535	6	10.032	3	9.309	3
9.416	10	10.887	11	9.768	6	8.432	6	7.913	3	7.19	3	6.415	2
11.463	11	10.144	6	8.638	6	7.9	3	7.177	3	7.69	3	7.194	3
9.585	6	7.961	6	7.245	3	6.514	3	6.941	3	7.523	4	5.867	4
5.167	6	4.99	3	4.595	3	5.317	3	5.931	4	4.37	4	3.95	3
5.993	3	5.609	3	6.448	3	7.048	4	5.397	4	6.476	4	6.232	4
2.708	3	3.875	3	4.603	4	3.177	4	4.256	4	4.24	4	4.076	4
4.133	3	4.792	4	3.294	4	4.357	4	4.342	4	4.178	4	3.945	4
4.384	4	3.628	4	4.864	4	4.848	4	4.685	4	4.452	4	4.195	3
3.354	4	4.617	4	4.71	4	4.546	4	4.313	4	6.387	5	6.011	5
4.83	4	4.93	4	4.513	4	4.28	4	6.353	5	9.057	8	7.354	8
4.647	4	4.586	4	4.38	4	6.442	5	9.116	8	7.483	8	6.826	6
4.138	4	3.975	4	6.216	5	8.889	8	7.256	8	7.139	6	6.973	5
3.85	4	6.103	5	8.826	8	7.193	8	7.076	6	7.06	5	6.353	5
6.253	5	8.958	8	7.325	8	7.208	6	7.193	5	6.468	5	6.125	6
8.134	8	6.494	8	6.371	6	6.355	5	5.735	5	5.392	6	4.915	6
6.442	8	6.318	6	6.411	5	5.735	5	5.392	6	7.19	8	5.924	9
6.939	6	6.938	5	5.621	5	5.208	6	6.998	8	8.062	11	6.136	11
6.536	5	4.85	5	4.441	6	6.184	8	7.248	11	9.384	15	5.651	12
4.485	5	4.091	6	5.998	8	7.063	11	9.199	15	8.006	14	5.345	11
4.437	6	6.5	8	7.414	11	9.334	15	8.184	14	5.632	11	4.728	10
7.969	8	8.842	11	10.721	15	9.542	14	6.869	11	6.946	11	6.457	10
9.176	11	11.027	15	9.834	14	7.077	11	7.155	11	6.665	10	5.166	9
12.276	15	11.044	14	8.135	11	8.182	11	7.688	10	6.342	9	5.564	10
13.725	14	9.832	11	9.85	11	9.286	10	7.725	9	7.788	11	7.183	9
10.651	11	10.875	11	10.331	10	8.678	9	8.732	11	12.205	13	9.519	11
11.718	11	11.201	10	9.653	9	9.683	11	13.151	13	12.832	13	11.833	10
10.409	10	8.724	9	8.658	11	12.11	13	11.769	13	11.92	11	10.296	8
8.098	9	7.818	11	11.223	13	10.847	13	10.985	11	9.362	8	8.089	8
8.892	11	12.157	13	10.962	13	10.944	11	9.171	8	7.576	8	6.523	8
14.277	13	13.049	13	13.112	11	11.339	8	9.716	8	8.952	8	7.939	8
12.732	13	12.73	11	10.937	8	9.243	8	8.312	8	10.318	11	9.89	10
13.734	11	11.819	8	9.731	8	8.716	8	10.617	11	10.244	10	9.301	8
9.213	8	7.104	8	6.866	8	9.013	11	8.584	10	11.181	11	7.795	8
6.25	8	5.997	8	8.092	11	7.863	10	10.459	11	7.523	8	6.655	8
7.663	8	9.217	11	8.988	10	11.584	11	8.648	8	7.738	8	6.682	8
9.8	11	9.571	10	12.001	11	9.065	8	8.072	8	6.849	8	6.078	7
10.794	10	13.25	11	10.423	8	9.346	8	8.123	8	8.683	8	6.474	5
12.222	11	9.263	8	8.206	8	7.391	8	7.943	8	6.797	6	5.035	5
8.175	8	7.162	8	6.444	8	7.163	8	6.423	6	4.979	5	4.067	5
6.912	8	6.56	8	7.207	8	6.434	6	4.936	5	5.497	6	4.65	6
7.636	8	7.628	8	6.689	6	5.145	5	5.655	6	4.737	6	4.259	6
7.938	8	6.918	6	5.3	5	5.778	6	4.838	6	4.361	6	4.008	6
7.685	6	5.913	5	6.302	6	5.838	6	5.361	6	5.008	6	4.471	5
5.176	5	6.015	6	5.7	6	5.222	6	4.869	6	4.662	5	4.116	5
5.262	6	4.853	6	4.189	6	3.835	6	3.629	5	4.163	6	3.97	5
5.647	6	4.262	6	3.935	6	3.718	5	4.221	6	5.098	6	4.881	7
5.714	6	5.33	6	5.091	5	5.395	6	6.172	6	6.495	7	5.788	6
5.619	6	5.37	5	5.7	6	6.466	6	6.789	7	6.064	6	5.136	6
5.62	5	5.822	6	6.541	6	6.864	7	6.105	6	5.178	6	4.77	6
5.8	6	6.594	6	6.911	7	6.275	6	5.335	6	4.885	6	4.428	5
6.792	6	7.108	7	6.581	6	5.585	6	5.052	6	5.87	6	4.994	5
6.514	7	5.993	6	5.246	6	4.63	6	5.67	6	5.874	6	5.374	5
6.016	6	5.253	6	4.641	6	5.669	6	5.873	6	6.454	6	6.274	6
4.888	6	4.291	6	5.484	6	5.688	6	6.269	6	7.629	7	7.018	5
5.333	6	6.497	6	6.75	6	7.331	6	8.691	7	8.188	5	7.632	7
7.08	6	7.334	6	7.748	6	9.107	7	8.522	5	7.798	7	7.315	7
6.584	6	7.498	6	8.857	7	8.188	5	7.965	7	7.482	7	6.568	7
6.504	6	7.89	7	7.05	5	6.826	7	6.343	7	6.76	8	6.154	6

Table A.3: predicted and real number of beds for males in a situation in which the admissions for the coming period are known

15.18	15	14.332	14	14.822	14	15.254	13	14.515	13	13.307	10	11.475	10
14.345	14	14.85	14	15.311	13	14.565	13	13.357	10	11.855	10	10.85	12
14.092	14	14.407	13	13.81	13	12.602	10	11.1	10	11.415	13	9.879	11
14.791	13	14.193	13	12.989	10	11.465	10	12.014	13	13.859	14	12.602	14
13.628	13	12.643	10	11.341	10	12.05	13	14.14	14	15.061	16	14.117	15
12.438	10	11.143	10	12.004	13	14.08	14	14.993	16	14.509	15	13.844	14
9.161	10	10.481	13	12.945	14	13.721	16	13.291	15	12.796	14	11.883	14
11.666	13	14.143	14	14.806	16	14.377	15	13.881	14	14.139	15	13.492	13
15.209	14	15.669	16	15.308	15	14.757	14	15.014	15	14.567	13	13.708	12
14.41	16	13.959	15	13.498	14	13.737	15	13.289	13	15.874	15	14.644	14
15.759	15	14.881	14	15.202	15	14.675	13	17.24	15	16.99	15	15.199	15
15.09	14	15.353	15	14.888	13	17.453	15	17.176	15	17.584	17	16.959	14
14.615	15	14.174	13	17.177	15	16.971	15	17.422	17	18.257	15	16.876	15
14.662	13	17.65	15	17.464	15	17.838	17	18.627	15	17.392	15	16.999	16
16.634	15	16.444	15	16.898	17	17.688	15	16.453	15	18.23	18	16.813	16
15.595	15	16.058	17	16.956	15	15.722	15	17.499	18	17.412	17	14.915	17
15.165	17	15.984	15	14.779	15	16.556	18	16.423	17	17.362	20	13.787	15
17.756	15	16.18	15	18.006	18	17.873	17	18.766	20	18.26	18	16.278	15
14.373	15	16.218	18	16.495	17	17.561	20	17.009	18	16.233	16	14.259	14
17.056	18	16.57	17	17.788	20	17.236	18	16.459	16	14.946	14	13.459	14
17.595	17	18.727	20	18.198	18	17.421	16	15.874	14	14.427	14	12.728	14
19.13	20	18.842	18	18.122	16	16.752	14	15.305	14	15.777	16	14.528	10
19.085	18	18.263	16	16.88	14	15.428	14	15.899	16	14.98	10	13.467	10
16.695	16	15.296	14	14.004	14	14.695	16	13.776	10	12.723	10	11.771	7
14.646	14	13.524	14	14.15	16	13.194	10	12.141	10	12.339	8	10.323	8
12.652	14	13.134	16	12.018	10	10.905	10	11.103	8	12.176	11	10.373	10
14.41	16	13.068	10	12.06	10	12.252	8	13.292	11	11.918	10	10.682	10
13.682	10	12.598	10	12.787	8	13.653	11	12.153	10	11.086	10	9.544	10
9.825	10	10.51	8	12.001	11	10.618	10	9.676	10	10.455	12	8.573	8
10.88	8	12.398	11	11.029	10	10.087	10	10.866	12	10.145	9	8.297	9
14.69	16	13.582	17	12.41	10	12.143	10	14.734	13	16.468	16	15.82	14
14.523	17	12.345	10	12.147	10	14.661	13	16.395	16	16.207	14	15.269	14
13.07	10	12.715	10	14.951	13	16.686	16	16.465	14	15.64	14	14.383	13
10.164	10	12.819	13	14.609	16	14.312	14	13.68	14	13.788	14	12.611	14
12.845	13	14.662	16	14.173	14	13.542	14	13.649	14	14.802	16	13.39	14
15.005	16	14.041	14	13.541	14	13.641	14	14.748	16	14.772	15	14.194	13
15.232	14	14.652	14	14.716	14	15.823	16	15.847	15	17.419	15	16.869	16
13.776	14	13.756	14	14.982	16	15.414	15	17.258	15	16.932	16	14.992	15
13.033	13	14.721	15	15.593	14	17.436	14	17.096	15	15.469	14	14.66	13
15.103	15	16.061	14	17.925	14	17.565	15	15.219	14	14.576	13	13.567	13
16.074	14	17.874	14	17.571	15	15.147	14	14.505	13	13.665	13	12.974	13
16.04	14	15.932	15	13.35	14	12.764	13	12.106	13	12.745	14	12.202	14
14.079	15	12.026	14	11.589	13	10.931	13	11.57	14	12.487	15	10.881	11
13.131	14	12.666	13	12.039	13	12.657	14	13.574	15	14.957	14	12.946	13
13.905	13	13.247	13	13.902	14	14.82	15	16.144	14	14.314	13	13.875	12
12.352	13	12.938	14	14.007	15	15.241	14	13.326	13	13.347	12	12.297	11
13.344	14	14.426	15	15.524	14	13.476	13	13.497	12	12.617	11	11.391	11
15.428	15	16.484	14	14.138	13	13.56	12	12.68	11	12.484	12	11.67	12
16.424	14	14.012	13	13.532	12	12.604	11	12.408	12	12.924	13	11.572	14
12.826	13	12.347	12	11.638	11	11.332	12	11.749	13	11.823	15	10.419	9
13.394	12	11.761	11	11.466	12	11.873	13	11.881	15	11.615	10	10.886	10
11.288	11	11.012	12	11.494	13	11.643	15	11.33	10	11.808	11	11.546	11
11.043	12	11.519	13	12.069	15	11.882	10	12.429	11	12.623	11	12.267	11
12.114	13	12.406	15	12.143	10	12.673	11	12.842	11	12.656	11	12.453	11
13.212	15	12.749	10	13.321	11	13.462	11	13.276	11	14.243	12	13.87	12
14.251	10	14.773	11	14.895	11	14.703	11	15.671	12	17.581	14	16.743	14
11.121	11	11.299	11	11.32	11	12.287	12	14.131	14	14.848	15	14.16	14
11.372	11	11.404	11	12.421	12	14.231	14	14.949	15	14.361	14	13.765	13
11.513	11	12.548	12	14.349	14	15.066	15	14.35	14	14.898	14	13.876	12
12.246	12	14.084	14	14.953	15	14.236	14	14.785	14	15.223	13	13.314	12
14.023	14	14.906	15	14.245	14	14.793	14	15.232	13	14.492	13	13.114	10

Table A.4: Predicted and real number of occupied beds for femals in a situation in which the admissions for the coming period are known

Allocated operating time (in minutes)	Used operating time (in minutes)	Operating theater occupancy (in percentages)
480	520	108
480	415	86
480	300	63
240	165	69
240	150	63
480	405	84
480	490	102
240	330	138
480	375	78
240	125	52
240	190	79
480	120	25
240	295	123
240	295	123
480	330	69
480	430	90
240	195	81
240	145	60
480	320	67
480	430	90
480	430	90
480	370	77

Table A.5: Operating theater occupancy during the first measurement period

Allocated operating time (in minutes)	Used operating time (in minutes)	Operating theater occupancy (in percentages)
480	465	97
480	500	104
480	460	96
480	485	101
240	220	92
240	305	127
240	295	123
480	430	90
480	425	89
480	455	95
240	280	117
240	180	75
480	475	99
480	390	81
480	340	71
480	325	68
480	500	104
120	95	79
240	425	177
240	265	110
480	525	109
480	475	99
480	450	94
480	465	97
120	110	92
240	360	150
240	280	117
480	485	101

Table A.6: Operating theater occupancy during the second measurement period

date	ward 1	ward 2	number of occupied beds	total number of beds	occupance rate beds
01-06-1991	20	2	22	35	62.9 %
02-06-1991	20	2	22	35	62.9 %
03-06-1991	21	2	23	35	65.7 %
04-06-1991	25	4	29	35	82.9 %
05-06-1991	23	4	27	35	77.1 %
06-06-1991	27	4	31	35	88.6 %
07-06-1991	27	4	31	35	88.6 %
08-06-1991	24	4	28	35	80.0 %
09-06-1991	25	2	27	35	77.1 %
10-06-1991	22	3	27	35	77.1 %
11-06-1991	25	5	31	35	88.6 %
12-06-1991	26	4	30	35	85.7 %
13-06-1991	23	4	27	35	77.1 %
14-06-1991	19	3	23	35	65.7 %
15-06-1991	17	1	18	35	51.4 %
16-06-1991	20	4	24	35	68.6 %
17-06-1991	22	4	26	35	74.3 %
18-06-1991	23	6	29	35	82.9 %
19-06-1991	22	5	28	35	80.0 %
20-06-1991	25	4	30	35	85.7 %
21-06-1991	22	3	26	35	74.3 %
22-06-1991	19	2	23	35	65.7 %
23-06-1991	23	2	25	35	71.4 %
24-06-1991	23	3	26	35	74.3 %
25-06-1991	25	2	27	35	77.1 %
26-06-1991	27	3	30	35	85.7 %
27-06-1991	27	3	31	35	88.6 %
28-06-1991	25	3	29	35	82.9 %
29-06-1991	23	1	25	35	71.4 %
30-06-1991	23	1	25	35	71.4 %

