QUANTITATIVE METHODS OF PHYSICIAN SCHEDULING AT HOSPITALS

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Quantitative Methods of Physician Scheduling at Hospitals

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2010

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LIST OF ABBREVIATIONS

NRP	=	Nurse Rostering Problem
NSP	=	Nurse Scheduling Problem
PRP	=	Physician Rostering Problem
PSP	=	Physician Scheduling Problem
RRP	=	Resident Rostering Problem
RSP	=	Resident Scheduling Problem
MP	=	Mathematical Programming
IP	=	Integer Programming
ILP	=	Integer Linear Programming
MIP	=	Mixed Integer Programming
BIP	=	Binary Integer Programming
GP	=	Goal Programming
DP	=	Dynamic Programming
GS	=	Greedy Search
GA	=	Genetic Algorithm
TS	=	Tabu Search
AI	=	Artificial Intelligence
SA	=	Simulated Annealing
NLM	=	the US National Library of Medicine
NCBI	=	the National Center for Biotechnology Information

SUMMARY

Staff scheduling at hospitals is a widely studied area within the fields of operation research and management science because of the cost pressure on hospitals. There is an interest to find procedures on how to run a hospital more economically and efficient. Many of the studies about staff scheduling at hospital have been done about nurses, which work under common labor law restrictions. The goal of nurse scheduling is to minimize the staffing cost and maximizing their preferences. While the operation rooms are the engine of the hospitals, the physicians are the fueling for the hospitals. Without the physicians the patients would not be treated well and the hospital would not earn money.

This thesis studies the physician scheduling problem, which has not been studied so widely as the nurse scheduling problem. A limited number of literatures about this theme have been studied to answer the main research question:
How can we categorize physician scheduling at hospitals?

Studying the physician rostering problem on the search for efficiency and cost savings is an intricate process. One can read a lot about this theme develop a lot of models; and shape and test different hypotheses. However, to increase efficiency it is wise to make a plan of information to consider.

The categories searched for within this literature review are the level of experience, the planning period, the field of specialty, the type of shifts, whether cyclic or acyclic schedules are used and also which models and methods are used to solve this problem.

Level of experience was first divided between residents - that are still under education, and physicians - which are fully licensed. Physicians are medical trained doctors that provide medical treatment rather than surgical treatment in hospitals. After medical school, they have accomplished between three to seven years of residential internship before they obtain their license. The residents are still under education and must therefore participate in a number of assorted activities and patient treatments during their resident period to acquire their license. This situation

for resident makes scheduling unique as they are in a learning period and staffing the hospital at the same time.

The planning period is a category that is divided in three levels; short-term which lasts up to a month, midterm which lasts from one month up to six months and a long-term that lasts from six months up to one year.

The field of specialty is divided between the specialties of the physicians. In the numerous departments at a hospital, the work is distinctive from one another. A normal workday in a department that is only open during the day can be quite different from a workday in an emergency department.

Working in a hospital is unlike other type of jobs. A hospital or at least different departments in a hospital are open all day long, every day of the year. As a result, the hospital must be staffed all the time. The need for staffing varies during the day, the day of week; and during the different seasons, due to the fluctuation of the demands. An example for a solution is a variety of broad types of shifts. Scheduling these shift types can be made cyclic or acyclic.

Qualitative method has been used in this master’s thesis. The research question is a typically quantitative method starting with “how”. And to answer it, this thesis builds on a definite number of case studies. These case studies are limited to concern only about physician and resident scheduling problem written in English. These cases are primarily scientific articles and conference handouts. The cases are read - and interesting information is registered in a case study database.

The findings have shown different use of planning period after the level of experience. Few studies have been done with short-term planning period; physicians are mostly scheduled for a midterm planning period, whereas residents are mostly scheduled with a long-term planning period.

Most studies have scheduled physicians and residents for a day, evening and night shift, often in a combination with some kind of on-call shift. The field of specialty that is most studied is within emergency medicine. As the work in an emergency department is stressful, it is a complex task to make good schedules that satisfies the physicians and residents working there.

Exact approaches are the most used modeling technique used for physician scheduling.

PREFACE

This master's thesis was provided and constructed by Lehrstuhl für Technische Dienstleistungen und Operations Management at Technische Universität München (TUM), and is written as the final project that aims to the achievement Master of Science in Industrial and Information Management at the faculty of Engineering and Science at University of Agder (UiA) in Norway. This thesis was written over 20 weeks during the spring and summer of 2010.

The thesis is about classification of staff scheduling for hospital doctors, which is a topic studied under operation research and management science. The thesis lies under the strategy field in Master of Industrial and Information Management at UiA.

Supervisors for the master's thesis have been Dr.rer.pol. Jens Brunner by TUM and Dr.Ing. Bo Terje Kalsaas by UIA. I would like to thank my supervisors for guidance and support during this thesis.

I would also like to thank Haley Carney for her corrections of my language, as English is not my mother tongue.

Munich, September 6th 2010

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Christine Bekkan

1 INTRODUCTION

There is a great financial pressure on hospitals; they should reduce their costs and expenses, while there is a shortage of skilled labor. It is therefore optimal to meet these challenges now. Within the field of operational research, many studies have been attempted to solve these optimization difficulties. Most of these studies have been done about Nurse Scheduling Problem (NSP) (Burke, de Causmaecker, Vanden Berghe, & van Landeghem, 2004; Cheang, Li, Lim, & Rodrigues, 2003), and how to schedule nurses in a hospital department. In spite of this, this master thesis will be studying the scheduling of hospital doctors. A physician is a doctor licensed to practice medicine. Alternatively, a resident is a doctor who has graduated medical school, but still has to participate in educational training at a hospital before he or she can get licensed as a doctor. It is, in other words, a name for trainee, intern or graduate.

This scheduling problem is more complex than the NSP, since residents still need an educational praxis to get licensed as physicians. Whereas many physicians generally have individual contracts with their hospital with specific and limited details, the scheduling process is more challenging to involved these intricate agreements and these physicians will not be scheduled with other hospital staffs.

As mentioned above, there have been many studies of NSP. In addition many literature focusing on the physician scheduling problems (PSP) (Cardoen, Demeulemeester, & Belïen, 2009) and on the resident scheduling problem (RSP) have been examined. With current knowledge, these problems have been studied separately. For that reason, this thesis will characterize how we can schedule both physicians and residents in a hospital department.

1.1 Research Questions

The objective of this thesis is to determine an optimal procedure for scheduling hospital doctors. The main research question is:

How can we categorize physician scheduling at hospitals?

For further specification of this problem, subproblems have been developed. The objective of this scheduling problem is known, and many researchers have studied it.

A dimension for hospital rostering is the time planning period; the papers referred to in this thesis are divided into distinctive planning periods. The first subproblem is:

What does the time horizon mean for the rostering of physicians and residents in hospitals?

The papers referred to in this master's thesis are scheduling with different type of shifts. To get the knowledge of the primarily used shift types is the next subproblem:

What types of shifts and work rotations are used today for physicians and residents in hospitals?

The background of the most respective researchers for the physician scheduling problem may vary a lot, and consequently, they might use different approaches to define and solve this problem. The last research question is:

Which methods are used often for rostering physicians and residents within their field of specialty?

This thesis concerns on how to categorize the papers of physicians and residents rostering at the hospitals. From the studies already done, they have focused on either physicians or residents within a special hospital department, with a particular planning period and/ or with a defined type of shift. Similar scheduling problems from call centers, police or fire departments, airline crew planning or within other transportation areas will not be referred to in this thesis. An overview of the relevant papers first is necessary, and then a follow up with discussion about the results found afterwards.

1.2 Approach and Structure

The master's thesis is structured as followed: section 2 describes a theoretical framework about some relevant staff scheduling problems, and models and methods used for solving these scheduling problems. Section 3 explains the methods used for this master thesis, whereas section 4 elucidates the extensive literature that have been studied. In section 5 the findings; are presented, and section 6 explain the final conclusion and suggest future studies. In the appendix an overview of all the relevant papers is specified, and in addition they are presented with a title, an abstract, names of all the authors, and where they were published.

2 THEORETICAL FRAMEWORK

This work studies the physician and resident rostering problems in hospitals (PRP and RRP). These two problems are more complex than the more studied NRP. In order to categorize different solutions for these problems, the following sections introduce an overview of relevant terms, definitions of these problems, and descriptions of the different types of methods used to solve these problems.

2.1 Clarifying Important Terms

From the extensive literature review, different concepts and synonyms have been used. To avoid any following problems, important terms that are used in this paper are defined here:

Shift: A set of consecutive periods within a day, the length of a shift is the total amount of time it covers.

Roster: A combination of shifts and days-off assignments that covers a fixed period of time; a line-of-work.

Flexibility: For each employee, the ability to assign arbitrary shift lengths, shift starting times, and break periods, and to accommodate individual preferences, requests and constraints. (Brunner, Bard, & Kolisch, 2009a)

Physician: A person licensed to practice medicine. It is a doctor who specializes in medical rather than surgical treatment of patients.

Resident: A doctor who has graduated medical school, but still has to participate in educational training at a hospital before he or she can get licensed as a doctor. In other word, resident is a name for trainee, intern or graduate.

2.2 Presentation of Staff Rostering Problems

Personnel rostering or scheduling is the process of constructing work timetables for the staff so the organization can satisfy the demand for its goods or services. (Ernst, Jiang, Krishnamoorty, & Sier, 2004) Constructing rosters for hospitals is complicated, because the staff work around the clock seven days a week. The need for staff varies from hour to hour, and from day to day at a hospital. The different departments in a hospital may also have different needs for staff, because of inpatients and outpatients.

2.2.1 The Nurse Rostering Problem

Nurses work under collective agreements, in the NRP – the objectives are to maximize their individual satisfaction and minimize the cost of salaries. (Gendreau et al., 2006) NRP involves allocating nurses to work shifts and days subject to a variety of hard constraints, such as legal regulations, personnel policies, and soft constraints such as nurses' preferences and many requirements that may be hospital specific. (Topaloglu, 2008) For satisfaction of the nurses, it is important to assure as many as possible of the soft constraints.

Burk et al. (2004) and Cheang et al. (2003) have made bibliographic surveys concerning nurse rostering problems. The bibliographic from Burk et al., tries to present an analysis and discussions of key models and approaches for NRP used over the years and outline the current state of the art of the field from 2004. The bibliographic of Cheang et al. presents a survey of models and approaches for NRP made until 2003. The emphasis of this paper is to briefly cover mathematical programming (MP) methods, which are diverse kinds of constraint programming and metaheuristic.

2.2.2 The Physician Rostering Problem

The difference between NRP and PRP is that the demands of the nurses are during a period that is relatively constant, while the need for physicians can fluctuate widely. The PRP solely focuses that every shift of every day must be assigned to exactly one physician at a time (Gendreau et al., 2006). This depends on the physicians' labor contracts, what kind of department it is, and on the size of the hospital department. Physicians have more complex labor agreements than nurses, as physicians have individual contracts with their hospital that clarify their work regulations and work conditions. Shifts for physicians can start at different times depending on the need for their expertise. As nurses have more standard shifts with little or no variety of starting times, physicians are required for on-call services that make the scheduling more complicated. (Brunner et al., 2009a)

The complex nature of PRP makes it difficult to define a set of generally accepted hard and soft constraints, as in the case of nurse scheduling. As the hospitals often have detailed labor contracts with their physicians that vary by region, governing authority, seniority, specialty and training therefore discourages generalization (Brunner et al., 2009a). To achieve this goal, different kinds of constraints that have to be followed. The hard constraints are the "law" and cannot be violated; and softer constraints are accommodating, but will make the physicians dissatisfied when they are broken.

With a given a set of doctors, a set of shifts and a planning period, fair schedules for all physicians are desired in order to maximize their individual satisfaction. (Gendreau et al., 2006)

2.2.3 The Resident Rostering Problem

NRP usually deals with detailed shift scheduling, e.g., determining the exact hours nurses have to work during the next month, whereas residents are scheduled over a longer period – usually one year. Residents still have to complete education, and therefore have to alternate between different activities for gaining new experiences within their residential period. If they have to start up every new activity more than once, it would represent a discontinuation in their education. When a resident has a week off, he/she cannot be replaced by another resident because of his/her education, whereas nurses can switch weeks individually because of mutual agreements. (Belïen & Demeulemeester, 2007)

As part of their education, doctors first are spending four years in medical school, and then three to seven years as residents before they can get certified and licensed as physicians. In their resident period are they receiving additional supervision and guidance from more senior physicians. Scheduling periods often lasts from four to 12 weeks, where they are based at a specific facility to achieve specific educational goals. (Cohn, Root, Esses, Kymissis, & Westmoreland, 2006) Some papers focus on long-term periods, since it is easier to plan and schedule the education for the residents. This year of scheduling normally goes from July to June, and the residents then have to apply for their preferred vacations, weekends and days-off.

2.3 Physician Scheduling Approaches

The objective of this thesis is - to categorize the different papers of physician's scheduling. This theoretical framework is developed to make a better understanding of relevant factors for the rostering process. A sufficient knowledge of the methods used in these papers is needed. The methods used for scheduling can be divided in different ways, some use cyclic or acyclic scheduling methods, but the main division in this master's thesis is between exact and heuristics approaches.

For cyclic techniques, fixed sequences of shifts must be defined first, for they, are then assigned equally among the workers. Cyclic schedules are often used, where the same schedule can accommodate all workers, and needs to be adjusted for vacations and days-off. Acyclic methods must be considered as a solution, when a cyclic scheduling is impractical or as an optimization approach. Acyclic scheduling has two advantages compared to cyclic scheduling: 1) they require little human intervention and can almost be fully computerized, and; 2) when done right they can handle more rules simultaneously than a human expert can. (Beaulieu, Ferland, Gendron, & Michelon, 2000)

The exact and heuristic approaches have more subgroups underneath, and will be closer explained in the next sections.

Optimization problems are concerned with finding the values for one or several decision variables that meet the objective(s) to the best without violating the constraints. Depending on the objective function, optimization problems may have multiple solutions where some can be of local optima. (Maringer, 2005)

2.3.1 Exact approaches

In operations research is mathematical programming (MP) used to find solutions to optimize the problems. Exact approaches are based on MP, and MP uses mathematical models to describe and solve a problem.

In a mathematical optimization (or programming) a problem, one seeks to minimize or maximize a real function of real or integer variables, subject to constraints on the variables. The term mathematical optimization refers to the study of these problems: their mathematical properties, the development and implementation of algorithms to solve these problems, and the application of these algorithms to real world problems. The word "programming" does not specifically refer to computer programming as the term "mathematical programming" was applied before the word "programming" became closely associated with computer software. This confusion can be avoided by using the term optimization as an approximate synonym for mathematical programming. (Mathematical Optimization Society, 2010)

2.3.2 Linear programming

A major proportion of all scientific computation on computers is devoted to the use of linear programming (LP). The most common type of application involves the general problem of allocating limited resources among competing activities in an optimal way. The word linear refers to the mathematical functions in the model that is required to be linear functions. LP involves the planning of activities to obtain an optimal result, which is a result that reaches the specified best goal. (Hiller & Lieberman, 2006)

LP uses a mathematical model to describe the problem of concern, and any problem whose mathematical model fits the general format for the linear programming model is a LP problem. Almost any social organization is concerned with allocating resources in some context, and there is a growing recognition of the extremely wide applicability. It provides the basis for performing the various parts of post-optimality analysis very efficiently. (Hiller & Lieberman, 2006)

The goal of LP is to determine the values of decision variables that maximize or minimize a linear objective function, where the decision variables are subject to linear constraints. A LP problem is a special case of a general constrained optimization problem. The goal is to find a point that minimizes the objective function and at the same time satisfied the constraints, any point that satisfies the constraints is a feasible point. In a LP problem, the objective function is linear, and the set of feasible points is determined by a set of linear equations and/ or inequalities.

LP methods provide a way of choosing the best feasible point among the many possible feasible points. A LP problem can be solved simply by comparing the finite number of basic feasible solutions and finding one that minimizes or maximizes the objective function. For most practical decision problems, the finite number of basic feasible solutions is so large that the method of choosing the best solution by comparing them to each other is impractical. Consequently, it takes a lot of computational time to solve a problem. (Chong & Zak, 1996)

2.3.3 Integer programming

In many problems, the decision variables actually make sense only if they have integer values, as when assigning peoples, machines, and vehicles to activities in integer quantities. If requiring integer values is the only way in which a problem deviates from LP formulation, then it is an integer programming (IP) problem. The mathematical model for IP is the LP model with the one additional restriction that variables must have integer values. If some of the variables are required to be integer, the model is referred to as mixed-integer programming (MIP). When there also are applications involving yes-or-no decisions, then the values are binary (0-1), and it is a binary-integer programming (BIP). Size is one key factor in determining the required to solve an IP problem, if it can be solved at all.

The most important determinants of computation time for an IP algorithm are the number of integer variables and whether the problem has some special structure that can be exploited. For fixed number of integer variables, BIP problems generally are much easier to solve than problems with general variables, but adding continues variables MIP may not increase computation time substantially. (Hiller & Lieberman, 2006)

2.3.4 Goal programming

Goal programming is used for multi objective optimization, either as a multicriteria decision-making or multicriteria decision analysis methodology. It can be thought of as an extension or generalization of LP to handle multiple, normally conflicting objective measures. Each of these measures is given an objective value to be achieved. Unwanted deviations from this set of objective values are then minimized in an achievement function. A satisfaction of the goal is deemed to satisfy the decision maker(s), an underlying satisfying philosophy is assumed. (Schniederjans, 1995)

2.3.5 Branch-and-bound and branch-and-price

Branch-and-bound (B&B) was originally developed in the 1950s, and are therefore not much used anymore. When finding an optimum within a finite set of alternatives, an obviously approach is to enumerate all the alternatives and use the best. The rationale behind B&B was to reduce the number of alternatives that needed to be considered by repeatedly partitioning the problem into a set of sub-problems. As more branching goes on, it is needed to find the third and fourth most improving solution and further on. Specialized routines are needed for this process. Variable combined generation with appropriate branching rules and variable generation at the subproblems are known as branch-and-price (B&P). (Burke & Kendall, 2006)

2.3.6 Column generation

Column generation (CG) is an exact method that relies on the decomposition principles of MP; it is usually used to solve large and complex problems. In the CG method, each new column is generated by solving a secondary problem. This method has been successfully used in NRP, and can also be used in PRP with minor adjustments. (Gendreau et al., 2006)

2.3.7 Constraint programming

Constraint programming (CP) has its roots in artificial intelligence (AI) and computer science communities, while MP comes from the operational research communities. CP can be traced back to constraint satisfaction problems that searched for feasible solutions to satisfy all the given constraints. CP has been used to solve feasibly problems, but also been used for solving optimization problems. Because of its roots from computer sciences, it has together with MP been used in different computer programs for solving optimization problems. CP is not a part of MP, but they are using the same language. (Pinedo, 2005)

2.3.8 Dynamic programming

Dynamic programming (DP) is a general concept rather than a strict algorithm and can be applied to problems that have a temporary structure. To solve an optimization problem with this method, the problem needs to be divided into subproblems; without any connection between them when considered separately. (Maringer, 2005)

2.4 Heuristic approaches/ methods

When addressing a wide of variety of practical problems, algorithms do not always work. Some problems are too complicated that it may not be possible to solve for an optimal solution. In these situations there is still a need for finding a feasible solution close to optimal. And heuristics are often used in this kind of situations. (Hiller & Lieberman, 2006)

A heuristic method is a procedure to discover good solutions for a problem, but not necessarily the optimal solution, for a specific problem. Heuristics are often based on common-sense ideas for how to search for an optimal solution. Some problems are too complicated that it may not be possible to solve for an optimal solution, and there are still the need for finding a feasible solution that is at least reasonably close to being optimal. For this reason, heuristics are used to search for such a solution. (Hillier & Lieberman, 2006)

2.4.1 Metaheuristic

A metaheuristic is a general solution method that provides both a general structure and strategy guidelines for developing a specific heuristic to fit a particular problem.