Table A.7: Bed occupancy during the first measurement period.

date	ward 1	ward 2	number of occupied beds	total number of beds	occupancy rate beds
01-06-1992	16	0	16	35	45.7 %
02-06-1992	21	4	26	35	74.3 %
03-06-1992	22	5	28	35	80.0 %
04-06-1992	26	5	32	35	91.4 %
05-06-1992	20	3	24	35	68.6 %
06-06-1992	19	3	22	35	62.9 %
07-06-1992	21	3	24	35	68.6 %
08-06-1992	19	1	21	35	60.0 %
09-06-1992	16	3	19	35	54.3 %
10-06-1992	17	2	20	35	57.1 %
11-06-1992	20	4	26	35	74.3 %
12-06-1992	19	2	22	35	62.9 %
13-06-1992	17	2	19	35	54.3 %
14-06-1992	19	0	19	35	54.3 %
15-06-1992	20	3	23	35	65.7 %
16-06-1992	23	4	29	35	82.9 %
17-06-1992	24	1	27	35	77.1 %
18-06-1992	24	3	29	35	82.9 %
19-06-1992	23	2	25	35	71.4 %
20-06-1992	23	2	25	35	71.4 %
21-06-1992	25	2	27	35	77.1 %
22-06-1992	25	1	26	35	74.3 %
23-06-1992	30	2	32	35	91.4 %
24-06-1992	28	4	33	35	94.3 %
25-06-1992	28	4	34	35	97.1 %
26-06-1992	28	4	35	35	100.0 %
27-06-1992	25	2	27	35	77.1 %
28-06-1992	25	2	27	35	77.1 %
29-06-1992	23	1	24	35	68.6 %
30-06-1992	25	5	30	35	85.7 %

Table A.8: Bed occupancy during the second measurement period.

Appendix B
Raw Data Orthopedics 2

This appendix presents the raw data of the orthopedics 2 case. These data have been used to determine the fit between the predictions of the future availability of the beds and the real availability of the beds. Tables B.1 and B.2 present the predicted availability of the beds and the actual availability of the beds for males or females for predictions made 1 to 7 days in advance for a situation in which the admissions in the coming period are not known. Tables B.3 and B.4 present the same type of data for a situation in which the admissions in the coming period are known. Tables B.1 through B.4 each consist of fourteen columns. These columns can be divided in seven sets of two colums. The first of these columns always shows the predicted number of available beds. The second column shows the actual number of available beds. The data of the first set of columns represent the predicted and actual number of occupied beds for predictions made one day in advance, the second set of columns represents the same data for predictions made two days in advance etc.

4.964	3	4.964	3	4.891	3	4.855	3	4.782	2	3.691	2	3.618	2
3	3	2.925	3	2.887	3	2.811	2	2.717	2	2.642	2	1.251	0
2.925	3	2.887	3	2.811	2	2.717	2	2.642	2	1.251	0	0.954	0
2.959	3	2.878	2	2.776	2	2.694	2	1.291	0	0.989	0	0.868	0
2.915	2	2.809	2	2.723	2	1.313	0	1.009	0	0.884	0	0.652	0
2	2	2	2	0.76	0	0.52	0	0.48	0	0.29	0	0.29	0
4	4	2.76	2	2.52	2	2.48	2	2.29	2	2.29	2	2.24	2
2.76	2	2.52	2	2.48	2	2.29	2	2.29	2	2.24	2	2.19	2
2	2	2	2	2	2	2	2	2	2	2	2	0.76	0
2	2	2	2	2	2	2	2	2	2	0.76	0	0.52	0
3	3	3	3	3	3	2.9	3	1.66	1	1.42	1	1.28	1
4	4	4	4	3.9	4	2.66	2	2.42	2	2.28	2	2.09	2
4	4	3.9	4	2.66	2	2.42	2	2.28	2	2.09	2	2.09	2
4.9	5	3.66	3	3.42	3	3.28	3	3.09	3	3.09	3	3.04	3
3.76	3	3.52	3	3.369	3	3.179	3	3.179	3	3.129	3	2.329	3
3	3	2.889	3	2.889	3	2.889	3	2.889	3	2.139	3	1.139	2
2.889	3	2.889	3	2.889	3	2.889	3	2.139	3	1.139	2	1.139	2
3	3	3	3	3	3	2.25	3	1.25	2	1.25	2	1.25	2
3	3	3	3	2.25	3	1.25	2	1.25	2	1.25	2	1.25	2
4	4	3.25	4	2.25	3	2.1	3	2.1	3	2.1	3	2.1	3
3.25	4	2.25	3	2.1	3	2.1	3	2.1	3	2.1	3	1.77	2
3	3	2.85	3	2.85	3	2.85	3	2.85	3	1.77	2	1.77	2
2.85	3	2.85	3	2.85	3	2.85	3	1.77	2	1.77	2	1.54	2
4	4	4	4	4	4	2.906	3	2.906	3	2.635	3	2.541	3
4.07	5	4.06	5	2.956	4	2.926	4	2.655	4	2.561	4	2.342	4
4.857	5	3.62	4	3.192	4	2.921	4	2.827	4	2.608	4	2.465	4
4.119	6	3.549	6	3.209	5	3.085	5	2.865	5	2.699	5	1.736	3
5.064	6	4.428	5	3.896	5	3.667	5	3.467	5	2.207	3	2.064	3
5.295	5	4.691	5	4.462	5	3.962	5	2.601	3	2.434	3	1.684	2
4.852	5	4.579	5	4.079	5	2.515	3	2.515	3	1.765	2	1.176	2
5.011	6	4.451	6	2.805	4	2.805	4	2.055	3	1.44	3	1.31	3
5.306	6	3.494	4	3.494	4	2.709	3	2.04	3	1.62	3	1.62	3
5.142	5	5.142	5	3.856	4	3.187	4	2.667	4	2.667	4	2.206	3
5	5	3.714	4	3.313	4	2.629	4	2.629	4	2.371	3	2.055	2
4.024	5	3.563	5	2.819	5	2.819	5	2.561	4	2.245	3	1.875	3
4.348	5	3.471	5	3.471	5	3.213	4	2.897	3	2.237	3	1.997	3
4.076	5	4.076	5	3.728	4	3.412	3	2.652	3	2.412	3	2.068	2
6	6	5.652	5	4.652	4	3.728	4	3.488	4	3.144	3	2.638	3
5.652	5	4.652	4	3.728	4	3.488	4	3.144	3	2.638	3	2.04	3
6.05	6	5.046	6	4.776	6	4.626	5	4.05	5	3.72	5	2.63	3
5.004	6	4.744	6	4.622	5	4.045	5	3.713	5	2.623	3	2.522	3
5.662	6	5.522	5	4.195	5	3.857	5	2.747	3	2.626	3	2.299	2
5.833	5	4.389	5	4.049	5	2.908	3	2.756	3	2.397	2	1.808	2
3.914	5	3.565	5	2.515	3	2.454	3	2.189	2	1.674	2	1.634	1
4.642	5	3.588	3	3.52	3	3.253	2	2.736	2	2.696	1	2.452	1
4.939	4	4.864	4	4.593	3	3.99	3	3.95	2	3.699	2	3.669	2
3.919	4	3.647	3	3.042	3	3.002	2	2.747	2	2.715	2	2.6	2
4.725	4	4.116	4	4.076	3	3.666	3	3.631	3	3.511	3	2.373	2
4.63	5	4.63	4	4.408	4	4.371	4	4.298	4	3.208	3	3.055	3
5	4	4.775	4	4.737	4	4.661	4	3.567	3	3.412	3	3.261	3
3.85	4	3.85	4	3.85	4	2.85	3	2.77	3	2.77	3	1.54	2
4	4	4	4	3	3	2.906	3	2.906	3	1.635	2	1.541	2
4	4	3	3	2.906	3	2.906	3	1.635	2	1.541	2	1.447	1
3	3	2.906	3	2.906	3	1.635	2	1.541	2	1.447	1	1.447	1
3.906	4	3.906	4	2.635	3	2.541	3	2.447	2	2.447	2	2.365	2
5	5	3.701	4	3.597	4	3.494	3	3.494	3	3.403	3	3.403	2
3.701	4	3.597	4	3.494	3	3.494	3	3.403	3	3.403	2	3.403	2
3.852	4	3.704	3	3.704	3	3.574	3	3.574	2	3.574	2	3.426	1
4.826	4	4.826	4	4.674	4	4.674	3	4.624	3	4.45	2	3.7	1
5	5	4.816	5	4.816	4	4.766	4	4.555	3	3.805	2	3.805	0

Table B.1: predicted and actual number of occupied beds for males in a situation in which the admissions in the coming period are not known

14.534	14	13.464	13	12.656	12	12.048	12	11.43	10	10.423	10	10.12	10
12.949	13	12	11.528	12	10.894	10	9.808	10	9.49	10	8.846	10	
13.032	13	12.497	13	11.935	11	10.906	11	10.566	11	10.042	11	9.718	10
13.831	15	13.26	13	12.018	13	11.662	13	11.259	13	10.705	12	10.394	11
17.248	16	15.649	16	15.219	16	14.805	16	14.134	14	13.818	13	13.162	10
14.916	16	14.574	16	14.232	16	13.561	14	13.261	13	12.587	10	11.357	10
15.564	16	15.193	16	14.398	14	14.033	13	13.237	10	11.916	10	11.257	10
15.614	16	14.749	14	14.359	13	13.512	10	12.144	10	11.441	10	10.92	9
16.127	15	15.686	14	14.819	11	13.283	11	12.531	11	11.956	10	11.403	10
15.511	15	14.502	12	12.995	12	12.112	12	11.497	11	10.849	11	10.256	11
15.031	13	13.465	13	12.531	13	11.838	12	11.162	12	10.52	12	10.123	11
12.806	15	12.126	14	11.593	13	11.057	13	10.387	13	9.969	12	9.069	10
13.871	14	13.058	13	12.355	13	11.584	13	10.961	12	9.934	10	9.4	9
14.455	14	13.723	14	12.916	14	12.42	13	11.199	11	10.608	10	10.052	8
13.608	14	12.749	14	12.223	13	11.252	11	10.633	10	10.051	8	9.667	7
14.106	15	13.526	14	12.514	12	11.859	10	11.237	8	10.846	7	10.514	7
14.367	14	13.237	12	12.55	10	11.893	8	11.499	7	11.167	7	10.901	7
14.744	14	13.922	12	13.139	10	12.711	9	12.346	9	12.077	9	11.281	9
13.054	12	12.023	10	11.558	9	11.185	9	10.974	9	10.218	9	9.915	7
11.645	11	11.117	10	10.631	10	10.33	10	9.532	10	9.226	7	8.407	6
10.733	10	10.539	10	10.233	10	9.434	10	9.128	7	8.632	6	8.087	4
9.807	10	9.526	10	8.704	10	8.379	7	7.913	6	7.345	4	7.04	4
9.687	10	8.815	10	8.458	7	7.962	6	7.361	4	7.057	4	6.75	4
9.072	10	8.677	7	8.142	6	7.503	4	7.194	4	6.881	4	6.468	4
9.48	7	8.813	6	8.051	4	7.709	4	7.355	4	6.937	4	6.723	4
7.878	7	7.577	5	7.39	5	7.229	5	6.858	5	6.643	5	6.356	5
7.689	6	7.465	6	7.3	6	6.859	6	6.602	6	6.264	6	5.94	6
5.763	6	5.592	6	5.306	6	5.159	6	4.994	6	4.776	6	4.502	6
6.816	7	6.51	7	6.355	7	6.179	7	5.945	7	5.654	7	5.484	6
6.686	7	6.529	7	6.348	7	6.111	7	5.818	7	5.64	6	5.485	6
7.821	8	7.612	8	7.329	8	6.995	8	6.792	7	6.631	7	6.576	1
12.6	12	11.994	12	11.789	10	10.99	10	10.107	10	8.904	9	7.949	9
11.391	12	11.359	10	10.588	10	9.755	10	8.672	9	7.838	9	7.078	7
14.967	13	14.101	13	13.184	13	11.917	12	11.015	12	10.206	10	9.355	10
13.478	14	12.819	14	11.938	13	11.098	13	10.551	11	9.784	11	9.34	11
15.206	16	14.273	15	13.299	15	12.619	13	11.817	13	11.371	13	9.832	12
15.992	16	14.803	16	14.06	14	13.19	14	12.707	14	11.143	13	10.662	13
16.845	18	16.005	16	14.988	16	14.371	16	12.771	15	12.266	15	11.699	14
17.014	16	15.844	16	15.207	16	13.584	15	13.062	15	12.478	14	12.022	13
14.769	16	14.245	16	12.76	15	12.327	15	11.778	14	11.343	13	10.654	11
15.39	16	13.822	15	13.324	15	12.704	14	12.23	13	10.871	11	10.706	11
15.291	16	14.676	16	13.923	15	13.411	14	12.052	12	11.886	12	11.419	12
16.185	17	15.229	16	14.627	15	13.268	13	13.102	13	12.635	13	12.083	13
16.676	17	15.951	16	14.567	14	14.384	14	13.89	14	13.319	14	12.337	14
16.161	16	14.848	14	14.712	14	14.311	14	13.81	14	12.205	14	11.366	13
14.687	14	14.55	14	14.125	14	13.604	14	11.968	14	11.444	13	11.089	12
14	14	13.779	14	13.371	14	11.843	14	11.431	13	11.06	12	10.571	8
14.779	15	14.371	15	12.843	15	12.431	14	12.06	13	11.571	9	11.296	9
15.557	16	13.977	16	13.531	15	13.13	14	12.607	10	12.332	10	12.142	10
15.324	17	14.791	16	14.325	15	13.737	11	13.428	11	13.237	11	12.656	11
18.317	18	17.703	17	16.988	13	16.571	13	16.34	13	15.694	13	14.245	11
17.478	17	16.825	13	16.611	13	16.379	13	15.726	13	14.269	11	13.338	10
16.088	13	15.872	13	15.624	13	14.959	13	13.489	11	12.542	10	11.708	10
12.783	13	12.709	13	12.093	13	10.689	11	9.891	10	9.534	10	8.927	9
12.923	13	12.301	13	10.894	11	10.06	10	9.685	10	9.076	9	8.511	9
15.172	16	13.331	13	12.095	12	11.648	12	10.996	11	10.377	11	9.719	11
15.665	15	14.207	14	13.607	14	12.812	13	12.127	13	11.338	12	10.644	11
13.943	14	13.284	14	12.405	13	11.666	13	10.914	12	10.274	11	9.852	11
15.463	16	14.687	15	14.117	14	13.145	13	12.375	12	11.825	12	11.269	10
15.188	15	14.605	14	13.584	13	12.81	12	12.239	12	11.663	10	10.727	8