A metaheuristic is a general kind of solution method that coordinates the interaction between local improvement procedures and higher level strategies to create a process that is capable of escaping from local optima and performing a robust search of feasible region. (Hillier & Lieberman, 2010)

2.4.2 Local search

Local search (LS) is a metaheuristic for solving computationally complex optimization problems. Solution maximization problems among a number of neighboring solutions within a search area use a LS until a true solution is found or until the time interval elapses. This method has been used in NRP, where a solution is an assignment of nurses to shifts which satisfies all constraints. A local search procedure operates just like a local improvement procedure except that it may not require that each new trial solution is better than the preceding trial solution. (Hillier & Lieberman, 2010)

2.4.3 Tabu search

Tabu search (TS) is a widely used metaheuristic that use some common-sense ideas to enable the search process to escape from a local optimum. Any kind of tabu search includes as a subroutine a LS procedure that seems appropriate for the problem being addressed. The procedure begins by using this procedure as a local improvement procedure to find a local optimum. A key strategy of tabu search is that it then continues to search by allowing non-improving moves to the best solutions of the neighborhood of the local optimum. Once a point is reached where better solutions can be found in the neighborhood of current trial solution, the local improvement procedure is reapplied to find a new local optimum. (Hillier & Lieberman, 2006, 2010)

2.4.4 Genetic algorithms

A generic algorithm (GA) provides a third type of metaheuristic that is different from the first two. It tends to be particularly effective at exploring different parts of the feasible region and gradually evolving toward the best feasible solution. (Hillier & Lieberman, 2010)

A GA is a probabilistic search technique that has its roots in the principles of genetics. GA has been widely used as a tool in computer programming and artificial intelligence (AI) optimization, neural network training, and many other areas. This can be used for solving an optimization problem, such as to maximize the profit.

The underlying idea of a GA starts with an initial population. The objective function must be evaluated in the initial position, to create a new population. The creation of new populations involves certain operations, called crossover. This procedure is repeated, to create more new populations until an appropriate stopping criterion is reached. The purpose of the crossover operations is to create a new population with an average objective function value that is higher than the previous population. (Chong & Zak, 1996)

2.4.5 Greedy algorithm

Algorithms used for optimization problems go through a sequence of steps, with a set of possibilities at each step. A greedy algorithm always chose the possibility that looks best at the moment. It makes at locally optimal choice, and hopes that it will lead to a globally optimal solution. Greedy algorithms do not always yield an optimal solution, but they do for some. (Cormen, Leiserson, & Rivest, 1991)

2.5 Summary

To be able to make an optimal roster for physicians and residents, there are some concerns to take care of. As physicians have their individual contracts with the hospital, a general roster for all of them in one hospital department cannot be made. Every roster must therefore be individually catered to each physician needs. As the residents still are under education, the demands on which activities they have to participate in exist only.

Knowing the PRP and the RRP is just an important step in the process of making an optimal roster for physicians and residents. Next step in this process is to choose which model or method to solve the problem, to choose either an exact approach or a heuristic approach.

Under heuristics, there is also simulated annealing (SA), which have not been used in the papers that are referred to in this thesis. SA has been used for NRP. (Burke et al., 2004)

In addition, Artificial Intelligence (AI) exists, and this method has not been used in these papers either. AI techniques present an alternative method for solving NRPs (Topaloglu, 2008), this method have been widely used for the NRP (Burke et al., 2004).

3 METHOD CHAPTER

3.1 Data Collection

Staff scheduling has been studied for more than forty years within the field of operational research, personnel management and computer science. It covers mostly staffing, budgeting and short-term scheduling problems. Although these fields have different time horizons, they are strongly connected to one another. Because healthcare institutions work around the clock, unlike many other organizations, the rostering of hospital personnel is challenging because of the different staffing needs on different days and shifts.

Most of the relevant papers and articles precisely 165 were handed out, analyzed and evaluated of their relevance. They were evaluated and eliminated by reading their titles and abstracts, for articles with a level of uncertainty was more of them to be read. The ambition was to find more than twenty papers of relevance, in addition to some relevant bibliographies. This goal was not reached and methodical searches were completed through different academic search engines, such as: EbscoHost, PubMed, and Google Scholar. The relevant literature is limited to academic papers published in peer-reviewed journals or presented at a conference, to ensure that the literature is reliable and valid.

EBSCOhost

EBSCOhost is a worldwide leader in providing information access and management solutions through print, electronic journal subscription services; and research database development and production. EBSCO offers online access to more than 300 databases and thousands of e-journals, a full-featured OpenURL link resolver, and e-commerce book procurement. EBSCO has been serving libraries and business communities since it was founded in 1944 by Elton B. Stephens Company. EBSCO is an acronym for Elton B. Stephens Company. EBSCO have been placing their users at the core of their business and have taken advantage of the users' ingenuity for developing better services and products.

EBSCO Information Services has developed "e" discovery solutions, including EBSCO A-to-Z® and LinkSource®; as well as management solutions such as EBSCONET®, EBSCONET ERM Essentials™ and EBSCO MARC Updates. These services offer unparalleled integration to help librarians save time and money while empowering their users.

EBSCO also offers eBook and eAudioBook services as well as EBSCO Discovery Service, federated search services and a variety of partnership opportunities for publishers. (EBSCOhost, 2010)

PubMed

PubMed is a service of the US National Library of Medicine (NLM) that includes over 19 million citations for biomedical literature from MEDLINE, life science journals, and online books. Citations may include links to full-text content from PubMed Central and publisher web sites. The NLM is the world's largest medical library. The Library collects materials, provides information and research services in all areas of biomedicine and health care.

PubMed is available via the National Center for Biotechnology Information (NCBI) Entrez retrieval system; this is a text-base search and retrieval system. PubMed also provides access and links to the other Entrez molecular biology resources.

Publishers participating in PubMed electronically submit their citations to NCBI prior to or at the time of publication. If the publisher has a web site that offers full-text of its journals, PubMed provides links to that site as well as biological resources, consumer health information, research tools, and more. A charge to access the text or information may exist.

The PubMed Journals Database can be searched by subject or by using the journal title, the Title Abbreviation, their unique journal identifier NLM ID, the International Organization for Standardization (ISO) abbreviation, and the print and electronic International Standard Serial Numbers (pISSNs and eISSNs). The database includes journals in all Entrez databases (e.g., PubMed, Nucleotide, and Protein). (PubMed, 2010)

Google Scholar

Google Scholar is one of the services provided by Google Inc, and was introduced in November 2004. It provides a simple way to broadly search for “scholarly” literature. It is possible to search across many disciplines and sources: articles, theses, books, abstracts and court opinions, from academic publishers, professional societies, online repositories, universities and other web sites. (Google Scholar, 2010) (Google_Scholar, 2010)

The material found by Google Scholar is provided from both commercial and open source publishers. It retrieves document or page matches based on the keywords searched and then organizes the results using their own, secret algorithm. Since much of the content of Google Scholar's index comes from licensed commercial journal content, most of the outcomes are often just an abstract and not the full-text, with a possibility to pay to get the whole text.

This search engine is designed to get a quick answer to finish a task, and is not developed for comprehensive or exhaustive research. Therefore, this search engine is worthwhile and useful, but with a limited value. Google Scholar is a handy tool for verifying citations, and has a place in medical and scientific libraries. It is a perfectly straight search tool for those who are looking for quick answers and for questions where the outcome has little or no impact on clinical quality. (Vine, 2006)

Saunders et al. (2007) divides literature sources in three levels: primary (published and unpublished), secondary and tertiary: after the information flow from the original source.

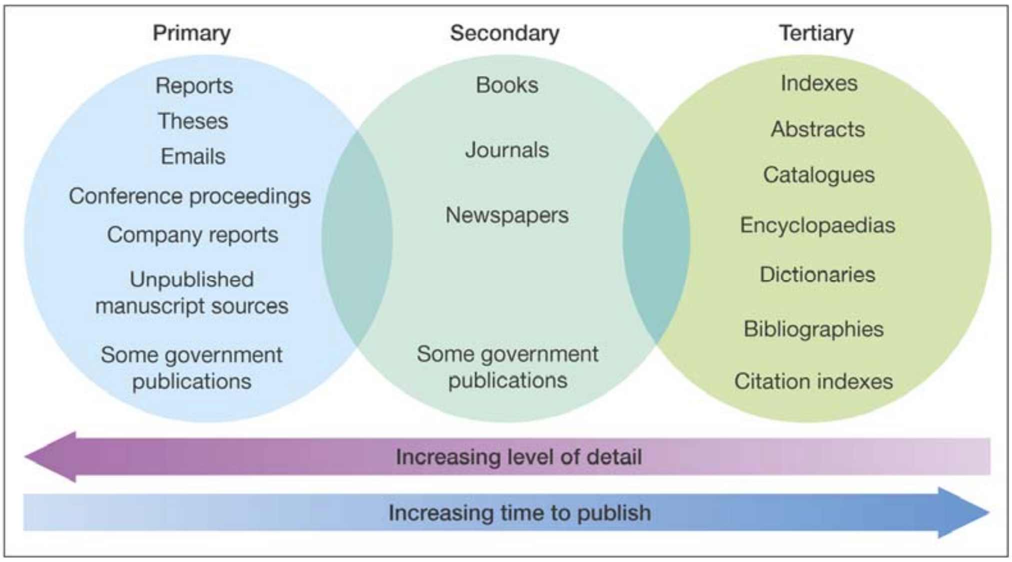

Figure 3.1: Literature sources available (Saunders et al., 2007 p.64)

The literature sources in this thesis are primarily reports, conference proceedings, as well as tertiary as bibliographies. The theoretical framework is compromised mainly from secondary sources, namely books.

Qualitative data are limited in a number of papers. The majority of the rosters developed in these papers have been tested in real-life. After the testing, the researchers have received feedback from the physicians or the residents.

3.2 Methodical Approach

The methods are mostly divided into quantitative and qualitative methods when working with a scientific study. These two methods can be used alone or together. Despite the title, "Quantitative methods of physician scheduling," qualitative approaches have been used, as it searches to explore the depth of physician scheduling procedures.

Qualitative methods are used when it is wanted to know "what-why-how", to understand a phenomenon. It is also used when small amount background information exists about our topic, and when the depth of the theme needs to be explored. The qualitative data are limited in a number of papers. The majority of the rosters developed in these papers have been tested in real-life. After the testing, the researchers have received feedback from the physicians or the residents. (Yin, 2009)

Quantitative data may describe what a case study is trying to explain, such as an evaluation of the result. In quantitative methods or statistical generalization, quantitative data can be related to an embedded unit of analysis within the case studied. Then the generalization mode is an analytical generalization. Analytical generalization can be used for both single- and multiple-cases, and one should try to aim toward analytical generalization when doing case studies. Quantitative data are central in explaining or testing of the key proposition of a case study. (Yin, 2009)

To raise the validity of a work, it can be useful to triangulate qualitative and quantitative methods. Data and conclusions are then controlled by combining different methods. Triangulation might be used as an effective control of the investigation of a single researcher's solution, so that it can be found by another researcher. (Jacobsen, 2005)

3.3 Reliability and validity of research work

Reliability and validity are important to scientific work; one has to be able to rely on it. Reliability is demonstrated when the different operations of a study can be repeated with the same result. A general way of approaching the reliability problem is to make as many steps as operational as possible, and to conduct research as if someone always was monitoring the man under observation. A case study protocol of what and how things have been done needs to be written, as well as with a case study database of data that have been found – and, with this combination there are good remedies for working with reliability. (Yin, 2009)

The reliability of this thesis lay in the use of a case study protocol and the development of a case study database. The case study protocol is used, to execute the process, so that other researchers later on can reach the same results as this thesis. The case study protocol explains all the steps in the process and what to search for. The case study database is developed to organize the data found for this study. Table 3.1 is an example for a case study database for this master's thesis.

The validity of an academic work can be divided into three different tests: constructing validity by using multiple sources, internal validity by doing pattern matching, and external validity to defining the domain to which study's findings can be generalized. (Yin, 2009)

This thesis uses multiple sources, findings in each one of them are registered in a spreadsheet to make the pattern matching easier. The theoretically generalization comes from studying a limited number of cases and then brings them to a theoretical level.

	Level of experience						Approach				Planning periode			Shift types								Field of specialty										Country					
	Physicians			Residents			Exact		Heuristic																												
	experienced > 5 years	experienced < 5 year	no differntiation	1st year	2nd - 4th year	no differntiation	Single criterion	multicriteria	Single criterion	Multicriteria	Short-term	Midterm	Long-term	Day shift	Day, evening & night	10+14h	Flexible	On-call	Emergency rotation	other	No info	ER	Anesthesia	Geriatric	Pulmonary	Ophthamology	Radiology	Psychiatry	Pediatrics	Family practice	No info/ Others	USA	Canada	Belgium	Germany	Spain	Turkey
Beaulieu et al. 2000	x	x						x				x			x					x		x											x				
Belïen 2006					x		x						x								x										x			x			
Belïen et al. 2006						x	x						x								x					x								x			
Belïen et al. 2007						x		x					x								x										x			x			
Brunner et al. 2009a			x				x				x						x	x					x												x		
Brunner et al. 2009b			x				x					x					x	x					x												x		
Carrasco 2010	x	x				x				x			x					x											x							x	
Carter et al. 2001	x	x								x		x			x			x				x											x				
Cohn et al. 2006					x		x						x					x										x				x					
Cohn et al. 2009					x			x					x					x										x				x					
Dexter et al. 2010						x		x					x	x									x									x					
Franz et al. 1993					x			x					x								x									x		x					
Gendreau et al. 2007			x					x				x			x							x											x				
Ovchinnikov 2008					x			x					x					x	x								x					x					
Puente et al. 2009			x							x		x			x			x				x														x	
Rousseau et al. 2002			x					x				x			x			x				x		x									x				
Sherali et al. 2002				x	x			x				x						x													x	x					
Topaloglu 2006				x	x			x				x				x						x															x
Topaloglu 2008				x	x			x				x				x		x							x												x
White 2003	x	x		x	x					x	x							x													x		x				

Table 3.1: Case study database

4 LITERATURE REVIEW OF RELATED PAPERS

To be able to categorize personnel scheduling for hospital doctors, some relevant focus areas are defined. The proposed literature review is structured using descriptive fields. Each field analyzes the cases from a descriptive perspective, which may be either problem or technically oriented. It is distinguished between three fields:

- Categorization
- Research approaches
- Decision delineation

4.1 Categorization

This categorization section is distinguished between five categories, which will be further clarified and referred to in the consecutive sections. The five categorize are:

- Level of experience
- Planning period
- Field of specialty
- Shift type
- Cyclic versus acyclic schedules

4.1.1 Level of experience

Forst, level of experience is dividing between two main levels of experience for the hospital doctors, namely on physicians and residents. These two levels are further divided into two sublevels – senior and junior. Some papers do not distinguish between the two seniority levels.

	Physicians	**Residents**
Junior	(Beaulieu et al., 2000; Carrasco, 2010; Carter & Lapierre, 2001; Gendreau et al., 2006; Rousseau, Gendreau, & Pesant, 2002; White & White, 2003)	(Sherali, Ramahi, & Saifee, 2002; Topaloglu, 2006, 2008; White & White, 2003)
Seniority	(Beaulieu et al., 2000; Carrasco, 2010; Carter & Lapierre, 2001; Gendreau et al., 2006; White & White, 2003)	(Belïen, 2006; Cohn et al., 2006; Cohn, Root, Kymissis, Esses, & Westmoreland, 2009; Franz & Miller, 1993; Ovchinnikov & Milner, 2008; Sherali et al., 2002; Topaloglu, 2006, 2008; White & White, 2003)
No differentiation	(Brunner et al., 2009a; Brunner, Bard, & Kolisch, 2009b; Puente, Gómez, Fernández, & Priore, 2009; Rousseau et al., 2002)	(Belïen & Demeulemeester, 2005, 2007; Carrasco, 2010; Dexter, Wachtel, Epstein, Ledolter, & Todd, 2010)

Table 4.1: Level of experience

In a hospital, another third level of experience might exist – medical students in practice during their studies. Only one paper had a focus on medical students, White & White (2003) have focus on medical students, as well as on both physicians and residents. They work with all levels of experience as units for gaining experience for the residents and students, and have also made a classification of the level of experience:

- Experienced doctors: seniors, physicians, radiologist, doctors
- Newer doctors: juniors, interns, trainees, residents, graduates
- Medical students: students

Within the group of physicians, these levels concern more or less than three/ five years of experience after the physicians are fully licensed. Beaulieu et al. (2000) have made schedules for approximately 20 physicians, 15 of them full-time physicians, where five are junior physicians with less than three years of experience after they got fully licensed.

Gendreau et al. (2006) highlights this problem of scheduling physicians in emergency rooms (ER). In this paper, no differentiation exists between the seniority of physicians, other than to mention seniority as a factor for availability. Instead, they focus more on full-time and part-time physicians. A normal full-time physician in an emergency department in Canada is scheduled twenty-eight hours per week, whereas a part-time physician is scheduled between eight and sixteen hours per week. Carter & Lapierre (2001) have studied six different ERs, where the number of physicians varies widely from three to sixteen full-time physicians and up to seventeen part-time physicians. In the different emergency departments, seniority of the physicians is treated differently. In some ERs the senior physicians work fewer night shifts than junior physicians. Carrasco (2010) has developed schedules for 20 – 30 employees of different seniority levels. The differentiation is made between junior and senior physicians, but not for the seniority level of the residents. Depending on the category an individual belongs to, the tasks he or she can perform are determined. Senior physicians can only be assigned to supervision tasks, whereas a resident cannot be scheduled for these tasks.

Brunner et al. (2009a) do not differentiate between seniority; but initiate their paper by telling that a strong hierarchy makes it difficult to implement new procedures to their hospital department, because someone in authority is always at disadvantage in the process. The paper divides between full-time and part-time anesthetists in their model, but they only use full-time anesthetists with the same qualification skills to make it simpler to model. In the other paper from Brunner et al. (2009b), they are working further with the same problem and either the seniority level neither is nor mentioned. In the former paper, they have calculated how many anesthetists are needed to avoid use of outsiders and overtime, and have found out that there must be sixteen full-time anesthetists to meet the peak demand without use of outsiders or overtime. By reducing the number to fifteen anesthetists they only need one additional outside hours. When reducing the number of full-time anesthetists to thirteen they only need four outside hours to meet the demand. In these cases, they do not need any overtime hours, and the amount of under time decrease since there are fewer regular hours available. In the latter paper, they have scheduled respectively fifteen and eighteen anesthetist using different methods to solve the problem. Rousseau et al. (2002) have studied two cases of PRP to make a general approach to this problem. The first case study is about an ER involving twenty-three physicians and the second case study concerns fifteen physicians in a geriatric department. The differentiation between levels of seniority may and may not be of importance depending on the context, and they do not differentiate between seniority in this paper. Puente et al. (2009) do not differentiate between seniority levels of the physicians.

The length of the resident period is normally between three to seven years in clinical settings, depending on their field of specialty and home country (Topaloglu, 2008). In this paper, residents are divided between 1st year (junior) and 2nd – 4th year (senior) residents, as it is these years that are treated in the respective papers.

Sherali et al. (2002) have divided between the seniority levels for residents, and made groups for all seniority levels, where a minimum number of each group must be present every night. Sherali et al. have scheduled between 50 – 100 1st to 3rd years residents, where the hospital has a requirement for the resident mix. Topaloglu (2006, 2008) differentiates between the seniority levels of residents. In the former paper, an apprenticeship relation between the senior and junior residents is mentioned. It is required a minimum allocation from each seniority level for each shift and a fair distribution of duties between the residents such as the supervisory resident position. In the latter paper, the residents are grouped according to their seniority level, considering that a single day spent more in a residency education can determine the resident’s seniority level. This is of importance for scheduling fair shift assignments. This paper have scheduled between 12 -40 residents from 3rd – 6th year of seniority.