Table B.2: predicted and actual number of beds for females in a situation in which the admissions in the coming period are not known

4.964	3	4.964	3	4.891	3	4.855	3	4.782	2	5.691	4	5.618	4
3	3	2.925	3	2.887	3	2.811	2	4.717	4	4.642	4	3.251	2
2.925	3	2.887	3	2.811	2	4.717	4	4.642	4	3.251	2	2.954	2
2.959	3	2.878	2	4.776	4	4.694	4	3.291	2	2.989	2	2.868	2
2.915	2	4.809	4	4.723	4	3.313	2	3.009	2	3.884	3	3.652	3
4	4	4	4	2.76	2	2.52	2	3.48	3	4.29	4	4.29	4
4	4	2.76	2	2.52	2	3.48	3	4.29	4	4.29	4	4.24	4
2.76	2	2.52	2	3.48	3	4.29	4	4.29	4	5.24	5	5.09	5
2	2	3	3	4	4	4	4	5	5	4.9	5	3.66	3
3	3	4	4	4	4	5	5	4.9	5	3.66	3	3.42	3
4	4	4	4	5	5	4.9	5	3.66	3	3.42	3	3.28	3
4	4	5	5	4.9	5	3.66	3	3.42	3	3.28	3	3.09	3
5	5	4.9	5	3.66	3	3.42	3	3.28	3	3.09	3	3.09	3
4.9	5	3.66	3	3.42	3	3.28	3	3.09	3	4.09	4	4.04	4
3.76	3	3.52	3	3.369	3	3.179	3	4.179	4	4.129	4	3.329	4
3	3	2.889	3	2.889	3	3.889	4	3.889	4	3.139	4	2.139	3
2.889	3	2.889	3	3.889	4	3.889	4	3.139	4	2.139	3	1.989	3
3	3	4	4	4	4	3.25	4	2.25	3	3.1	4	3.1	4
4	4	4	4	3.25	4	2.25	3	3.1	4	4.1	5	3.17	5
4	4	3.25	4	2.25	3	3.1	4	4.1	5	3.17	5	3.16	5
3.25	4	2.25	3	3.1	4	4.1	5	3.17	5	4.16	6	3.13	5
3	3	3.85	4	4.85	5	3.92	5	4.91	6	3.13	5	3.04	5
3.85	4	4.85	5	3.92	5	4.91	6	3.13	5	3.04	5	2.75	5
5	5	4.07	5	5.06	6	3.266	5	3.176	5	2.845	5	2.751	5
4.07	5	5.06	6	3.266	5	3.176	5	2.845	5	3.751	6	2.842	6
5.857	6	3.93	5	3.442	5	3.111	5	4.017	6	3.108	6	2.905	6
4.119	6	3.549	6	3.209	5	4.085	6	3.175	6	3.949	7	2.926	5
5.064	6	4.428	5	4.896	6	3.977	6	4.717	7	3.397	5	3.254	5
5.295	5	5.691	6	4.772	6	5.212	7	3.791	5	3.624	5	2.874	4
5.852	6	4.889	6	5.329	7	3.705	5	3.705	5	2.955	4	2.366	4
5.011	6	5.451	7	3.805	5	3.805	5	3.055	4	2.44	4	2.31	4
6.306	7	4.494	5	4.494	5	3.709	4	3.04	4	3.62	5	3.62	5
5.142	5	5.142	5	3.856	4	3.187	4	3.667	5	3.667	5	3.206	4
5	5	3.714	4	3.313	4	3.629	5	3.629	5	5.371	5	4.125	4
4.024	5	3.563	5	3.819	6	3.819	6	5.561	6	4.315	5	3.935	5
4.348	5	4.471	6	4.471	6	6.213	6	4.967	5	4.297	5	4.047	5
5.076	6	5.076	6	6.728	6	5.482	5	4.712	5	4.462	5	4.088	4
6	6	7.652	6	5.722	5	4.788	5	4.538	5	4.164	4	3.658	4
7.652	6	5.722	5	4.788	5	4.538	5	4.164	4	3.658	4	3.06	4
6.05	6	5.046	6	4.776	6	4.626	5	4.05	5	3.72	5	2.63	3
5.004	6	4.744	6	4.622	5	4.045	5	3.713	5	2.623	3	2.522	3
5.662	6	5.522	5	4.195	5	3.857	5	2.747	3	3.626	4	3.299	3
5.833	5	4.389	5	4.049	5	2.908	3	3.756	4	4.397	4	3.808	4
3.914	5	3.565	5	2.515	3	3.454	4	4.189	4	3.674	4	3.634	3
4.642	5	3.588	3	4.52	4	5.253	4	4.736	4	4.696	3	4.302	3
4.939	4	5.864	5	6.593	5	5.99	5	5.95	4	5.549	4	5.519	4
4.919	5	5.647	5	5.042	5	5.002	4	4.597	4	4.565	4	4.45	4
5.725	5	5.116	5	5.076	4	4.666	4	4.631	4	4.511	4	3.373	3
4.63	5	4.63	4	4.408	4	4.371	4	4.298	4	4.208	4	4.055	4
5	4	4.775	4	4.737	4	4.661	4	4.567	4	5.412	5	5.261	5
3.85	4	3.85	4	3.85	4	3.85	4	4.77	5	4.77	5	3.54	4
4	4	4	4	4	4	4.906	5	4.906	5	3.635	4	3.541	4
4	4	4	4	4.906	5	4.906	5	3.635	4	4.541	5	4.447	4
4	4	4.906	5	4.906	5	3.635	4	4.541	5	5.447	5	5.447	5
4.906	5	4.906	5	3.635	4	4.541	5	5.447	5	6.447	6	6.365	6
5	5	3.701	4	4.597	5	5.494	5	6.494	6	6.403	6	6.403	5
3.701	4	4.597	5	5.494	5	6.494	6	6.403	6	6.403	5	6.353	5
4.852	5	5.704	5	6.704	6	6.574	6	6.574	5	6.524	5	6.376	4
5.826	5	6.826	6	6.674	6	6.674	5	6.624	5	6.45	4	5.7	3
6	6	5.816	6	5.816	5	5.766	5	5.555	4	4.805	3	4.805	0

Table B.3: predicted and actual number of beds for males in a situation in which the admissions for the coming period are known

Raw Data Orthopedics 2

14.534	14	14.464	14	14.656	14	15.718	16	15.04	14	13.823	14	13.46	14
13.949	14	14.123	14	15.198	16	14.504	14	13.208	14	12.83	14	12.186	14
14.032	14	15.167	16	14.545	14	13.306	14	12.906	14	12.382	14	11.948	13
15.831	17	15.26	15	13.918	15	13.562	15	13.159	15	13.605	15	13.294	14
17.248	16	15.649	16	15.219	16	14.805	16	15.134	15	14.818	14	14.162	11
14.916	16	14.574	16	14.232	16	14.561	15	14.261	14	15.587	13	13.457	13
15.564	16	15.193	16	15.398	15	15.033	14	16.237	13	14.016	13	13.317	12
15.614	16	15.749	15	15.359	14	16.512	13	14.244	13	13.501	12	12.95	11
17.127	16	16.686	15	17.819	14	15.383	14	14.591	13	13.986	12	13.423	12
15.511	15	16.502	14	14.095	14	13.172	13	12.527	12	12.869	13	12.276	13
17.031	15	14.565	15	13.591	14	12.868	13	13.182	14	12.54	14	12.123	13
12.806	15	12.126	14	11.593	13	12.057	14	11.387	14	12.969	15	12.069	13
13.871	14	13.058	13	13.355	14	12.584	14	13.961	15	12.934	13	12.4	11
14.455	14	14.723	15	13.916	15	15.42	16	14.199	14	13.608	12	13.052	10
14.608	15	13.749	15	15.223	16	14.252	14	13.633	12	13.051	10	12.667	9
14.106	15	15.526	16	14.514	14	13.859	12	13.237	10	12.846	9	12.514	9
16.367	16	15.237	14	14.55	12	13.893	10	13.499	9	13.167	9	12.901	9
14.744	14	13.922	12	13.139	10	12.711	9	12.346	9	12.077	9	11.281	9
13.054	12	12.023	10	11.558	9	11.185	9	10.974	9	10.218	9	9.915	7
11.645	11	11.117	10	10.631	10	10.33	10	9.532	10	10.226	8	9.407	7
10.733	10	10.539	10	10.233	10	9.434	10	10.128	8	9.632	7	9.087	5
9.807	10	9.526	10	8.704	10	9.379	8	8.913	7	8.345	5	8.04	5
9.687	10	8.815	10	9.458	8	8.962	7	8.361	5	8.057	5	7.75	5
9.072	10	9.677	8	9.142	7	8.503	5	8.194	5	7.881	5	7.468	5
10.48	8	9.813	7	9.051	5	8.709	5	8.355	5	8.937	6	8.723	6
7.878	7	7.577	5	7.39	5	7.229	5	7.858	6	7.643	6	7.356	6
7.689	6	7.465	6	7.3	6	7.859	7	7.602	7	7.264	7	6.94	7
5.763	6	5.592	6	6.306	7	6.159	7	5.994	7	5.776	7	5.502	7
6.816	7	7.51	8	7.355	8	7.179	8	6.945	8	6.654	8	6.484	7
7.686	8	7.529	8	7.348	8	7.111	8	6.818	8	6.64	7	6.485	7
7.821	8	7.612	8	7.329	8	6.995	8	6.792	7	6.631	7	6.576	1
12.6	12	13.994	14	13.789	12	13.99	13	14.107	14	13.804	14	12.849	14
13.391	14	13.359	12	13.588	13	13.755	14	13.572	14	12.738	14	11.978	12
14.967	13	15.101	14	15.184	15	14.917	15	14.015	15	13.206	13	12.355	13
14.478	15	14.819	16	14.938	16	14.098	16	13.551	14	12.784	14	12.24	14
16.206	17	16.273	17	15.299	17	14.619	15	13.817	15	14.271	16	12.732	15
16.992	17	15.803	17	15.06	15	14.19	15	14.607	16	14.043	16	13.562	16
16.845	18	16.005	16	14.988	16	15.371	17	14.771	17	15.266	18	14.699	17
17.014	16	15.844	16	16.207	17	15.584	17	16.062	18	15.478	17	15.022	16
14.769	16	15.245	17	14.76	17	15.327	18	14.778	17	14.343	16	13.654	14
16.39	17	15.822	17	16.324	18	15.704	17	15.23	16	13.871	14	13.706	14
16.291	17	16.676	18	15.923	17	15.411	16	14.052	14	14.886	15	14.419	15
17.185	18	16.229	17	15.627	16	14.268	14	15.102	15	15.635	16	15.083	16
16.676	17	15.951	16	14.567	14	15.384	15	15.89	16	16.319	17	15.337	17
16.161	16	14.848	14	15.712	15	16.311	16	16.81	17	16.205	18	15.366	17
14.687	14	15.55	15	16.125	16	16.604	17	15.968	18	15.444	17	15.089	16
15	15	15.779	16	16.371	17	15.843	18	15.431	17	15.06	16	14.571	12
15.779	16	16.371	17	15.843	18	15.431	17	15.06	16	14.571	12	14.296	12
16.557	17	15.977	18	15.531	17	15.13	16	14.607	12	14.332	12	14.142	12
16.324	18	15.791	17	15.325	16	14.737	12	14.428	12	15.237	13	14.456	13
18.317	18	17.703	17	16.988	13	16.571	13	17.34	14	18.494	16	16.315	13
17.478	17	16.825	13	16.611	13	17.379	14	18.526	16	16.339	13	14.948	12
16.088	13	15.872	13	16.624	14	17.759	16	15.559	13	14.152	12	13.208	12
12.783	13	13.709	14	14.893	16	12.759	13	11.501	12	11.034	12	10.367	11
13.923	14	15.101	16	12.964	13	11.67	12	11.185	12	10.516	11	9.951	11
17.172	18	15.001	15	13.705	14	13.148	14	12.436	13	11.817	13	11.049	12
15.665	15	14.207	14	13.607	14	12.812	13	12.127	13	12.338	13	11.644	12
13.943	14	13.284	14	12.405	13	11.666	13	11.914	13	12.274	13	11.522	13
15.463	16	14.687	15	14.117	14	14.145	14	14.375	14	15.495	16	14.879	14
15.188	15	14.605	14	14.584	14	14.81	14	15.909	16	15.273	14	14.127	12

Table B.4: predicted and actual number of occupied beds for females in a situation in which the admissions for the coming period are known

Appendix C
Raw Data Gynecology

This appendix presents the raw data of the gynecology case. These data have been used to determine the fit between the predictions of the future availability of the beds and the real availability of the beds. Table C.1 presents the predicted availability of the beds and the actual availability of the beds for predictions made 1 to 7 days in advance for a situation in which the admissions in the coming period are not known. Table C.2 presents the same type of data for a situation in which the admissions in the coming period are known. Tables C.1 and C.2 each consist of fourteen columns. These columns can be divided in seven sets of two colums. The first of these columns always shows the predicted number of available beds. The second column shows the actual number of available beds. The data of the first set of columns represent the predicted and actual number of occupied beds for predictions made one day in advance, the second set of columns represents the same data for predictions made two days in advance etc.

12.031	11	10.728	11	8.779	10	8.046	9	7.156	8	6.395	7	4.953	5
10.042	11	8.482	10	7.907	9	7.13	8	6.383	7	4.969	5	3.521	3
10.261	11	9.568	10	8.713	9	7.858	8	6.344	6	4.815	4	4.22	4
11.904	12	10.753	10	9.91	9	8.467	7	6.918	5	6.305	5	5.592	4
13.124	12	11.985	11	10.564	9	8.974	7	8.354	7	7.633	6	6.565	5
14.307	13	12.845	11	11.077	9	10.444	9	9.689	8	8.535	7	7.6	7
12.502	12	10.37	9	9.544	9	8.752	8	7.565	7	6.681	7	6.064	7
9.925	9	9.285	9	8.661	8	7.443	7	6.616	7	6.073	7	4.677	5
8.66	9	8.194	8	7.441	7	6.296	7	5.788	7	4.623	5	3.223	3
9.465	9	8.621	8	7.398	8	6.856	8	5.664	6	4.238	4	3.258	4
10.321	10	9.129	10	8.677	10	7.492	8	6.128	6	5.214	6	4.453	6
11.819	14	10.834	13	9.526	11	8.155	9	7.199	9	6.402	8	6.156	7
13.292	15	11.254	13	9.794	11	8.832	11	8.033	9	7.726	8	7.17	8
11.672	13	10.045	11	9.059	11	8.245	9	7.93	8	7.366	8	5.869	5
11.94	12	11.202	12	10.528	10	10.273	9	9.803	9	7.803	6	6.463	5
11.503	12	11.182	10	10.965	9	10.499	9	8.602	6	7.259	5	5.963	2
12.164	11	11.621	10	11.021	10	9.069	7	7.687	5	6.345	2	5.274	2
10.232	10	9.517	10	7.495	7	6.07	5	4.683	2	3.58	2	1.963	1
10.474	11	8.676	8	7.328	6	5.937	3	4.845	3	3.176	2	2.657	2
10.454	8	8.493	6	6.648	3	5.507	3	3.737	2	3.161	2	2.648	2
7.092	6	6.011	3	5.208	3	4.437	2	3.901	2	3.452	2	3.137	1
5.21	3	4.446	3	3.804	2	3.374	2	3.049	2	2.761	1	2.646	1
2.859	3	2.342	2	1.919	2	1.697	2	1.585	1	1.515	1	1.201	1
5.084	5	4.342	4	4.05	4	3.919	3	3.819	3	3.394	2	3.114	2
6.265	6	5.838	6	5.727	4	5.291	4	4.446	3	3.86	3	3.499	2
7.84	9	7.38	7	7.2	6	6.415	5	6.075	5	5.765	4	5.305	3
8.255	8	7.787	7	6.922	6	6.546	6	6.184	5	5.678	4	4.897	4
8.33	8	7.862	7	7.446	7	7.029	6	6.493	5	5.607	5	4.428	4
9.166	8	8.458	8	7.765	7	7.207	6	6.408	6	5.196	5	4.055	5
7.521	8	7.146	7	6.726	6	6.261	6	5.149	5	4.115	5	3.114	4
7.541	7	7.029	6	6.519	6	5.321	5	4.219	5	3.182	4	2.387	3
6.531	6	6.251	6	5.364	5	4.202	5	3.129	4	2.325	3	1.433	2
5.824	6	5.1	5	4.109	5	3.093	4	2.276	3	1.489	2	0.953	2
5.242	5	4.216	5	3.175	4	2.335	3	1.521	2	0.982	2	0.887	2
3.883	5	2.899	4	2.078	3	1.243	2	0.709	2	0.656	2	0.574	1
3.601	4	2.551	3	1.548	2	0.93	2	0.866	2	0.769	1	0.63	0
2.714	3	1.606	2	0.89	2	0.788	2	0.642	1	0.464	0	0.312	0
1.573	2	0.831	2	0.748	2	0.664	1	0.551	0	0.393	0	0.393	0
2.25	3	2.25	3	2.25	2	1.795	1	1.682	1	1.682	1	1.682	1
3	3	3	2	2.545	1	2.091	1	2.091	1	2.091	1	2.091	1
3	2	2.545	1	2.091	1	2.091	1	2.091	1	2.091	1	2.091	1
2	1	1.545	1	1.545	1	1.545	1	1.545	1	1.545	1	1.545	1
1.65	2	1.4	2	1.33	2	1.31	2	1.28	2	1.24	2	1.23	2
1.615	2	1.508	2	1.477	2	1.431	2	1.369	2	1.354	2	1.292	1
3.825	4	3.775	4	3.7	4	3.6	4	3.575	4	3.475	3	3.32	3
6.589	7	6.248	7	6.057	7	6.007	7	5.856	6	5.645	6	5.514	6
8.969	10	7.842	9	7.549	9	7.354	8	7.085	8	6.901	8	6.445	7
8.082	9	7.596	9	7.379	8	7.091	8	6.924	8	6.432	7	5.671	6
9.898	11	9.64	10	9.314	10	9.117	10	8.592	9	7.75	8	6.477	7
12.379	11	11.79	11	11.514	11	10.788	10	9.907	9	8.425	8	7.037	6
10.393	11	10.249	11	9.755	10	8.892	9	7.578	8	6.311	6	5.114	6
12.783	13	12.247	12	11.322	11	9.61	10	7.948	8	6.405	8	5.458	8
15.115	15	13.839	14	11.759	12	9.768	10	7.842	9	6.597	9	5.313	9
15.459	16	13.092	14	10.994	12	9.004	11	7.685	11	6.327	11	5.708	10
13.101	14	11.061	12	8.994	11	7.702	11	6.297	11	5.694	10	5.346	9
14.795	15	12.636	14	11.694	14	10.544	14	9.823	13	9.363	12	8.546	11
13.618	15	12.227	15	10.794	15	10.208	14	9.671	13	8.758	12	7.57	9
12.262	15	10.402	15	9.737	14	9.114	13	8.085	12	6.862	9	5.197	6
14.17	17	13.197	16	12.272	15	10.882	14	9.411	11	7.49	8	5.656	8
16.781	17	15.654	16	13.755	15	12.179	12	10.117	9	8.109	9	6.72	5
16.896	17	14.068	16	11.779	13	9.481	10	7.371	10	5.953	6	4.955	0

Table C.1: predicted and actual number of occupied beds for females in a situation in which the admissions for the coming period are not known

12.031	11	11.728	12	11.779	13	12.446	14	13.236	14	13.385	13	11.333	11
11.042	12	11.482	13	12.307	14	13.21	14	13.373	13	11.349	11	9.541	8
12.261	13	12.968	14	13.793	14	13.848	13	11.724	11	9.835	8	9.16	8
13.904	14	14.753	14	14.9	13	12.847	11	10.938	8	11.245	9	10.492	8
15.124	14	14.975	13	12.944	11	10.994	8	11.294	9	12.553	10	11.455	9
15.307	14	13.245	12	11.157	9	11.444	10	12.689	11	15.535	14	13.39	14
12.502	12	10.37	9	10.544	10	11.752	11	14.565	14	14.471	16	12.604	15
9.925	9	10.285	10	11.661	11	14.443	14	14.406	16	12.613	15	10.697	13
9.66	10	11.194	11	14.441	14	14.086	16	12.328	15	11.643	14	10.143	12
11.465	11	14.621	14	14.188	16	12.396	15	11.684	14	10.178	12	9.178	12
14.321	14	13.919	16	12.217	15	11.512	14	10.068	12	9.134	12	8.343	10
13.819	16	12.234	15	11.606	14	10.155	12	9.199	12	8.402	10	8.096	9
13.292	15	12.254	14	10.794	12	9.832	12	9.033	10	9.726	10	9.17	10
12.672	14	11.045	12	10.059	12	9.245	10	9.93	10	10.366	10	8.479	7
11.94	12	11.202	12	10.528	10	11.273	10	11.803	10	9.473	7	7.803	6
11.503	12	11.182	10	11.965	10	12.499	10	10.272	7	8.599	6	6.963	3
12.164	11	12.621	11	13.021	11	10.739	8	9.027	6	7.345	3	6.274	3
11.232	11	11.517	11	9.165	8	7.41	6	5.683	3	6.58	5	4.963	4
11.474	11	9.346	8	7.668	6	5.937	3	6.845	5	7.176	5	6.657	5
10.454	8	8.493	6	6.648	3	7.507	5	7.737	5	9.161	7	8.638	7
7.092	6	6.011	3	7.208	5	8.437	5	9.901	7	9.442	7	9.117	6
5.21	3	6.446	5	7.804	5	9.374	7	9.039	7	9.741	7	9.266	7
4.859	5	6.342	5	7.919	7	7.687	7	8.565	7	8.135	7	7.401	6
7.084	6	8.342	7	8.04	7	8.899	7	8.439	7	7.654	6	7.054	6
8.265	8	7.828	8	8.707	7	8.231	7	7.386	6	6.78	6	6.409	5
7.84	9	8.38	8	8.2	7	7.415	6	7.075	6	6.765	5	6.305	4
9.255	9	8.787	8	7.922	7	7.546	7	7.184	6	6.678	5	5.837	5
8.33	8	7.862	7	7.446	7	7.029	6	6.493	5	5.607	5	4.428	4
9.166	8	8.458	8	7.765	7	7.207	6	6.408	6	5.196	5	4.055	5
7.521	8	7.146	7	6.726	6	6.261	6	5.149	5	4.115	5	3.114	4
7.541	7	7.029	6	6.519	6	5.321	5	4.219	5	3.182	4	2.387	3
6.531	6	6.251	6	5.364	5	4.202	5	3.129	4	2.325	3	1.433	2
5.824	6	5.1	5	4.109	5	3.093	4	2.276	3	2.489	3	1.953	3
5.242	5	4.216	5	3.175	4	2.335	3	2.521	3	1.982	3	1.887	3
3.883	5	2.899	4	2.078	3	2.243	3	1.709	3	1.656	3	1.574	2
3.601	4	2.551	3	2.548	3	1.93	3	1.866	3	1.769	2	1.63	1
2.714	3	2.606	3	1.89	3	1.788	3	1.642	2	1.464	1	1.312	1
2.573	3	1.831	3	1.748	3	1.664	2	1.551	1	1.393	1	1.393	1
2.25	3	2.25	3	2.25	2	1.795	1	1.682	1	3.682	3	3.682	3
3	3	3	2	2.545	1	2.091	1	4.091	3	5.091	4	5.091	4
3	2	2.545	1	2.091	1	4.091	3	5.091	4	7.091	6	6.491	6
2	1	1.545	1	3.545	3	4.545	4	6.545	6	5.945	6	5.625	5
1.65	2	3.4	4	4.33	5	6.31	7	5.68	7	7.32	8	7.23	8
3.615	4	4.508	5	6.477	7	5.831	7	7.449	8	7.354	8	7.292	7
4.825	5	6.775	7	6.1	7	7.68	8	7.575	8	7.475	7	7.32	7
8.589	9	7.648	9	9.137	10	9.007	10	8.856	9	10.645	11	10.514	11
8.969	10	9.842	11	9.549	11	9.354	10	11.085	12	12.901	14	12.445	13
10.082	11	9.596	11	9.379	10	11.091	12	12.924	14	14.432	15	13.601	14
9.898	11	9.64	10	11.314	12	13.117	14	14.592	15	13.74	14	12.137	12
12.379	11	13.79	13	15.514	15	16.788	16	15.897	15	16.085	15	13.977	13
12.393	13	14.249	15	15.755	16	14.882	15	15.238	15	13.251	13	11.414	13
14.783	15	16.247	16	15.312	15	15.59	15	13.568	13	11.665	13	10.418	13
17.115	17	15.829	16	15.739	16	13.708	14	11.782	13	12.517	15	11.123	15
15.459	16	15.092	16	12.994	14	11.004	13	11.685	15	11.227	16	10.408	15
15.101	16	13.061	14	10.994	13	11.702	15	11.197	16	12.394	17	11.116	15
14.795	15	12.636	14	13.694	16	13.444	17	14.523	18	14.153	17	12.426	16
13.618	15	14.227	17	13.694	18	14.908	19	14.461	18	12.638	17	10.67	14
14.262	17	13.302	18	14.437	19	13.904	18	11.965	17	9.962	14	8.137	11
15.17	18	16.197	19	15.562	18	13.462	17	11.411	14	9.49	11	7.596	11
18.781	19	17.944	18	15.335	17	13.179	14	11.117	11	9.109	11	7.72	7
17.896	18	15.068	17	12.779	14	10.481	11	8.371	11	7.953	8	5.955	0

Table C.2: predicted and actual number of occupied beds for females in a situation in which the admissions for the coming period are known

Appendix D
Simulation Results

This appendix presents the results of the simulation study.