Franz & Miller (1993) have assigned residents to training rotations in associated clinics. Once the assigning problem is solved, they have scheduled residents to each clinic with a midterm planning period. There are 12 2nd and 12 3rd year residents in this paper. Schedules for each resident are different because of their specific interest and educational goals as well as the department requirements. Ovchinnikov & Milner (2008) have scheduled 15 residents, and divided between the seniority levels, and specified different constraint for 1st, 2nd, 3rd and 4th year of residency. Cohn et al. (2006, 2009) have scheduled 10 - 20 psychiatric medical residents to rotations between three different hospitals. The rotations are different after their seniority level. The 2nd year residents have to participate in two 6-week block at hospital A during the planning period, and these blocks are already determined before the scheduling in this paper begins. During these periods are the 2nd year residents unavailable to be scheduled in one of the other hospitals. There is also a demand of how many shifts each resident has to be scheduled in hospital B, this hospital is scheduled with residents from the group in this paper, but also from another resident group. Hospital C is only scheduled with residents from this paper.

Dexter et al. (2010) have scheduled 30 residents without specifying their seniority level, and one of their objectives is to find out how many residents that can be scheduled to single specialties each day. Nor have Belïen & Demeulemeester (2005, 2007) made differentiations between the levels of seniority for residents.

4.1.2 Planning period

Different researchers use different definitions and length of period to describe their planning period. Planning period is in this thesis the duration time for a schedule – how long it lasts. Operational planning deals with short-term activities, generally with a one-year horizon. In this paper has short-term scheduling a planning period shorter than a month, but short-term planning period can also be for only one day when there is a need to adjust an already existing schedule. In the literature review only two papers had a short-term planning period. Short-term is often used to make adjustments for absenteeism or personnel requests. (Brunner et al., 2009a; White & White, 2003)

Planning period	**Physicians**	**Residents**
Short-term	(Brunner et al., 2009a; White & White, 2003)	(White & White, 2003)
Midterm	(Beaulieu et al., 2000; Brunner et al., 2009b; Carter & Lapierre, 2001; Gendreau et al., 2006; Puente et al., 2009; Rousseau et al., 2002)	(Sherali et al., 2002; Topaloglu, 2006, 2008)
Long-term	(Carrasco, 2010)	(Belïen, 2006; Belïen & Demeulemeester, 2005, 2007; Carrasco, 2010; Cohn et al., 2006; Cohn et al., 2009; Dexter et al., 2010; Franz & Miller, 1993; Ovchinnikov & Milner, 2008)

Table 4.2: Planning period

The majority of the papers referred to in this thesis have a midterm or tactical planning period. Midterm planning period, will in this thesis last from one month to six months. Brunner et al. (2009b) have worked further on their above mentioned paper, and have tested their method with different planning periods; first it is a two-week period, then a four-week period and ends with a six-week period. Their choice of not using a rolling period approach is stated by their desire to determine the difficulty by solving instances of fixed lengths. In this paper, the problem difficulty increases when the length of planning period increases, and the total number of supply hours was decreased, and the proportion of full timers to part timers was increased.

Beaulieu et al. (2000), Carter et al. (2001) and Gendreau et al. (2007) have developed rosters for physicians in the ER with a midterm planning period. They are also using the same type of shifts, and Carter et al. also have added on-call shifts. Rousseau et al. (2002) have tried to make a general approach to physician rostering using a midterm planning period. They have studied two cases, and tested the problem within two different contexts. Puente et al. (2009) have developed monthly schedules

for physicians in an emergency department where there are variability and unpredictability of patient demand, range of service offered, combination of shifts, types of labor contracts and different kinds of work undertaken in the department.
Sherali et al. (2002) have chosen a midterm planning period to schedule residents to work nights. They have made an acyclic schedule because of the dynamics of the departments fluctuating needs for staff, patient mix, anticipated workload, residents availabilities and the preferences of the residents. Because of different condition every moth has Topaloglu (2006; 2008) developed schedules with a midterm planning period for residents with different seniority levels. The number of residents varies each month, as well as the number of residents in each group. The number of weekday and weekend day shifts that will be assigned to a resident and on which day of week they will be scheduled depends upon the seniority rules laid down by the unit itself and on the residents' special requests.

The last planning period defined in this thesis is long-term or strategic planning period. It last from six months to one year in this context. Strategic approach is the process of identifying an organization's long-term goals and objectives, and then determining the best approach for achieving those goals and objectives. As a consequence of this, long-term planning period is often used for scheduling residents because of their on-going education.

Belïen & Demeulemeester (2005, 2007) have used a long-term planning period with three different lengths; 18, 35, and 52 periods to schedule residents. It is chosen because of the widely divergent number of activities they have to perform during a given period. By scheduling with a long-term planning period, it should not be too much alternating between the activities the residents have to perform, for avoiding a discontinuing in their education. A new activity need some time to be mastered and it is therefore important to make a good roster. For this reason, the residents must quantify their preferences for vacation and days-off before the beginning of a new resident year. Belïen 2006, Cohn et al. (2006; 2009), Franz et al. (1993), Ovchinnikov et al. (2008), Dexter et al. (2010) have chosen this planning period because of strategic planning of the residents' education. Carrasco (2010) is the only paper scheduling both physician and residents with a long-term planning period, concerning the exchange of experience.

4.1.3 Field of specialty

The cases referred to in this thesis focus on different field of specialty for the doctors. The majority of the cases have studied emergency medicine, which is a complex case to schedule. Emergency medicine doctors work under a great pressure all day long, as this hospital department is open 24 hours a day the whole year round, and must therefore be continuously staffed.

A physician trained in anesthesia and residents practicing anesthesia normally work in an operating room in connection with operations. Operating rooms are mostly open during the normal work hours, but must stay open if an operation is delayed. (Brunner et al., 2009a, 2009b; Dexter et al., 2010)

Field of specialty	**Physicians**	**Residents**
Emergency department	(Beaulieu et al., 2000; Carter & Lapierre, 2001; Gendreau et al., 2006; Puente et al., 2009; Rousseau et al., 2002)	(Topaloglu, 2006)
Anesthesia	(Brunner et al., 2009a, 2009b)	(Dexter et al., 2010)
Radiology		(Ovchinnikov & Milner, 2008)
Pulmonary unit		(Topaloglu, 2008)
Ophthalmology		(Belïen & Demeulemeester, 2005)
Family practice		(Franz & Miller, 1993)
Psychiatry		(Cohn et al., 2006; Cohn et al., 2009)
Geriatric	(Rousseau et al., 2002)	
Pediatrics	(Carrasco, 2010)	(Carrasco, 2010)
No information	(White & White, 2003)	(Belïen, 2006; Belïen & Demeulemeester, 2007; Sherali et al., 2002; White & White, 2003)

Table 4.3: Field of specialty

Ochinnikov & Milner (2008) have scheduled residents to work weekday nights in a radiology department. Certified radiologists do not work weekday nights, so the resident is in total control of the radiology service at the hospital during nights.
In the second case studied by Rousseau et al. (2002), the physicians are scheduled for a geriatric hospital department. Cohn et al. (2006, 2009) have scheduled psychiatry resident to rotate between three different hospitals. Topaloglu (2008) has scheduled residents to a pulmonary unit. Carrasco (2010) has scheduled residents and physicians in a pediatrics department.

Franz & Miller (1993) assigns residents to rotation assignments in a family practice, where the residents are trained to be general practitioners. The program seeks to provide wide exposure to the variety of experiences relevant to the non-specialists. The residents are required to participate in a set of core experiences as part of their education, and they choose a different mix of courses and rotations after where they would like to work when they are fully licensed physicians.

Not all of the related papers have specified which field of specialty they concerns, for instance, have some of the papers without any field of specialty studied rounds or rotations for residents. (White & White, 2003) Sherali et al. (2002) have either not specified the field of specialty in their case study, but they have studied three different scenarios for scheduling. Belïen & Demeulemeester (2005, 2007) schedules residents in an ophthalmology department. In their latter paper is the field of specialty not mentioned, they rather make a general approach by decomposing of the RRP on staff members and on activities instead.

4.1.4 Shift types

The wide range of hospital departments needs different types and combination of shifts to be correctly staffed.

Shift types	**Physicians**	**Residents**
Day shift		(Dexter et al., 2010)
Day, evening & night	(Beaulieu et al., 2000; Carter & Lapierre, 2001; Gendreau et al., 2006; Puente et al., 2009; Rousseau et al., 2002)	
10 h + 14 h		(Topaloglu, 2006, 2008)
Flexible	(Brunner et al., 2009a, 2009b)	
On-call	(Brunner et al., 2009a, 2009b; Carrasco, 2010; Carter & Lapierre, 2001; Puente et al., 2009; Rousseau et al., 2002; White & White, 2003)	(Carrasco, 2010; Cohn et al., 2006; Cohn et al., 2009; Ovchinnikov & Milner, 2008; Sherali et al., 2002; Topaloglu, 2008; White & White, 2003)
Other	(Beaulieu et al., 2000)	(Ovchinnikov & Milner, 2008)
No information		(Belïen, 2006; Belïen & Demeulemeester, 2005, 2007; Franz & Miller, 1993)

Table 4.4: Type of shifts

Most departments only needs to be fully staffed during the work hours, (Brunner et al., 2009a, 2009b; Dexter et al., 2010) whereas other departments, such as the emergency department needs to be staffed all day and all night. As can be seen from Table 4.5 the emergency department is staffed with day, evening & night shift, but also with on-call or follow-up shifts. (Beaulieu et al., 2000; Carter & Lapierre, 2001; Gendreau et al., 2006; Puente et al., 2009; Rousseau et al., 2002; Topaloglu, 2006)

Paper	Department	Shift type
Beaulieu et al. (2000)	ER	Day, evening & night, follow up
Carter et al. (2001)	ER	Day, evening & night, On-call
Gendreau et al. (2007)	ER	Day, evening & night
Puente et al. (2009)	ER	Day, evening & night, On-call
Rousseau et al. (2002)	ER	Day, evening & night, On-call
(Topaloglu, 2006)	ER	10 hours day & 14 hours night, On-call

Table 4.5: Overview of ER related papers and type of shifts

Departments only "open" during the day have some kind of on-call service during the off-hours. On-call shift or service is also called 24 hour duty, guard, call, etc by the different researchers. The duration of on-call shift also vary among the different researchers, by some of them it last 16 hours after a normal day shift and for others it last 24 hours.