FCFS Procedure
Sixteen patients at the waiting list
Distribution of operating capacity over two days of the week
Situation 1

Beds	14	15	16	17
Occupancy operating room (o.r.)	0.6671	0.7135	0.75702	0.7955
Standard deviation occupancy o.r.	0.1920	0.1831	0.17788	0.1605
Occupancy beds	0.6941	0.6920	0.69036	0.6833
Standard deviation occupancy beds	0.2557	0.2713	0.25112	0.3000
Waiting time patients category 1	6.2819	5.8542	5.46322	5.1819
Standard deviation waiting time patients category 1	1.1064	0.9924	1.0169	0.9102
Waiting time patients category 2	6.3756	5.8883	5.4627	5.0974
Standard deviation waiting time patients category 2	1.3817	1.3116	1.14086	1.1805
Waiting time patients category 3	6.3071	5.9568	5.61292	5.1954
Standard deviation waiting time patients category 3	1.2275	1.0847	1.11864	1.1567
Number of treated patients category 1	356.6	377.2	397.6	418.4
Number of treated patients category 2	203.4	215.2	232.4	247.0
Number of treated patients category 3	209.4	226.2	238.6	249.2

Beds	18	19	20	21
Occupancy operating room (o.r.)	0.8327	0.87066	0.9007	0.9233
Standard deviation occupancy o.r.	0.1482	0.12768	0.1123	0.0873
Occupancy beds	0.6746	0.66842	0.6574	0.6422
Standard deviation occupancy beds	0.3141	0.24142	0.3388	0.3507
Waiting time patients category 1	4.8479	4.60046	4.3398	4.2181
Standard deviation waiting time patients category 1	0.9286	0.91736	0.9210	0.8970
Waiting time patients category 2	4.8265	4.63116	4.3773	4.3040
Standard deviation waiting time patients category 2	1.2540	1.21852	1.2090	1.2349
Waiting time patients category 3	4.9954	4.60898	4.5415	4.3858
Standard deviation waiting time patients category 3	1.0902	1.17872	1.1537	1.1987
Number of treated patients category 1	440.6	461.2	478.4	492.4
Number of treated patients category 2	257.4	268.6	278.8	286.2
Number of treated patients category 3	260.8	272.8	281.4	287.8

Simulation Results

FCFS Procedure
Sixteen patients at the waiting list
Distribution of operating capacity over three days of the week
Situation 1

Beds	14	15	16	17
Occupancy operating room (o.r.)	0.7927	0.8342	0.8739	0.8978
Standard deviation occupancy o.r.	0.1876	0.1652	0.1424	0.1158
Occupancy beds	0.8267	0.8110	0.7966	0.7712
Standard deviation occupancy beds	0.1620	0.1732	0.1831	0.1919
Waiting time patients category 1	5.1201	4.7832	4.5330	4.3265
Standard deviation waiting time patients category 1	1.0360	1.0553	0.9730	0.8912
Waiting time patients category 2	5.1697	4.8524	4.5480	4.3868
Standard deviation waiting time patients category 2	1.1934	1.1153	1.0639	1.0537
Waiting time patients category 3	5.2686	4.9547	4.6804	4.6012
Standard deviation waiting time patients category 3	1.1995	1.1220	1.0686	1.1227
Number of treated patients category 1	415.4	440.6	463.8	477.0
Number of treated patients category 2	246.4	258.4	270.0	278.8
Number of treated patients category 3	248.6	261.2	273.4	280.0

Beds	18	19	20	21
Occupancy operating room (o.r.)	0.9217	0.9297	0.9371	0.9402
Standard deviation occupancy o.r.	0.0961	0.0820	0.0799	0.0670
Occupancy beds	0.7483	0.7155	0.6850	0.6544
Standard deviation occupancy beds	0.1973	0.2037	0.2116	0.2117
Waiting time patients category 1	4.1784	4.1546	4.1382	4.1101
Standard deviation waiting time patients category 1	0.9083	0.9037	0.9383	0.9265
Waiting time patients category 2	4.2852	4.2402	4.1953	4.1975
Standard deviation waiting time patients category 2	1.0706	1.0965	1.0870	1.0852
Waiting time patients category 3	4.4299	4.4388	4.3730	4.3726
Standard deviation waiting time patients category 3	1.0903	1.0754	1.1456	1.0859
Number of treated patients category 1	491.6	498.0	502.6	503.6
Number of treated patients category 2	287.8	290.6	294.4	294.8
Number of treated patients category 3	286.2	288.0	289.4	290.8

FCFS Procedure
Sixteen patients at the waiting list
Distribution of operating capacity over two days of the week
Situation 2

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.8131	0.84516	0.8750	0.90274
Standard deviation occupancy o.r.	0.1664	0.15158	0.1316	0.10954
Occupancy beds	0.8467	0.8381	0.8290	0.81734
Standard deviation occupancy beds	0.1714	0.17014	0.1872	0.16886
Waiting time patients category 1	5.0510	4.78892	4.5317	4.35906
Standard deviation waiting time patients category 1	0.9869	0.97904	0.9760	0.90676
Waiting time patients category 2	5.0146	4.8013	4.6439	4.36228
Standard deviation waiting time patients category 2	1.1860	1.18982	1.2547	1.24
Waiting time patients category 3	5.1310	4.85622	4.6244	4.493
Standard deviation waiting time patients category 3	1.1661	1.23046	1.2031	1.17378
Number of treated patients category 1	428.2	447.6	464.8	479.8
Number of treated patients category 2	252.0	261.6	270.0	279.8
Number of treated patients category 3	254.8	264.4	273.8	281.8

Beds	24	25	26	27
Occupancy operating room (o.r.)	0.9195	0.9404	0.9519	0.9576
Standard deviation occupancy o.r.	0.0949	0.07468	0.0589	0.05232
Occupancy beds	0.7979	0.7838	0.7625	0.73858
Standard deviation occupancy beds	0.2011	0.166	0.2132	0.15908
Waiting time patients category 1	4.2579	4.09484	4.0070	3.99146
Standard deviation waiting time patients category 1	0.9467	0.97302	0.9703	0.9986
Waiting time patients category 2	4.3157	4.23708	4.2231	4.1379
Standard deviation waiting time patients category 2	1.2275	1.23754	1.1945	1.2201
Waiting time patients category 3	4.4206	4.31506	4.2916	4.28808
Standard deviation waiting time patients category 3	1.1767	1.1882	1.2011	1.18984
Number of treated patients category 1	489.6	503.4	510.2	513.4
Number of treated patients category 2	285.4	294	299.6	301.2
Number of treated patients category 3	286.6	291.4	293.8	295.6

Simulation Results

FCFS Procedure
Sixteen patients at the waiting list
Distribution of operating capacity over three days of the week
Situation 2

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.8506	0.8811	0.8995	0.9179
Standard deviation occupancy o.r.	0.1565	0.1379	0.1140	0.0943
Occupancy beds	0.8845	0.8738	0.8520	0.8315
Standard deviation occupancy beds	0.1187	0.1225	0.1331	0.1382
Waiting time patients category 1	4.7563	4.5056	4.2984	4.1930
Standard deviation waiting time patients category 1	0.9623	0.9501	0.8931	0.8702
Waiting time patients category 2	4.7686	4.5335	4.4512	4.3527
Standard deviation waiting time patients category 2	1.1019	1.0695	1.0488	1.0566
Waiting time patients category 3	4.8185	4.6352	4.5934	4.4877
Standard deviation waiting time patients category 3	1.0936	1.0756	1.0882	1.0843
Number of treated patients category 1	449.4	466.6	478.4	490.2
Number of treated patients category 2	262.4	272.4	279.0	286.0
Number of treated patients category 3	266.8	275.8	280.6	285.2

Beds	24	25	26	27
Occupancy operating room (o.r.)	0.9286	0.9341	0.9385	0.9433
Standard deviation occupancy o.r.	0.0875	0.0735	0.0702	0.0658
Occupancy beds	0.8069	0.7793	0.7532	0.7281
Standard deviation occupancy beds	0.1447	0.1480	0.1515	0.1528
Waiting time patients category 1	4.1574	4.1242	4.1168	4.1012
Standard deviation waiting time patients category 1	0.9312	0.9084	0.8861	0.9046
Waiting time patients category 2	4.2774	4.2349	4.1739	4.1655
Standard deviation waiting time patients category 2	1.0920	1.0826	1.0521	1.0895
Waiting time patients category 3	4.4558	4.3444	4.3925	4.3228
Standard deviation waiting time patients category 3	1.0798	1.0678	1.0915	1.0739
Number of treated patients category 1	497.8	501.0	508.4	505.4
Number of treated patients category 2	290.6	292.8	290.8	295.6
Number of treated patients category 3	287.4	288.8	290.6	291.8

FCFS Procedure
Sixteen patients at the waiting list
Distribution of operating capacity over six days of the week
Situation 2

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.8309	0.8549	0.8704	0.8777
Standard deviation occupancy o.r.	0.1886	0.1673	0.1561	0.1420
Occupancy beds	0.8655	0.8472	0.8233	0.7938
Standard deviation occupancy beds	0.1095	0.1153	0.1209	0.1275
Waiting time patients category 1	4.7932	4.6313	4.5178	4.4726
Standard deviation waiting time patients category 1	0.9270	0.9218	0.9347	0.9702
Waiting time patients category 2	4.8222	4.6432	4.5484	4.4998
Standard deviation waiting time patients category 2	0.9663	0.9743	0.9905	1.0220
Waiting time patients category 3	5.1205	4.9542	4.8581	4.8321
Standard deviation waiting time patients category 3	0.9857	1.0163	1.0039	1.0252
Number of treated patients category 1	439.0	453.0	462.2	465.4
Number of treated patients category 2	257.2	265.0	269.0	270.6
Number of treated patients category 3	260.2	267.2	272.2	275.0

Beds	24	25	26	27
Occupancy operating room (o.r.)	0.8822	0.8854	0.8849	0.88558
Standard deviation occupancy o.r.	0.1378	0.13522	0.1373	0.13494
Occupancy beds	0.7647	0.7368	0.7083	0.68266
Standard deviation occupancy beds	0.1290	0.10402	0.1324	0.09776
Waiting time patients category 1	4.4369	4.42052	4.4202	4.41876
Standard deviation waiting time patients category 1	0.9725	0.98066	0.9941	0.981
Waiting time patients category 2	4.4743	4.4621	4.4667	4.46648
Standard deviation waiting time patients category 2	1.0384	1.04066	1.0599	1.05608
Waiting time patients category 3	4.8273	4.81756	4.8205	4.81744
Standard deviation waiting time patients category 3	1.0367	1.04852	1.0527	1.04724
Number of treated patients category 1	467.4	470.6	469.4	470.6
Number of treated patients category 2	273.0	274	274.0	274.2
Number of treated patients category 3	276.0	276.6	276.6	276.6

Simulation Results

FCFS Procedure
Sixteen patients at the waiting list
Distribution of operating capacity over two days of the week
Situation 3

Beds	16	17	18	19
Occupancy operating room (o.r.)	0.7310	0.77486	0.8086	0.8368
Standard deviation occupancy o.r.	0.2273	0.2201	0.2064	0.1886
Occupancy beds	0.7667	0.76176	0.7511	0.7376
Standard deviation occupancy beds	0.2144	0.20604	0.2261	0.2372
Waiting time patients category 1	5.6436	5.2904	4.9960	4.7386
Standard deviation waiting time patients category 1	1.0665	1.05384	1.1014	1.1174
Waiting time patients category 2	5.6990	5.2966	5.0208	4.7851
Standard deviation waiting time patients category 2	1.1943	1.27872	1.2580	1.2873
Waiting time patients category 3	5.7492	5.36394	5.1084	4.8578
Standard deviation waiting time patients category 3	1.2090	1.21124	1.2568	1.2340
Number of treated patients category 1	385.2	405.6	425.0	442.0
Number of treated patients category 2	222.6	238.6	250.6	258.4
Number of treated patients category 3	231.0	244.2	253.6	262.4

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.8731	0.8924	0.9083	0.92758
Standard deviation occupancy o.r.	0.14824	0.1382	0.1253	0.10804
Occupancy beds	0.73084	0.7126	0.6928	0.67716
Standard deviation occupancy beds	0.18275	0.2379	0.2485	0.17646
Waiting time patients category 1	4.45854	4.3987	4.2844	4.1314
Standard deviation waiting time patients category 1	1.02996	1.0552	1.0780	1.07544
Waiting time patients category 2	4.5764	4.3325	4.2085	4.25078
Standard deviation waiting time patients category 2	1.2709	1.3063	1.2820	1.26068
Waiting time patients category 3	4.76278	4.5684	4.4898	4.33688
Standard deviation waiting time patients category 3	1.21014	1.2041	1.2315	1.20354
Number of treated patients category 1	462.2	473.8	483.8	496.6
Number of treated patients category 2	271.8	276.8	282.0	289.6
Number of treated patients category 3	272.4	278.6	283.0	287.6

FCFS Procedure
Sixteen patients at the waiting list
Distribution of operating capacity over three days of the week
Situation 3

Beds	16	17	18	19
Occupancy operating room (o.r.)	0.8039	0.8370	0.8657	0.8858
Standard deviation occupancy o.r.	0.1947	0.1715	0.1596	0.1351
Occupancy beds	0.8402	0.8249	0.8059	0.7818
Standard deviation occupancy beds	0.1539	0.1655	0.1790	0.1838
Waiting time patients category 1	5.0590	4.7902	4.5975	4.4499
Standard deviation waiting time patients category 1	0.9652	0.9211	0.8928	0.9065
Waiting time patients category 2	5.1322	4.7964	4.6366	4.4703
Standard deviation waiting time patients category 2	1.0404	1.0594	1.0443	1.0241
Waiting time patients category 3	5.1814	5.0100	4.7991	4.6554
Standard deviation waiting time patients category 3	1.0911	1.0395	1.0413	1.0529
Number of treated patients category 1	422.6	442.4	459.4	470.2
Number of treated patients category 2	249.0	259.2	268.4	275.4
Number of treated patients category 3	252.2	262.0	270.4	276.2

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.9112	0.9239	0.9313	0.9368
Standard deviation occupancy o.r.	0.1092	0.0953	0.0825	0.0762
Occupancy beds	0.7637	0.7396	0.6773	0.6838
Standard deviation occupancy beds	0.1992	0.2071	0.2159	0.2183
Waiting time patients category 1	4.2486	4.1690	4.0978	4.1098
Standard deviation waiting time patients category 1	0.8852	0.8601	0.8433	0.8691
Waiting time patients category 2	4.3464	4.2785	4.2386	4.1923
Standard deviation waiting time patients category 2	1.0436	1.0498	1.0486	1.0575
Waiting time patients category 3	4.5090	4.4719	4.4057	4.3790
Standard deviation waiting time patients category 3	1.0594	1.0576	1.0648	1.0794
Number of treated patients category 1	484.8	495.0	499.2	502.8
Number of treated patients category 2	283.0	288.4	291.6	294.4
Number of treated patients category 3	284.0	286.4	288.2	289.2

Simulation Results

FCFS Procedure
Sixteen patients at the waiting list
Distribution of operating capacity over six days of the week
Situation 3

Beds	16	17	18	19
Occupancy operating room (o.r.)	0.8111	0.8367	0.8547	0.8704
Standard deviation occupancy o.r.	0.2076	0.1934	0.1707	0.1568
Occupancy beds	0.8487	0.8232	0.7958	0.7676
Standard deviation occupancy beds	0.1355	0.1480	0.1606	0.1651
Waiting time patients category 1	4.9488	4.7609	4.6273	4.4989
Standard deviation waiting time patients category 1	0.9010	0.8854	0.9160	0.9153
Waiting time patients category 2	4.9820	4.7814	4.6610	4.5572
Standard deviation waiting time patients category 2	0.9328	0.9408	0.9670	0.9951
Waiting time patients category 3	5.2253	5.5072	4.9692	4.8779
Standard deviation waiting time patients category 3	1.0079	0.9687	0.9942	1.0317
Number of treated patients category 1	426.2	442.0	453.2	462.2
Number of treated patients category 2	252.2	259.0	264.6	269.4
Number of treated patients category 3	254.0	262.0	267.2	272.0

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.8752	0.8805	0.8828	0.88268
Standard deviation occupancy o.r.	0.1446	0.1404	0.1380	0.13728
Occupancy beds	0.7330	0.7023	0.6721	0.64292
Standard deviation occupancy beds	0.1740	0.1774	0.1811	0.128
Waiting time patients category 1	4.4649	4.4386	4.4190	4.42524
Standard deviation waiting time patients category 1	0.9561	0.9737	0.9858	0.99592
Waiting time patients category 2	4.5202	4.4814	4.4806	4.48394
Standard deviation waiting time patients category 2	1.0138	1.0367	1.0350	1.04914
Waiting time patients category 3	4.8367	4.8154	4.8202	4.82006
Standard deviation waiting time patients category 3	1.0469	1.0407	1.0312	1.04104
Number of treated patients category 1	465.0	466.8	468.0	468.0
Number of treated patients category 2	269.8	271.6	272.6	272.8
Number of treated patients category 3	274.0	275.8	276.4	276.2

FCFS Procedure
Sixteen patients at the waiting list
Distribution of operating capacity over six days of the week
Situation 1

Beds	14	15	16	17
Occupancy operating room (o.r.)	0.8125	0.8457	0.8630	0.8745
Standard deviation occupancy o.r.	0.2016	0.1793	0.1584	0.1454
Occupancy beds	0.8474	0.8223	0.7868	0.7504
Standard deviation occupancy beds	0.1386	0.1529	0.1597	0.1711
Waiting time patients category 1	4.9443	4.6765	4.5579	4.4658
Standard deviation waiting time patients category 1	0.8883	0.8806	0.9168	0.9519
Waiting time patients category 2	4.9636	4.7257	4.5956	4.5197
Standard deviation waiting time patients category 2	0.9216	0.9163	0.9587	1.0092
Waiting time patients category 3	5.2179	4.9803	4.8977	4.5197
Standard deviation waiting time patients category 3	0.9554	0.9680	1.0018	1.0625
Number of treated patients category 1	427.2	447.8	458.0	464.4
Number of treated patients category 2	251.8	261.4	267.0	270.4
Number of treated patients category 3	254.8	264.8	269.8	273.4

Beds	18	19	20	21
Occupancy operating room (o.r.)	0.8813	0.8846	0.8853	0.8862
Standard deviation occupancy o.r.	0.1377	0.1358	0.1383	0.1347
Occupancy beds	0.7140	0.6793	0.6459	0.6159
Standard deviation occupancy beds	0.1747	0.1760	0.1758	0.1768
Waiting time patients category 1	4.4506	4.4281	4.4259	4.4169
Standard deviation waiting time patients category 1	0.9637	0.9745	0.9788	0.9811
Waiting time patients category 2	4.8095	4.4640	4.4686	4.4604
Standard deviation waiting time patients category 2	1.0304	1.0462	1.0551	1.0560
Waiting time patients category 3	4.8095	4.8208	4.8236	4.8153
Standard deviation waiting time patients category 3	1.0438	1.0470	1.0419	1.0441
Number of treated patients category 1	466.8	469.8	470.8	471.2
Number of treated patients category 2	272.6	274.2	274.2	274.6
Number of treated patients category 3	275.8	276.2	276.4	276.6

Myopic Procedure
Sixteen patients at the waiting list
Distribution of operating capacity over two days of the week
Situation 1

Beds	14	15	16	17
Occupancy operating room (o.r.)	0.6713	0.7151	0.76114	0.8037
Standard deviation occupancy o.r.	0.1806	0.1856	0.17292	0.1747
Occupancy beds	0.6979	0.6955	0.6945	0.6898
Standard deviation occupancy beds	0.2644	0.2832	0.25854	0.3140
Waiting time patients category 1	8.6649	8.5686	8.25722	7.5286
Standard deviation waiting time patients category 1	18.0781	13.7472	11.34334	7.9822
Waiting time patients category 2	2.8599	3.0147	2.8429	3.0217
Standard deviation waiting time patients category 2	1.2821	1.3887	1.06302	1.2452
Waiting time patients category 3	2.5640	2.5903	2.55062	2.5461
Standard deviation waiting time patients category 3	0.6094	0.6384	0.60748	0.5641
Number of treated patients category 1	357.4	381.8	401.2	422.6
Number of treated patients category 2	203.6	216.8	233.6	249.2
Number of treated patients category 3	211.6	225.2	239.6	252.0

Beds	18	19	20	21
Occupancy operating room (o.r.)	0.8425	0.88308	0.9149	0.9377
Standard deviation occupancy o.r.	0.1573	0.13426	0.1178	0.1028
Occupancy beds	0.6822	0.6782	0.6678	0.6530
Standard deviation occupancy beds	0.3275	0.25018	0.3549	0.3628
Waiting time patients category 1	7.0260	6.28	6.0899	5.5937
Standard deviation waiting time patients category 1	6.6525	5.23692	4.0645	2.7971
Waiting time patients category 2	4.0790	3.16838	3.2333	3.4105
Standard deviation waiting time patients category 2	1.3039	1.22418	1.2247	1.3123
Waiting time patients category 3	2.5975	2.61448	2.6351	2.6507
Standard deviation waiting time patients category 3	0.6644	0.6349	0.6576	0.6784
Number of treated patients category 1	447.6	469	486.6	502.6
Number of treated patients category 2	259.2	273.6	283.4	294.0
Number of treated patients category 3	264.0	275.8	285.6	290.0

Myopic Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over three days of the week
Situation I

Beds	14	15	16	17
Occupancy operating room (o.r.)	0.8133	0.8679	0.9143	0.9562
Standard deviation occupancy o.r.	0.2223	0.1851	0.1506	0.1084
Occupancy beds	0.8484	0.8453	0.8347	0.8225
Standard deviation occupancy beds	0.1711	0.1778	0.1877	0.1947
Waiting time patients category 1	7.2172	6.2894	5.7669	5.1646
Standard deviation waiting time patients category 1	6.4967	5.3164	3.9840	2.7957
Waiting time patients category 2	2.7572	2.7415	2.9832	3.2445
Standard deviation waiting time patients category 2	2.1033	1.7982	1.7833	1.5341
Waiting time patients category 3	1.7350	1.7453	1.9810	2.2203
Standard deviation waiting time patients category 3	1.0422	0.9166	1.1205	1.1504
Number of treated patients category 1	429.2	460.6	486.8	512.4
Number of treated patients category 2	251.8	268.8	285.0	301.6
Number of treated patients category 3	254.8	271.2	284.4	294.8

Beds	18	19	20	21
Occupancy operating room (o.r.)	0.9849	0.9943	0.9979	0.9988
Standard deviation occupancy o.r.	0.0632	0.0341	0.0208	0.0125
Occupancy beds	0.7994	0.7645	0.7293	0.6953
Standard deviation occupancy beds	0.2013	0.2097	0.2111	0.2149
Waiting time patients category 1	4.8227	4.5565	4.4377	4.4282
Standard deviation waiting time patients category 1	1.6951	1.2617	1.0662	1.0448
Waiting time patients category 2	3.5835	3.6699	3.7980	3.7855
Standard deviation waiting time patients category 2	1.2793	1.1598	1.0488	1.0396
Waiting time patients category 3	2.5448	2.8726	2.9034	2.9442
Standard deviation waiting time patients category 3	1.1826	1.2108	1.1651	1.1298
Number of treated patients category 1	527.0	532.4	535.4	535.6
Number of treated patients category 2	308.4	311.4	313.0	313.2
Number of treated patients category 3	305.0	307.8	308.4	308.8

Simulation Results

Myopic Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over six days of the week
Situation 1

Beds	14	15	16	17
Occupancy operating room (o.r.)	0.8832	0.9259	0.9678	0.9919
Standard deviation occupancy o.r.	0.2443	0.2101	0.1417	0.0626
Occupancy beds	0.9217	0.9027	0.8840	0.8531
Standard deviation occupancy beds	0.1180	0.1380	0.1416	0.1514
Waiting time patients category 1	5.9584	5.4021	4.7100	4.3055
Standard deviation waiting time patients category 1	3.0016	2.1520	1.1472	0.9420
Waiting time patients category 2	3.3624	3.4461	3.6270	3.7425
Standard deviation waiting time patients category 2	1.9045	1.6275	1.2981	1.0903
Waiting time patients category 3	2.1818	2.3838	2.9308	3.1936
Standard deviation waiting time patients category 3	1.6623	1.5672	1.4376	1.2586
Number of treated patients category 1	468.8	497.8	518.0	530.2
Number of treated patients category 2	273.4	289.8	305.2	311.6
Number of treated patients category 3	276.0	286.2	298.6	306.8

Beds	18	19	20	21
Occupancy operating room (o.r.)	0.9988	0.9993	0.9999	1.0000
Standard deviation occupancy o.r.	0.0166	0.0095	0.0014	0.0000
Occupancy beds	0.8114	0.7690	0.7312	0.6964
Standard deviation occupancy beds	0.1580	0.1660	0.1713	0.1734
Waiting time patients category 1	4.1622	4.1073	4.0908	4.0834
Standard deviation waiting time patients category 1	0.8119	0.8180	0.8309	0.8398
Waiting time patients category 2	3.7244	3.7682	3.7459	3.7626
Standard deviation waiting time patients category 2	0.9700	0.9702	0.9575	0.9489
Waiting time patients category 3	3.3562	3.4024	3.4521	3.4639
Standard deviation waiting time patients category 3	1.1360	1.0833	1.0285	1.0173
Number of treated patients category 1	537.0	536.2	537.0	537.2
Number of treated patients category 2	313.2	313.4	313.4	313.4
Number of treated patients category 3	308.4	308.8	309.0	309.0

Myopic Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over two days of the week
Situation 2

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.8148	0.8489	0.8834	0.91042
Standard deviation occupancy o.r.	0.1810	0.16612	0.1437	0.12736
Occupancy beds	0.8478	0.84056	0.8362	0.824232
Standard deviation occupancy beds	0.1869	0.1845	0.1998	0.18362
Waiting time patients category 1	7.2586	6.73022	6.1207	6.064
Standard deviation waiting time patients category 1	7.4577	5.42636	4.2020	3.91868
Waiting time patients category 2	3.1293	3.202	3.2744	3.30266
Standard deviation waiting time patients category 2	1.3490	1.4692	1.3746	1.24552
Waiting time patients category 3	2.6185	2.62446	2.6264	2.64386
Standard deviation waiting time patients category 3	0.6649	0.65836	0.6475	0.68438
Number of treated patients category 1	430.0	449.4	468.6	484.2
Number of treated patients category 2	252.4	261.2	273.8	283.6
Number of treated patients category 3	255.2	226.4	276	283.4

Beds	24	25	26	27
Occupancy operating room (o.r.)	0.9351	0.95334	0.9700	0.97724
Standard deviation occupancy o.r.	0.1083	0.0905	0.0693	0.0621
Occupancy beds	0.8122	0.79376	0.7771	0.754
Standard deviation occupancy beds	0.2166	0.17728	0.2262	0.17134
Waiting time patients category 1	5.6356	5.50184	5.3090	5.2063
Standard deviation waiting time patients category 1	3.1232	2.53728	2.0124	1.65698
Waiting time patients category 2	3.3184	3.4879	3.4309	3.64164
Standard deviation waiting time patients category 2	1.3221	1.3352	1.3049	1.3402
Waiting time patients category 3	2.6492	2.64918	2.7170	2.70668
Standard deviation waiting time patients category 3	0.6513	0.6955	0.7846	0.73574
Number of treated patients category 1	501.8	512.8	521.6	525
Number of treated patients category 2	293.2	299.6	305.2	307.4
Number of treated patients category 3	289.0	294	299.0	301.4

Simulation Results

Myopic Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over three days of the week
Situation 2

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.8640	0.8987	0.9318	0.9579
Standard deviation occupancy o.r.	0.1936	0.1616	0.1433	0.1150
Occupancy beds	0.8980	0.8912	0.8831	0.8670
Standard deviation occupancy beds	0.1294	0.1353	0.1416	0.1498
Waiting time patients category 1	6.0366	5.5629	5.2977	4.9718
Standard deviation waiting time patients category 1	4.9188	4.2002	3.3985	2.5293
Waiting time patients category 2	3.0352	3.1274	3.2097	3.3918
Standard deviation waiting time patients category 2	1.8901	1.6732	1.6081	1.3769
Waiting time patients category 3	1.9609	2.0443	2.2878	2.3962
Standard deviation waiting time patients category 3	1.0501	1.1227	1.1676	1.1584
Number of treated patients category 1	460.0	481.6	498.6	515.0
Number of treated patients category 2	267.2	278.4	292.4	302.4
Number of treated patients category 3	269.8	279.6	288.2	294.8

Beds	24	25	26	27
Occupancy operating room (o.r.)	0.9819	0.9922	0.9983	0.9992
Standard deviation occupancy o.r.	0.0695	0.0465	0.0153	0.0092
Occupancy beds	0.8513	0.8258	0.7993	0.7704
Standard deviation occupancy beds	0.1511	0.1522	0.1518	0.1536
Waiting time patients category 1	4.7385	4.5751	4.4955	4.4728
Standard deviation waiting time patients category 1	1.7866	1.3082	1.0382	1.0077
Waiting time patients category 2	3.5773	3.7119	3.7440	3.8235
Standard deviation waiting time patients category 2	1.2562	1.1616	1.0337	1.0614
Waiting time patients category 3	2.6132	2.7973	2.9253	2.8806
Standard deviation waiting time patients category 3	1.1999	1.1752	1.1424	1.1524
Number of treated patients category 1	525.8	531.2	535.6	535.4
Number of treated patients category 2	308.6	311.0	313.0	313.0
Number of treated patients category 3	303.4	307.0	308.6	309.2

Myopic Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over six days of the week
Situation 2

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.8854	0.9236	0.9513	0.9795
Standard deviation occupancy o.r.	0.2395	0.2038	0.1672	0.1077
Occupancy beds	0.9236	0.9179	0.9010	0.8859
Standard deviation occupancy beds	0.1050	0.1074	0.1171	0.1184
Waiting time patients category 1	5.6357	5.2383	4.8034	4.4687
Standard deviation waiting time patients category 1	3.5738	2.6001	1.8172	1.2187
Waiting time patients category 2	3.3307	3.4835	3.5622	3.6651
Standard deviation waiting time patients category 2	1.9876	1.7079	1.5283	1.2460
Waiting time patients category 3	2.4064	2.5949	2.8514	3.0790
Standard deviation waiting time patients category 3	1.7163	1.6375	1.4590	1.3451
Number of treated patients category 1	470.6	494.2	509.2	524.4
Number of treated patients category 2	276.4	288.8	300.2	307.6
Number of treated patients category 3	275.4	286.2	293.4	302.8