Brunner et al. (2009a, 2009b) have used the term on-call for a 16 hour shift that follows the daytime shift during the weekdays and for a 24 hour long day shift during the weekends. During the weekdays, the anesthetist that is scheduled for the on-call shift must work an eight hour dayshift first, and not be scheduled the consecutive day. They have also developed and tested the use of flexible shifts, these shift have a flexible start and end times, as well as flexible duration time. The Figure 4.1 is an illustration of a weekly roster they have made for eight physicians, the lighter grey areas are the flexible daytime shift and the darker grey areas are on-call shifts.

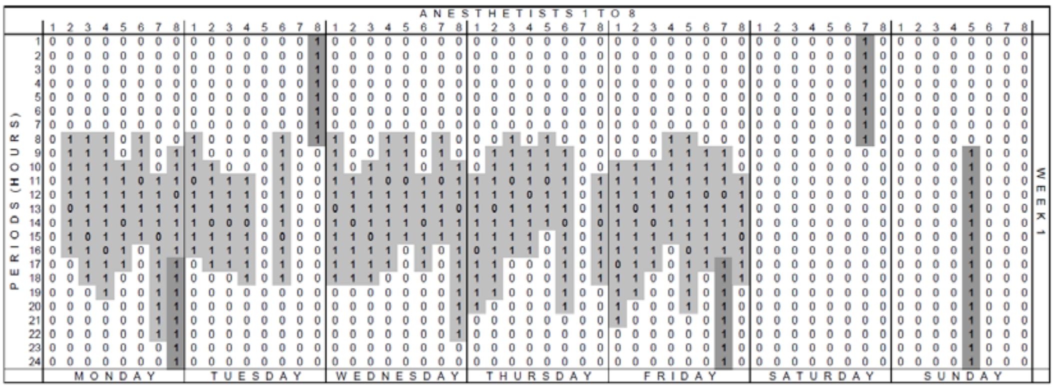

Figure 4.1: Example of a roster for eight physicians (Brunner et al., 2009a p.18)

Carrasco (2010) has scheduled physicians and residents to on-call shifts in addition to their normally work hours, in a pediatrics department. During the weekday nights there has to be one supervisor/ senior physician and one assistant/ junior physician or resident on-call. During the weekends it must be one supervisor and two assistants to cover the on-call shifts. White & White (2003) have also scheduled their teams to overnight duties, such as on-call shifts. Each individual have to work a maximum of seven on-calls during twenty-eight days, and the number of on-calls may be reduced depending on the number of vacation days taken, and the rank of the individual involved. These calls should be evenly and fair distributed among the staff.

Sherali et al. (2002) have scheduled night shifts, not specifying how long they last. This is treated as an on-call shift in this thesis, as the on-call shifts often are used when there are not explicit needs for medical aid, but when it has to be available.

Ovchinnikov & Milner (2008) have scheduled residents for working on-calls during the weekday nights and in weekends. During the weekends, residents are also scheduled for emergency rotations assignments. The responsible resident is then responsible for general radiology tasks often related to the emergency room.

Cohn et al. (2006, 2009) have scheduled on-call shifts to residents, these shifts serves two purposes; to provide additional training for the residents and staffing for the hospital. At one of the hospitals in this paper, they have both a primary call and a backup call. The three hospitals in this paper are staffed differently. One hospital is only staffed with 2nd year residents having their blocks there. A block is fixed period, when the residents have to be at this particular hospital. The second hospital is staffed with the residents from this resident program and can be staffed by outsiders or “extra on-calls” requesting a moonlight opportunity if needed. Moonlighters are people working extra in addition to their normal job, especially doing night shifts. The last hospital is staffed by residents from two different resident programs.

Puente et al. (2009) uses both day evening & night shifts during the weekdays, as well as on-call shifts to follow up the patients that are under a 24 hours observation, and in weekends and holidays.

Scheduling day, evening & night shifts can be flexible, and is mostly divided into 3 * 8 hours, but can also be divided into 2 * 7 hours + 10 hours or into 10 hours + 14 hours.

Beaulieu et al. (2000) have scheduled with a wide range of shifts. During the weekday day and evening shifts are three physicians scheduled, whereas one only works with trauma cases. During the weekend and holiday day and evening shifts are two physicians scheduled, and during the night shifts only one physician is scheduled and is in responsibility for both the ordinary and the trauma shifts. The differentiation of seniority is clear when it comes to scheduling of nights and weekend shifts, most seniors work fewer of these shifts. They have additionally scheduled a four-hour follow-up shift three days a week to take care of patients that have recently been treated in the emergency rooms.

Rousseau et al. (2002) uses day, evening & night shift in both their case studies, but in their study of the geriatric department they also have on-call shifts for weekend and holidays. Carter & Lapierre (2001) have scheduled physicians to day, evening & night shifts at two different hospital, one of the hospitals are also scheduled with on-calls. Both hospitals have a variety of different start times for each shift.

Topaloglu (2008) has searched for the optimal weekday and weekend day shift assignments for residents after their seniority level, and has schedule one senior and one junior to work weekday nights and on-calls in the weekends.

Belïen (2006) and Franz & Miller (1993) have not spcified type of shift in their papers. Nor have Belïen & Demeulemeester (2005, 2007) specified which type of shift used in their papers, in the former paper have they focus on activites to be done by the residents. In the latter papers, they have decomposed the problem on staff members and on activites.

4.1.5 Cyclic versus acyclic schedules

Cyclic techniques proceed by defining fixed sequences of shifts, which are equally assigned among the workers (Beaulieu et al., 2000). When building cyclic rosters are the personnel considered as interchangeable: the personnel then rotate on the schedule until everyone has been assigned to each schedule (Rousseau et al., 2002).

Carter & Lapierre (2001) have been studying how rostering has been done in six different ERs in Montreal. The majority of rosters are acyclic, and created from scratch each period, where there are no equally rosters for the physicians. Some of the hospitals use cyclic schedules without rotation, which is constructed such that each physician constantly repeats the same shift pattern. There is also cyclic schedule with rotations this type of roster is constructed by building a single pattern for one physician. The roster is developed such that every physician follows the same pattern, only with different start times. When reaching the end of the roster, one starts at the beginning again. This type of schedule is not optimal, since it cannot accommodate personal preferences or special requests. It takes mostly shorter time to produce a cyclic roster than an acyclic roster, but an acyclic roster tends to be of better quality as it takes more care about the needs of the personnel.

In the paper of Puente et al. (2009), monthly schedules are generated without memory of earlier schedules. They can be considered as acyclic and can lead to big differences both qualitatively and quantitatively between the physicians. Carrasco (2010) is prevented from using cyclic schedules, because of fluctuating demands. Because of the dynamism of the scheduling process, have Sherali et al. (2002) not followed a cyclically repeated roster system, but is designing it from scratch on monthly basis.

4.2 Research Approaches used within the Literature Review

This section tells about which models and methods which are used for scheduling in the different papers. From the literature review is a wide range of research methodologies revealed. Most of the hospital departments referred to in the papers are already making feasible rosters, but uses a lot of time on rostering. They want to reduce their rostering time and to optimize their rostering process to find an optimal solution. Other hospital departments have trouble finding a feasible roster without violating their constraints. The objective for these departments is to find a feasible roster without violating the constraints.

The analysis used for solving the rostering problem is firstly divided between exact and heuristic approaches and then after which type of objective function they have. In this thesis it is primarily about optimization and/ or satisfaction. A single criterion function search after an optimal solution, multicriteria functions search for any feasible solution.

Exact	
Single criterion	(Belïen, 2006; Belïen & Demeulemeester, 2005; Brunner et al., 2009a, 2009b; Cohn et al., 2006)
Multicriteria	(Beaulieu et al., 2000; Belïen & Demeulemeester, 2007; Cohn et al., 2009; Dexter et al., 2010; Franz & Miller, 1993; Gendreau et al., 2006; Ovchinnikov & Milner, 2008; Rousseau et al., 2002; Sherali et al., 2002; Topaloglu, 2006, 2008)
Heuristic	
Single criterion	
Multicriteria	(Carrasco, 2010; Carter & Lapierre, 2001; Puente et al., 2009; White & White, 2003)

Table 4.6: Type of analysis

Table 4.6 provides an overview of the ways in which scheduling problems are analyzed. Most of the problems are formulated with mathematical programming models and solved as a combinatorial optimization/ satisfaction problem. An optimization problem search for an optimal solution, whereas a satisfaction problem searches for a feasible solution.

Table 4.7 lists the various solution and evaluating techniques that are applied to the problem settings, such as mathematical programming or heuristics.

Mathematical programming	(Beaulieu et al., 2000; Cohn et al., 2006; Dexter et al., 2010; Gendreau et al., 2006; Rousseau et al., 2002; Topaloglu, 2008)
Integer linear programming	(Belïen & Demeulemeester, 2007; Dexter et al., 2010)
Linear programming	(Cohn et al., 2009; Franz & Miller, 1993)
Goal programming	(Topaloglu, 2006)
Mixed integer programming	(Brunner et al., 2009a, 2009b; Cohn et al., 2009; Sherali et al., 2002)
Dynamic programming	(Belïen & Demeulemeester, 2005)
Column generation	(Gendreau et al., 2006)
Branch-and-price	(Belïen, 2006; Belïen & Demeulemeester, 2006, 2007; Brunner et al., 2009b)
Branch-and-bound	(Beaulieu et al., 2000)
Constraint programming	(Belïen & Demeulemeester, 2007; Gendreau et al., 2006; Ovchinnikov & Milner, 2008; Rousseau et al., 2002)
Improvement heuristic	(Beaulieu et al., 2000; Brunner et al., 2009a, 2009b; Carrasco, 2010; Franz & Miller, 1993; Sherali et al., 2002)
Metaheuristic/ Local search	(Rousseau et al., 2002)
Tabu search	(Carter & Lapierre, 2001; Gendreau et al., 2006; White & White, 2003)
Genetic algorithm	(Puente et al., 2009; Rousseau et al., 2002)

Table 4.7: Solution technique

From Table 4.6 and 4.7 is it noticeable that most of the papers have used an exact approach to solve the rostering problem. The problem is often modeled as a MP model, and solved with a mix of exact and heuristic approaches.