Beds	24	25	26	27
Occupancy operating room (o.r.)	0.9921	0.99826	0.9996	0.99992
Standard deviation occupancy o.r.	0.0705	0.02778	0.0072	0.00144
Occupancy beds	0.8605	0.8312	0.8007	0.77116
Standard deviation occupancy beds	0.1225	0.09904	0.1268	0.09498
Waiting time patients category 1	4.2498	4.13822	4.0889	4.08972
Standard deviation waiting time patients category 1	0.9600	0.85158	0.8342	0.83386
Waiting time patients category 2	3.7256	3.71762	3.7716	3.7501
Standard deviation waiting time patients category 2	1.0823	0.97114	1.0045	0.94038
Waiting time patients category 3	3.2871	3.40514	3.4427	3.45288
Standard deviation waiting time patients category 3	1.1760	1.1111	1.0501	1.0337
Number of treated patients category 1	531.4	535.0	535.4	535.8
Number of treated patients category 2	310.8	312.8	313.4	313.6
Number of treated patients category 3	307.0	308.8	309.2	309.2

Simulation Results

Myopic Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over two days of the week
Situation 3

Beds	16	17	18	19
Occupancy operating room (o.r.)	0.7013	0.74426	0.7862	0.8197
Standard deviation occupancy o.r.	0.2131	0.20468	0.1947	0.1946
Occupancy beds	0.7366	0.734	0.7321	0.7219
Standard deviation occupancy beds	0.2811	0.27674	0.3054	0.3221
Waiting time patients category 1	9.1033	8.06548	7.1472	6.6489
Standard deviation waiting time patients category 1	10.2447	7.69058	5.4226	3.7641
Waiting time patients category 2	3.6334	3.63538	3.7102	3.8561
Standard deviation waiting time patients category 2	1.6983	1.78642	1.6991	1.7807
Waiting time patients category 3	2.7521	2.79112	2.7241	2.7813
Standard deviation waiting time patients category 3	1.0747	1.13518	1.0581	1.0293
Number of treated patients category 1	369.2	391.0	412.8	433.2
Number of treated patients category 2	212.6	225.6	243.8	253.8
Number of treated patients category 3	222.2	236.0	246.6	256.6

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.85584	0.8891	0.9154	0.9424
Standard deviation occupancy o.r.	0.17076	0.1517	0.1266	0.1069
Occupancy beds	0.71846	0.7106	0.6993	0.68776
Standard deviation occupancy beds	0.26526	0.3338	0.3386	0.22926
Waiting time patients category 1	6.08172	5.6857	5.2903	5.15096
Standard deviation waiting time patients category 1	2.96104	2.0117	1.8313	1.6748
Waiting time patients category 2	3.79354	3.7800	3.6546	3.63292
Standard deviation waiting time patients category 2	1.71586	1.6721	1.4828	1.46484
Waiting time patients category 3	2.75344	2.7447	2.7029	2.69946
Standard deviation waiting time patients category 3	1.03238	0.9727	0.8575	0.79688
Number of treated patients category 1	454.8	473.0	489.4	505.0
Number of treated patients category 2	266.4	276.8	285.4	295.6
Number of treated patients category 3	266.6	276.8	284.2	291.4

Myopic Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over three days of the week
Situation 3

Beds	16	17	18	19
Occupancy operating room (o.r.)	0.8346	0.8761	0.9183	0.952
Standard deviation occupancy o.r.	0.2072	0.1788	0.1467	0.1178
Occupancy beds	0.8733	0.8641	0.8570	0.8404
Standard deviation occupancy beds	0.1558	0.1671	0.1746	0.1798
Waiting time patients category 1	7.2298	6.7113	5.9817	5.5291
Standard deviation waiting time patients category 1	6.5164	5.0307	3.7971	2.7082
Waiting time patients category 2	2.9796	2.9247	3.1156	3.4083
Standard deviation waiting time patients category 2	2.0036	1.9433	1.6744	1.5985
Waiting time patients category 3	1.7247	1.7871	1.9234	2.1000
Standard deviation waiting time patients category 3	0.9423	0.9773	1.0186	1.0898
Number of treated patients category 1	441.0	464.2	493.2	511.2
Number of treated patients category 2	259.0	273.6	286.6	300.0
Number of treated patients category 3	261.0	272.8	284.4	293.4

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.9781	0.9913	0.9970	0.9981
Standard deviation occupancy o.r.	0.0767	0.0391	0.0222	0.0139
Occupancy beds	0.8191	0.7911	0.7601	0.7280
Standard deviation occupancy beds	0.1946	0.2087	0.2155	0.2290
Waiting time patients category 1	4.9457	4.7805	4.5534	4.4488
Standard deviation waiting time patients category 1	1.8050	1.3734	1.1019	1.0825
Waiting time patients category 2	3.5763	3.6504	3.7158	3.7842
Standard deviation waiting time patients category 2	1.4092	1.2380	1.1069	1.0529
Waiting time patients category 3	2.4503	2.6205	2.8577	2.9402
Standard deviation waiting time patients category 3	1.1749	1.1289	1.1580	1.1531
Number of treated patients category 1	523.4	530.6	535.6	536.6
Number of treated patients category 2	307.6	311.0	312.2	313.0
Number of treated patients category 3	302.2	306.6	308.3	308.2

Simulation Results

Myopic Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over six days of the week
Situation 3

Beds	16	17	18	19
Occupancy operating room (o.r.)	0.8812	0.9227	0.9592	0.9791
Standard deviation occupancy o.r.	0.2589	0.2160	0.1530	0.1148
Occupancy beds	0.9241	0.9122	0.8929	0.8635
Standard deviation occupancy beds	0.1124	0.1196	0.1347	0.1505
Waiting time patients category 1	5.9647	5.2988	4.8958	4.5476
Standard deviation waiting time patients category 1	2.1783	1.5289	1.2003	0.8893
Waiting time patients category 2	3.6180	3.7006	3.7068	3.6756
Standard deviation waiting time patients category 2	1.8694	1.6198	1.3778	1.1329
Waiting time patients category 3	2.3245	2.5446	2.7094	3.0537
Standard deviation waiting time patients category 3	1.6388	1.5663	1.4429	1.3434
Number of treated patients category 1	468.8	494.4	514.4	525.0
Number of treated patients category 2	274.6	288.4	302.2	307.6
Number of treated patients category 3	274.2	285.8	295.8	302.4

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.9902	0.9956	0.9992	0.99932
Standard deviation occupancy o.r.	0.0705	0.0502	0.0117	0.01156
Occupancy beds	0.8299	0.7949	0.7621	0.72904
Standard deviation occupancy beds	0.1654	0.1751	0.1788	0.1268
Waiting time patients category 1	4.2730	4.1806	4.1532	4.0928
Standard deviation waiting time patients category 1	0.8116	0.8232	0.7907	0.79976
Waiting time patients category 2	3.7215	3.7699	3.7369	3.76712
Standard deviation waiting time patients category 2	1.0655	0.9840	0.9847	0.96818
Waiting time patients category 3	3.2979	3.3800	3.4489	3.45794
Standard deviation waiting time patients category 3	1.1721	1.1194	1.0533	1.03402
Number of treated patients category 1	530.0	533.8	536.6	536.8
Number of treated patients category 2	310.0	312.6	313.2	313.2
Number of treated patients category 3	306.6	307.6	308.8	308.8

Balancing Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over two days of the week
Situation 1

Beds	14	15	16	17
Occupancy operating room (o.r.)	0.6714	0.7188	0.76734	0.8114
Standard deviation occupancy o.r.	0.1122	0.1025	0.11172	0.1130
Occupancy beds	0.6994	0.6993	0.70052	0.6965
Standard deviation occupancy beds	0.3169	0.3281	0.29826	0.3511
Waiting time patients category 1	7.9659	7.1763	6.51812	6.0040
Standard deviation waiting time patients category 1	3.5137	2.8479	2.52052	2.1440
Waiting time patients category 2	4.9073	4.7917	4.39136	4.1116
Standard deviation waiting time patients category 2	2.0223	1.8830	1.59624	1.5234
Waiting time patients category 3	3.6242	3.5231	3.5667	3.5431
Standard deviation waiting time patients category 3	1.6295	1.4145	1.35416	1.2942
Number of treated patients category 1	359.0	381.0	402.0	427.8
Number of treated patients category 2	204.2	217.6	236.6	251.4
Number of treated patients category 3	211.0	227.2	241.6	254.2

Beds	18	19	20	21
Occupancy operating room (o.r.)	0.8559	0.72626	0.9339	0.9620
Standard deviation occupancy o.r.	0.1029	0.06582	0.0945	0.0725
Occupancy beds	0.6937	0.56248	0.6828	0.6700
Standard deviation occupancy beds	0.3615	0.207	0.3794	0.3806
Waiting time patients category 1	5.4942	3.46372	4.6133	4.2462
Standard deviation waiting time patients category 1	1.8793	1.3777	1.8990	1.5656
Waiting time patients category 2	4.0021	3.08086	3.5336	3.4878
Standard deviation waiting time patients category 2	1.3797	1.07108	1.2256	1.2222
Waiting time patients category 3	3.4062	3.34766	3.4341	3.7397
Standard deviation waiting time patients category 3	1.1682	1.23864	1.1806	1.1892
Number of treated patients category 1	454.2	387.0	499.8	516.4
Number of treated patients category 2	264.4	225.2	291.6	303.0
Number of treated patients category 3	267.8	226.4	289.6	296.6

Simulation Results

Balancing Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over three days of the week
Situation 1

Beds	14	15	16	17
Occupancy operating room (o.r.)	0.8324	0.8877	0.9415	0.9762
Standard deviation occupancy o.r.	0.1355	0.1114	0.0866	0.0618
Occupancy beds	0.8753	0.8698	0.8641	0.8419
Standard deviation occupancy beds	0.1851	0.1881	0.2052	0.2125
Waiting time patients category 1	4.8228	4.4405	4.2999	4.0354
Standard deviation waiting time patients category 1	1.7128	1.5207	1.5131	1.4523
Waiting time patients category 2	4.9829	4.5265	3.7318	3.2429
Standard deviation waiting time patients category 2	1.7244	1.5224	1.6625	1.4190
Waiting time patients category 3	4.4595	4.0333	3.7361	3.9811
Standard deviation waiting time patients category 3	2.2389	1.9986	1.8378	1.7062
Number of treated patients category 1	441.0	471.6	504.8	522.2
Number of treated patients category 2	257.6	275.0	295.8	306.8
Number of treated patients category 3	260.4	277.2	290.8	301.8

Beds	18	19	20	21
Occupancy operating room (o.r.)	0.9878	0.9891	0.9899	0.9904
Standard deviation occupancy o.r.	0.0370	0.0341	0.0313	0.0309
Occupancy beds	0.8051	0.7639	0.7270	0.6924
Standard deviation occupancy beds	0.2110	0.2100	0.2135	0.2161
Waiting time patients category 1	3.6920	3.4126	3.3140	3.3076
Standard deviation waiting time patients category 1	1.1548	0.9876	0.9185	0.9113
Waiting time patients category 2	3.5571	3.7548	3.8506	3.8754
Standard deviation waiting time patients category 2	1.2611	1.1371	1.1247	1.0909
Waiting time patients category 3	4.3277	4.6832	4.7669	4.7542
Standard deviation waiting time patients category 3	1.4685	1.3748	1.2612	1.2453
Number of treated patients category 1	529.6	529.0	531.0	530.6
Number of treated patients category 2	309.8	310.0	309.6	310.0
Number of treated patients category 3	305.4	306.2	306.4	306.6

Balancing Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over six days of the week
Situation 1

Beds	14	15	16	17
Occupancy operating room (o.r.)	0.8219	0.8952	0.9366	0.9404
Standard deviation occupancy o.r.	0.2508	0.1710	0.1245	0.0994
Occupancy beds	0.9325	0.9197	0.8901	0.8425
Standard deviation occupancy beds	0.1180	0.1059	0.1134	0.1207
Waiting time patients category 1	1.0692	2.1412	2.6316	2.5452
Standard deviation waiting time patients category 1	1.1355	1.8002	1.5043	1.3804
Waiting time patients category 2	4.1194	4.7747	4.4487	4.4085
Standard deviation waiting time patients category 2	2.6559	2.0852	1.7443	1.4900
Waiting time patients category 3	11.8567	7.3314	6.1425	6.2562
Standard deviation waiting time patients category 3	3.4518	3.0355	2.4686	2.1217
Number of treated patients category 1	435.0	475.8	499.4	504.6
Number of treated patients category 2	256.4	277.2	294.2	295.0
Number of treated patients category 3	256.2	279.6	290.0	290.6

Beds	18	19	20	21
Occupancy operating room (o.r.)	0.9479	0.9473	0.9517	0.9524
Standard deviation occupancy o.r.	0.0928	0.0916	0.0885	0.0877
Occupancy beds	0.8016	0.7591	0.7242	0.6900
Standard deviation occupancy beds	0.1314	0.1312	0.1364	0.1411
Waiting time patients category 1	2.4443	2.4834	2.5220	2.5056
Standard deviation waiting time patients category 1	1.3076	1.2963	1.2346	1.2385
Waiting time patients category 2	4.5550	4.5202	4.5635	4.5378
Standard deviation waiting time patients category 2	1.3365	1.3050	1.1984	1.2146
Waiting time patients category 3	6.2151	6.2255	6.1279	6.1330
Standard deviation waiting time patients category 3	1.9506	1.8344	1.6682	1.6531
Number of treated patients category 1	505.0	506.2	507.2	507.4
Number of treated patients category 2	299.4	297.6	298.8	300.0
Number of treated patients category 3	292.8	293.0	294.8	294.6

Simulation Results

Balancing Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over three days of the week
Situation 2