The objective of the cases are to find a feasible solution, to find an optimal solution or to reduce the use of overtime paid out (Brunner et al., 2009a, 2009b).

Beaulieu et al. (2000) have used a mathematical programming approach to solve the rostering problem. They considered using a B&B on the problem formulation to find a solution, but dropped the approach, due to a large number of variables and constraints. They used a heuristic approach based on a partial B&B instead of a complete B&B, which requires more computational times as solution technique. The B&B process is repeated until it no longer can find any feasible schedule. This method is more efficient than making a roster by hand, because it takes care of more constraints simultaneously.

Rousseau et al. (2002) have developed a general approach to the PRP, by presenting a hybridization of a constraint programming (CP) model with a local search technique and genetic algorithms to solve the problem. And they have made a case study of two different cases. The CP model provides model flexibility, and they have formulated two generic constraints; distributions and pattern constraints. The objective is to fulfill all the hard constraints. The former case is solved with mathematical programming, and is treated as an optimization problem. The latter case is solved using a CP approach and is a satisfaction problem. To solve a satisfaction problem must the first identified solution be of good quality.

Cohn et al. (2006) have modeled the constraints and solved the model with mathematical programming. The problem was defined and redefined throughout their research process, by repeatedly modifying their original model. They solved small parts of the problems at a time instead of one single, large model, and had no clearly defined objective.

Ovchinnikov & Milner (2008) have considered whether to use a constraint-based or a weighted-objective method to solve the RRP, and decided to use the constraint method. They developed a resident-assignment spreadsheet model to solve the problem. They developed a spreadsheet as a calculator first, and then a spreadsheet as an optimizer with MS Excel. The optimization model was developed with constraint programming.
Gendreau et al. (2006) have proposed a series of generic constraints to describe the PRP. As the specific constraints in any given case study may vary widely, can it be difficult to come up with solution methods that can be used in general settings. They have not come up with a solution of the PRP, but instead discussed four different optimization techniques used for scheduling nurses and physicians: mathematical programming, column generation, tabu search and constraint programming. Every optimization technique has been related to other relevant papers.

Topaloglu (2008) has modeled the problem as a mathematical programming model, and tried to solve it using sequential and weighted methods. The weighted method found an integer feasible solution for all the test problems. When the number of residents increased to 30, 35 and 40, the weighted method could not solve every problem within the iteration. The same problems are solved to optimality when scheduling two senior and junior residents. The sequential method did not achieve optimality for nine problems, and for the remaining 12 problem, it could not find any feasibly solution. The sequential method solved only those problems optimally that had a maximum of 15 residents to be scheduled. The model could not generate solution preemptively, when the staff size was less than 15 residents. Both weighted and sequential methods produced schedules of the same quality. The model was tested using both the sequential and weighted solution approaches, as well as the rosters were prepared manually. The rosters generated by the model were considered better than the handmade ones, while the constraints and the objectives were better satisfied. The hospital department started using this model by the end of the test/ scheduling period, because it satisfied the residents better.

Belïen & Demeulemeester (2005) are scheduling residents using a branch-and-price (B&P) approach. The problem is formulated as an integer program (IP) and as an alternative also with a B&P algorithm, which has been used for decomposing of the problem on the activities. The B&P algorithm starts with a heuristic in order to find an initial solution, and is solved with a dynamic programming (DP) approach. They have also used different speed-up techniques to reduce the computation time of the two models. The B&P algorithm outperforms the ILP optimizer used on the old formulation.

Brunner et al. (2009a) have formulated the PRP as a mixed integer programming (MIP) model and solved it with CPLEX. They have used a heuristic decomposition strategy that divides the two-week main problem into one-week subproblems. The computational results indicates that the strategy works well and the one-week subproblems are easy to solve with CPLEX, but when the two-weeks decomposition is employed the corresponding subproblems require too much computational effort to be solved to optimality. In their second paper, Brunner et al. (2009b) also have used the MIP to formulate the problem and they have developed a B&P algorithm that uses two different branching strategies to solve it. First they branch on the master problem variables and then they branch on the subproblem variables to generate new rosters. The essence of the algorithm they have developed is the decomposition of the original MIP into a set covering-type master problem and a series of physician-based subproblems to generate promising rosters in the form of columns. A heuristic decomposition strategy is also used in this paper, which is divided with three different planning periods. First are they scheduling 18 full-time and part-time physicians for a two-week planning period without using overtime, then they are scheduling with four- and six-week planning periods. They uses both branching strategies and both strategies perform equally well on the two- and four-week problems, but when the schedule the six-week problem is it more efficient to use the subproblem as a decomposition strategy. The problem difficulty increased when the length of planning period was increased, the total number of supply hours was decreased and the ratio of full-time to part-time was increased. For all the two-week instances was verifiable optima obtained, but for the six-week instances the B&P algorithm failed to find the optimum in half the cases. The length of planning period affects the algorithm, both the initialization heuristic and the complexity of the subproblems. The branching schemes both performed equally well in finding optimal or high quality solutions and neither dominated the other.

Franz & Miller (1993) have modeled the problem with a linear programming (LP) model, and solved it using rounding heuristics until they have found an integer solution. They have designed a decision support system to facilitate the decision process. This system is built around a LP model with an objective function comprised of priority weights associated with particularly desirable assignments. All system requirements are formulated as constraints, and any possible solution is feasible. Good feasible solutions incorporate the desirable assignments specified in the objective function.

Sherali et al. (2002) have used a MIP model to solve the RRP and heuristic solution procedures are developed for three different scenarios in their article. The scenarios are solved via the CPLEX-MIP and with heuristic approaches.

Belïen & Demeulemeester (2007) decomposes the problem on both staff and activities by using column generation (CG). Decomposition of the scheduling problems means to divide it into subproblems. They start with scheduling of activities that must be performed and which require special skills, and then they schedules easier activities without requirements for specific skills. The researchers have therefore focus on difficult activities in this paper. When decomposition on activities, they have made an activity pattern where all the residents having to perform an activity are scheduled. When using column generation on this problem, each activity will be represented by its own column.

Period	Activity schedule			
	Trainee 1	Trainee 2	Trainee 3	Trainee 4
1		act 1		
2		act 1		
3		act 1		
4			act 1	
5			act 1	
6			act 1	
7				act 1
8				act 1
9	act 1			
10	act 1			

Figure 4.2: A column for activity (Belïen & Demeulemeester, 2007 p. 148)

When decomposition on the staff will the schedule for each resident is represented by its own column. The researchers have also compared the two decomposition approaches to each other, searching for an optimal solution.

Period	Activity schedule			
	Trainee 1	Trainee 2	Trainee 3	Trainee 4
1		act 1		
2		act 1		
3		act 1		
4				
5		act 3		
6		act 3		
7		act 3		
8				
9		act 2		
10		act 2		

Figure 4.3: A column for trainee 2 (Belïen & Demeulemeester, 2007 p. 150)

Both the decomposition strategies have been solved using a B&P approach. Both real-life problems have indicated that a decomposition approach outperforms standard IP for solving these kinds of problems. The researchers have also composed a test set to make conclusion about it. The computation time tend to be higher when decomposition on residents than decomposition on activities. And the number of residents that have to perform each activity is an important factor for the difficulty of the problem. The computational tests revealed that decomposition on the activities clearly outperforms decomposition on the staff members, since most staff scheduling problems has more constraints. Activity-based decomposition is appropriate to use if each combination of activity schedules automatically satisfies all the individual staff member constraints.

Cohn et al. (2009) have used an IP formulation to model the RRP, and solved it by formulating a mixed integer feasibility problem that captures all the hard constraints of the system. The researchers worked closely with the chief resident, and adjusted and improved the model and the value of the constraints during the period this was beneficial for the model. The feedback from the residents was good as their preferences for vacation vast granted.

Dexter et al. (2010) have modeled the problem as a MP model and solved it using ILP. Their problem is a multi-objective problem, where they shall maximize the number of residents who can be scheduled to each activity every day and assign them to those cases. Another objective is to create hybrid rotations of two specialties and therefore increase the number of residents to be scheduled.

Some of the papers have studied more cases, or embedded units. For example, have Carter & Lapierre (2001) studied the scheduling process for physicians in six different hospitals, but comes with a solution for how they can do it more efficiently in two of these hospitals. The problem is formulated and solved with tabu search. They have search to find a general solution procedure.

Topaloglu (2006) use a goal programming (GP) model for scheduling residents in an emergency room. The objective is to reduce violation of constraints and to reduce the time actually used for making this schedule manually. The manually made roster is of poor quality, since it cannot handle all the constraints simultaneously. The propose model is capable to generating high-quality rosters with all its constraints. Comparing these two models, shows that the goal programming model satisfies the soft constraints better.

Carrasco (2010) starts with defining all the constraints, both hard and soft. Then a possible solution of the problem is solved by combining random and greedy strategies with heuristics. The greedy algorithm is used to provide reasonably solutions.

White & White (2003) have used tabu search to perform a heuristic optimization to solve the problem. Their initial roster first schedules the weekends and then the rest of the week and vacation requests. After a feasible roster is developed, they use a multiphase tabu search to optimize their roster. After an optimal roster is found, a post-optimization process may be used for adjusting the roster if needed, for instance, when the staff is unavailable. This method was not good enough to be used by the hospital it was developed for, since the initial schedule was not greatly enough improved. Tabu optimization alone, cannot find regions of great improvement if the initial region is not fairly good. They have concluded that the initial solution has a great influence on the final solution, and the definition of neighborhoods must be quite good to lead to improved solutions.

The objective function for Puente et al. (2009) is to make optimal use of the physicians, concerning shift types, holidays, hard and soft constraints. After defining both hard and soft constraints, a heuristic-schedule builder is designed to satisfy all the hard constraints. The initial population of feasible solution is produced, and then they use genetic algorithms to obtain feasible rosters individually.