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.8677	0.9209	0.9488	0.9736
Standard deviation occupancy o.r.	0.1873	0.1161	0.0733	0.0534
Occupancy beds	0.9314	0.9242	0.9076	0.8898
Standard deviation occupancy beds	0.1219	0.1303	0.1314	0.1341
Waiting time patients category 1	3.4818	4.1528	3.7008	3.5747
Standard deviation waiting time patients category 1	1.8857	1.9152	1.4630	1.3155
Waiting time patients category 2	4.1004	3.8173	3.7495	3.5567
Standard deviation waiting time patients category 2	1.6562	1.7434	1.5358	1.4222
Waiting time patients category 3	6.6805	4.2829	4.5667	4.6371
Standard deviation waiting time patients category 3	3.2298	2.2545	2.0533	1.8201
Number of treated patients category 1	458.4	491.4	510.4	522.8
Number of treated patients category 2	269.6	287.4	298.6	306.2
Number of treated patients category 3	271.2	286.0	292.4	300.4

Beds	24	25	26	27
Occupancy operating room (o.r.)	0.9775	0.9829	0.9813	0.9823
Standard deviation occupancy o.r.	0.0481	0.0397	0.0403	0.0394
Occupancy beds	0.8555	0.8258	0.7931	0.7646
Standard deviation occupancy beds	0.1349	0.1406	0.1398	0.1431
Waiting time patients category 1	3.2837	3.2329	3.1968	3.1513
Standard deviation waiting time patients category 1	1.3284	1.0153	1.0331	0.9992
Waiting time patients category 2	3.8237	3.8645	3.8798	3.9678
Standard deviation waiting time patients category 2	1.3284	1.1776	1.1650	1.0921
Waiting time patients category 3	4.9562	5.0574	5.1410	5.1237
Standard deviation waiting time patients category 3	1.6708	1.4662	1.4623	1.4577
Number of treated patients category 1	524.0	527.4	528.0	527.6
Number of treated patients category 2	305.8	308.6	308.0	308.2
Number of treated patients category 3	302.6	303.6	302.8	303.4

Balancing Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over six days of the week
Situation 2

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.8415	0.8853	0.9152	0.9373
Standard deviation occupancy o.r.	0.2292	0.1848	0.1626	0.1191
Occupancy beds	0.9367	0.9270	0.9080	0.8843
Standard deviation occupancy beds	0.0861	0.0841	0.0868	0.0906
Waiting time patients category 1	0.6542	1.3177	1.8132	2.0638
Standard deviation waiting time patients category 1	0.8876	1.4515	1.7382	1.7127
Waiting time patients category 2	2.0187	4.4287	4.3594	4.1412
Standard deviation waiting time patients category 2	1.9328	2.5694	2.2357	1.9277
Waiting time patients category 3	14.1457	9.4296	7.9248	7.4516
Standard deviation waiting time patients category 3	3.1216	3.6106	3.0759	3.0169
Number of treated patients category 1	448.0	469.0	485.0	500.2
Number of treated patients category 2	263.0	274.6	284.6	293.8
Number of treated patients category 3	261.4	276.6	285.6	290.4

Beds	24	25	26	27
Occupancy operating room (o.r.)	0.9406	0.98784	0.9487	0.987
Standard deviation occupancy o.r.	0.1046	0.03758	0.0880	0.0382
Occupancy beds	0.8500	0.85172	0.7892	0.78952
Standard deviation occupancy beds	0.0930	0.08086	0.1003	0.07758
Waiting time patients category 1	1.8644	2.37228	2.0123	2.20604
Standard deviation waiting time patients category 1	1.6117	1.51544	1.4323	1.41566
Waiting time patients category 2	3.8849	4.02272	4.2133	4.18406
Standard deviation waiting time patients category 2	1.9066	1.49976	1.6288	1.37006
Waiting time patients category 3	7.7593	6.14976	7.2670	6.32092
Standard deviation waiting time patients category 3	3.1031	2.27304	2.5981	2.08278
Number of treated patients category 1	503.0	530.0	505.4	529.2
Number of treated patients category 2	293.6	309.2	298.2	309.4
Number of treated patients category 3	291.8	305.6	293.8	305.2

Balancing Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over three days of the week
Situation 3

Beds	16	17	18	19
Occupancy operating room (o.r.)	0.8265	0.8703	0.9121	0.9478
Standard deviation occupancy o.r.	0.1876	0.1744	0.1515	0.1314
Occupancy beds	0.8768	0.8668	0.8558	0.8406
Standard deviation occupancy beds	0.1833	0.1956	0.2018	0.2065
Waiting time patients category 1	4.6817	4.4268	4.3008	4.0598
Standard deviation waiting time patients category 1	2.1251	1.7575	1.7903	1.5303
Waiting time patients category 2	5.0068	4.5689	4.0762	3.5598
Standard deviation waiting time patients category 2	2.0139	1.6956	1.6586	1.5425
Waiting time patients category 3	4.8882	4.2776	3.9968	4.1069
Standard deviation waiting time patients category 3	2.8441	2.4263	2.1333	1.9410
Number of treated patients category 1	438.4	463.8	486.2	507.6
Number of treated patients category 2	256.2	271.2	284.2	297.6
Number of treated patients category 3	258.2	270.6	283.6	293.0

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.9665	0.9815	0.9850	0.9862
Standard deviation occupancy o.r.	0.0999	0.0549	0.0451	0.0390
Occupancy beds	0.8130	0.7873	0.7552	0.7230
Standard deviation occupancy beds	0.2047	0.2059	0.2122	0.2119
Waiting time patients category 1	3.7468	3.4773	3.3395	3.2743
Standard deviation waiting time patients category 1	1.2680	1.0571	0.9407	0.8727
Waiting time patients category 2	3.5414	3.8003	3.7428	3.8752
Standard deviation waiting time patients category 2	1.3652	1.2208	1.1944	1.1522
Waiting time patients category 3	4.4763	4.6513	4.8626	4.8933
Standard deviation waiting time patients category 3	1.6682	1.4761	1.3782	1.3767
Number of treated patients category 1	519.2	525.2	527.2	528.0
Number of treated patients category 2	304.2	308.0	308.8	308.6
Number of treated patients category 3	298.0	303.6	304.8	305.4

Balancing Procedure
Sixteen patients at the waiting list
Distribution of the operating capacity over six days of the week
Situation 3

Beds	16	17	18	19
Occupancy operating room (o.r.)	0.8044	0.8578	0.9113	0.9333
Standard deviation occupancy o.r.	0.2797	0.2254	0.1647	0.1419
Occupancy beds	0.9136	0.9028	0.8903	0.8611
Standard deviation occupancy beds	0.1266	0.1171	0.1139	0.1242
Waiting time patients category 1	0.7416	1.3668	2.1298	2.2009
Standard deviation waiting time patients category 1	0.9025	1.3354	1.5434	1.4411
Waiting time patients category 2	2.7523	4.4612	4.6626	4.5191
Standard deviation waiting time patients category 2	2.5617	2.5600	1.9581	1.6658
Waiting time patients category 3	14.2744	10.0189	7.3132	6.8431
Standard deviation waiting time patients category 3	3.0590	3.4444	2.8809	2.5835
Number of treated patients category 1	425.8	454.6	484.6	498.4
Number of treated patients category 2	248.8	266.0	283.2	291.2
Number of treated patients category 3	251.8	268.0	284.0	289.8

Beds	20	21	22	23
Occupancy operating room (o.r.)	0.9472	0.9537	0.9527	0.99202
Standard deviation occupancy o.r.	0.1137	0.0891	0.0876	0.03046
Occupancy beds	0.8261	0.7923	0.7551	0.7527
Standard deviation occupancy beds	0.1395	0.1378	0.1436	0.10598
Waiting time patients category 1	2.2884	2.3794	2.3078	2.40174
Standard deviation waiting time patients category 1	1.3844	1.2452	1.2630	1.17632
Waiting time patients category 2	4.3146	4.3342	4.4479	4.29456
Standard deviation waiting time patients category 2	1.7470	1.3676	1.3288	1.11816
Waiting time patients category 3	6.5899	6.3447	6.4087	5.77828
Standard deviation waiting time patients category 3	2.4741	2.0222	2.0261	1.60348
Number of treated patients category 1	506.8	512.0	511.4	531.2
Number of treated patients category 2	297.6	300.0	300.0	310.8
Number of treated patients category 3	292.8	294.2	293.8	307.0

Summary

The intent of this study was to improve the patient flow control by means of admission planning in a situation with multiple resource constraints. Interviews with hospital managers showed that they experience difficulties achieving a high utilization of all resources and a better patient service in this type of situation. These difficulties were mainly due to a lack of knowledge and information about:

1) the capacity needs of an individual patient for the individual processing steps,
2) the availability of resources in the future, and
3) the type of policies that have to be used in this type of situation.

A decision support system was developed to provide the admission planner with information about the capacity needs of an individual patient for the individual processing steps and the availability of resources in the future. This type of information was based upon the prediction models of Kusters. In addition, the system provided the planner with information about the patient's waiting time, the results of the preoperative screening and the requirements for blood or a prosthesis.

The decision support system was implemented in three hospitals in order to determine:

- whether the prediction models developed by Kusters could be applied in practice,
- whether using the decision support system could lead to improving the achievement of the admission planning goals, and
- whether the system design was satisfactory.

Results from these case studies showed that:

- the prediction models developed by Kusters could, with minor adjustments, by applied in practice,
- using the decision support system could improve the achievement of the admission planning goals, and
- the system design was judged to be satisfactory on almost every aspect.

In our study, the admission planning in a situation with multiple resource constraints is modelled as a flow shop with a number of different orders and without buffers between the individual processing steps. This way of modelling makes is clear that in this type of situation:

- control of all the resources at the operational level of planning is only possible by selecting patients from the waiting list to be admitted into the hospital, and
- blocking can occur.

- beheersing van de bezetting van alle capaciteiten op het operationele nivo van planning alleen mogelijk is door een selectie te maken van patienten uit de wachtlijst, en
- blokkering kan optreden.

Blokkering is hier gedefinieerd als het verschijnsel dat optreedt in situatie waarin capaciteit in één behandelingsstap niet gebruikt kan worden, omdat de benodigde capaciteit voor deze patient in een andere behandelingsstap ontbreekt. Als blokkering optreedt kan dit leiden tot een daling in de bezetting. Om een hoge bezetting van de capaciteiten te bereiken is het dus belangrijk om het optreden van blokkering te minimaliseren.

Om te onderzoeken welk type beslissingsregels gebruikt moet worden in een situatie met meerdere schaarse capaciteiten zijn twee nieuwe beslissingsregels geformuleerd en vergeleken met twee in de praktijk gebruikte beslissingsregels met behulp van simulatie. De resultaten van deze simulatie tonen aan welke beslissingsregel het beste gebruikt kan worden in welke situatie. Bovendien laten de resultaten van deze simulatie zien dat een hoge benutting van de capaciteiten het beste bereikt kan worden als de operatiecapaciteit over zoveel dagen in de week verdeeld is als mogelijk is.

Curriculum Vitae

The author of this dissertation was born on December 28, 1965 in Heerlen. In 1984 she received her high school diplocm at the pre-university level (vwo) from the Hertog Jan College in Valkenswaard, whereafter she started her study Industrial Engineering and Management Science at Eindhoven University of Technology. She received her Master's Degree in August 1988 after a research project concerning the coordination between two production departments.

Since September 1988, she conducted research at the Graduate School of Industrial Engineering and Management Science concerning admission planning in hospitals. This thesis concludes this research. The research was sponsored by the National Hospital Institute in the Netherlands and conducted in close cooperation with a number of hospitals.

STELLINGEN

behorende bij het proefschrift

"Decision Support
for
Admission Planning
under
Multiple Resource Constraints"

van

Petra M.A. Groot

I

Als een gebruiker de patienten voor opname naar ingreep classificeert en deze classificatie gebruikt wordt als invoer voor het door Kusters ontwikkelde voorspelmodel voor de beddenbezetting in de toekomst, wordt een groot deel van de variantie in de bedbezetting, die in de praktijk optreedt, verklaard.

(Dit proefschrift, hoofdstukken 5, 6 en 7)

II

Het gebruiken van voorspellingen betreffende de bezetting van capaciteiten in de toekomst, bijvoorbeeld op de wijze waarop dit in het beslissingsondersteunende systeem gebeurt, kan leiden tot het bereiken van een betere benutting van deze capaciteiten en een hogere doorstroomsnelheid van de patienten.

(Dit proefschrift, hoofdstukken 5 en 7)

III

De opnameplanning op een chirurgische afdeling waar zowel de beddencapaciteit als de operatiecapaciteit schaars is kan gemodelleerd worden als een flowshop waarin meerdere producten worden bewerkt en waarin zich geen buffers tussen de opeenvolgende bewerkingsstadia bevinden. Deze wijze van modelleren maakt het duidelijk dat in een dergelijke situatie capaciteit verloren kan gaan door het optreden van "blocking"-verschijnselen.

(Dit proefschrift, hoofdstuk 3 en hoofdstuk 6)

IV

De externe budgetfinanciering sluit niet aan op de wijze waarop de patientenstroom in ziekenhuizen beheerst wordt.

V

Het feit dat specialisten nog steeds apart betaald worden voor ligdagen, operaties en onderzoeken, vormt een blokkade voor het verbeteren van het primaire proces in een ziekenhuis.

VI

De huidige Ziekenhuis Informatie Systemen bieden weinig ondersteuning aan de planning van de operationele activiteiten.

VII

Het doorlopen van een promotie-traject kan, als neveneffect, een grote mate van zelf-inzicht in de persoonlijkheid van de promovendus opleveren.

VIII

Indien ervan uitgegaan wordt dat bijzonder verlof toegekend wordt om iemand de gelegenheid te geven aan bijzondere situaties in zijn persoonlijke leven het hoofd te bieden, dan zou het bijzonder verlof van de man in verband met de geboorte van zijn kind verlengd moeten worden.

IX

Softbalteams die geen scheidsrechter beschikbaar stellen, dienen niet toegelaten moeten worden tot de competitie.

X

De verbouwing van de kantine in het paviljoen heeft de mogelijkheid geschapen tot grotere sociale controle tussen de medewerkers onderling.

XI

Het feit dat promoveren een traject van vallen en opstaan is en niemand daarbij zo goed ondersteuning kan bieden als iemand die hetzelfde traject doorloopt pleit ervoor om twee promovendi in een werkruimte onder te brengen.

XII

Het woord leesvoer moet bedacht zijn door iemand die kleine kinderen geobserveerd heeft.

Eindhoven, 21 september 1993.