4.3 Other scheduling decision variables

A variety of scheduling decision is studied in these cases. Table 4.8 provides an overview of types of some other decision variables found in the cases. The cases are also divided in after level of experience.

	Physicians	**Residents**
Lines-of-work	(Brunner et al., 2009a, 2009b)	
Vacation	(Carter & Lapierre, 2001)	(Cohn et al., 2006; Cohn et al., 2009; Franz & Miller, 1993)
Holiday	(Carter & Lapierre, 2001; Puente et al., 2009)	(Ovchinnikov & Milner, 2008)
Rotations		(Dexter et al., 2010; Franz & Miller, 1993)
Team	(Carrasco, 2010; White & White, 2003)	(Carrasco, 2010; Sherali et al., 2002; Topaloglu, 2006, 2008; White & White, 2003)
Work rotations	(Carter & Lapierre, 2001)	

Table 4.8: Type and level of decision variables

Brunner et al. (2009a, 2009b) have constructed lines-of-work for physicians, considering regular hours, overtime, and individual arrangement between the hospital and the physicians. Lines-of-work depends on building of blocks such as a shift, and assign it to a physician's work day. When constructing lines-of-work one has to abide constraints concerning rest days constraints following night shifts and/ or sequences of consecutive shifts. (Ernst et al., 2004)

Under teams there are two types of teams mentioned in the papers; firstly there are teams consisting of individuals with different levels of experience, and secondly also teams in a broad sense. That is, pairing people but with different persons every time (Carrasco, 2010). Within these teams there are also different roles such as a supervisor, which only a senior physician can have. Teams are chosen for experience exchange. Rotations for residents are also a way of experience exchange. Topaloglu (2006, 2008) schedules teams consisting of residents with different seniority levels, consisting of a maximum number of team members of each seniority group.

Carter & Lapierre (2001) have different scheduling rules for scheduling holidays and vacation, in some of the hospitals they have studied are days-off during the holiday season distributed so that the physicians either work on Christmas or New Year's Eve. And in other hospitals are vacation request given after a rotating priority, while some distribute the vacations directly or leave it up to the individuals.

Scheduling vacations and holidays is specifically treated in some papers. Cohn et al. (2006, 2009) are studying vacation scheduling within both cyclic and acyclic rosters.

Puente et al. (2009) are scheduling holidays using on-call shifts, whereas Ovchinnikov & Milner (2008) are scheduling residents according to the constraints after their seniority level. Franz & Miller (1993) are scheduling resident vacations in relation to their rotations during the planning period.

Work rotation is another decision variable treated in the papers. Work rotation must be handled in hospital departments which are open every day but also in those departments using on-call shifts. A standard work rotation for normal workdays is five days on and two days off. Carter & Lapierre (2001) have handled this problem. A normal work week for a full-time physician is 3.5 eight-hour shifts per week is average, and a part-time physician works between 1 and 2.25 eight-hour shifts per week. And the typical work pattern for a full-time physician might be three days on and three days off.

	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su
Sch1	12	12	12			17	17			0	0				7	7	7			12	12
Sch2			16	16	16				7	7			17	17			0	0			
Sch3	7	7	7			12	12			16	16	16			0	0				7	7
Sch4			17	17	17			0	0				8	8	8			12	12		
Sch5	16	16			0	0	0				8	8			12	12	12			17	17
Sch6			0	0				8	8	8			12	12			17	17	17		
Sch7		8	8			16	16				7	7			17	17				8	8
Sch8	8			12	12			16	16				7	7			16	16	16		
Sch9	0	0				8	8			17	17	17				8	8			16	16
Sch10				7	7			17	17			0	0	0				8	8		
Sch11	17	17				7	7	7			12	12			16	16			0	0	0
Sch12				8	8			12	12	12			16	16				7	7		

Figure 4.4: Example of a cyclic schedule with rotations (Carter & Lapierre, 2001)

When scheduling work rotations, is the preferable to schedule as many consecutive days-off as possible. Single days-off between following work days do not give the same feeling of a day-off as more consecutive days-off. The number of required days-off or after a specified shift or a sequence of shifts is defined as hard constraint that cannot be violated.

Other papers have also considered some work rotations, but not as specific as Carter & Lapierre. Residents should at most be scheduled for an on-call every third day. (Ovchinnikov & Milner, 2008; Topaloglu, 2008) In the paper of Dexter et al. (2010) are residents only scheduled if they can participate in a typical activity five days a week, a hybrid rotation is developed so the residents can rotate between different types of surgeries during the week.

5 FINDINGS

In the Introduction, the physician scheduling problem has been presented. The financial and the efficiency pressure on the daily operations of hospitals make it necessary to find good procedure to optimize these operations. The objective of this thesis is not to find an optimal solution, but to find optimal procedures to solve the physician scheduling problem. One way of finding good procedures is to study other cases done, and learn from what other researchers have dealt with. If they also have evaluated their work by explaining their successes or mistakes, or if they have suggested future studies, could be of great value for others. This thesis is a literature review of existing cases of physician scheduling. The research question to be answered in this thesis is:

How can we categorize physician scheduling at hospitals?

The categorization of physician scheduling can be done after which fields that are interesting for the potential researchers or schedulers. To find good or successfully procedures for solving this problem require knowledge of the problem and methods used for solving it. As it has been presented, the cases are divided between physicians and residents scheduling. These problems are a bit different from each other considering labor law restrictions and of the level of skills. The next category that was studied was the planning period.

What does the planning period mean for rostering of physicians and residents in hospitals?

The planning period is of interest, because of the complexity of the scheduling process. Scheduling with a short-term planning period is not that complex as scheduling with a longer planning period, because of fewer variables or personnel preferences. From Table 4.2 is it obvious that few studies have been done about short-term planning period. Within this thesis have only two papers used short-term planning period. The researchers that had chosen this planning period state it for making adjustments of absenteeism or personnel requests. The physicians and residents may want to visit a conference or seminar, or wants take a vacation impulsively, and this needs to be handled quickly.

The midterm planning period has mostly been used for scheduling physicians, and is chosen because of fluctuation of demand, variety of patients. Midterm planning period used for residents is justified of the variation of residents from month to month.

The long-term planning period has mostly been used for scheduling residents because of their on-going education. Planning or scheduling what they have to learn by participation and when they have to learn it. Most activities require basic skills from other activities, and the residents have to master different tasks before they can participate in new and more complex tasks. It is therefore vise to create a schedule with a long-term planning period, to build a rough and detailed plan over the whole year. Doing this can also make complications when, for example, a resident might get sick and cannot participate in the education during a limited period. To solve a problem like this must be done quickly, and it is necessary to make adjustments for more than this one resident that's not available.

What types of shifts and work rotations are used today for physicians and residents in hospitals?

From Table 4.4 have most of the papers used some kind of on-call shift. This type of shift has either been scheduled on its own or as a supplement with other shift types. On-call shift are 24 hour duties, mostly used when there is no acute need for a physician but when there has to be medical aid available. After on-calls, the day, evening and night shifts are widely studied.

Most of the papers in this thesis have not scheduled typically sequences of work rotations such as "five consecutive days on and two days off" or "four on, four off". The work rotation is still a topic, because of days-off requirements after some of the shift types. Work rotations are mostly defined as hard constraints in the papers, and it is wanted as many consecutive days-off that is possible.

Which methods are mostly used for rostering physicians and residents within their field of specialty?

The methods used to solve the rostering problems in this thesis are divided between exact and heuristic approaches. From Table 4.6 is it obvious that exact approaches is mostly used for analyzing of the problem. As can be seen, the problems are mostly multicriteria problems. A few papers have defined a single criterion problem, these papers search for one optimal solution to their problem.

Underneath is a table describing which methods that are used to solve the different scheduling problems found in the literature review. The *italic* initials *"GA"* are used for heuristic approaches and the other initials describes exact approaches used for modeling.

Field of specialty	**Physicians**	**Residents**
Emergency medicine	3 * MIP, *TS, GA*	GP
Anesthesia	2 * MIP	MIP
Geriatric	MIP	
Pulmonary		MIP
Ophthalmology		B&P
Radiology		MP
Pediatrics	*GS*	*GS*
Psychiatry		MP, IP
Family practice		MIP
No information	*TS*	MIP, B&P, ILP, *TS*

Table 5.1: Methods used for modeling the problems

Mathematical models may be preferred to solve the scheduling problem because most of the researchers search for a good or near optimal solution, whereas other only search for a feasible solution. As seen in Table 4.7 are the preferred solving techniques mostly within the exact approaches, but the ratio of heuristic approaches has increased. Heuristic approaches have often been used to speed up the computation time for the mathematical models. (Ovchinnikov & Milner, 2008; Topaloglu, 2008)

6 CONCLUSION AND FURTHER RECOMMENDATIONS

Good procedures for physicians scheduling can release some of the pressure on the daily operations at hospitals, further studies of the different categories exposed here could be performed. As the category system developed in this thesis, only contains information from a restricted assortment, it is still of value for generalization for further studies to be recommended.

Within the planning period; short-term period can be studied for both experience levels with benefit. The midterm planning can be studied more for the resident scheduling, whereas the long-term planning period might be studied for the physician scheduling.

For the other categories studies, the findings are not that explicit. A conclusion to be drawn from the field of specialty is difficult to discover. The first suggestion would be to study other fields than emergency medicine for physicians. As the field of specialty for residents is wider spread, a recommendation could be to study resident scheduling within emergency medicine.

Within the types of shift, a suggestion for further studies can be shift rotation, or combinations of type of shifts in the same study.

To summarize, this master thesis have demonstrated that there is many important factors to consider for physician scheduling. From this limited assortment of literatures studied here, a clear picture of this scheduling problem has been drawn. The two categories that should be further studied are short-term planning period, and of the field of specialty for both physicians and residents.

REFERENCES

Beaulieu, H., Ferland, J. A., Gendron, B., & Michelon, P. (2000). A mathematical programming approach for scheduling physicians in the emergency room. *Health Care Management Science*, 3, 193-200.

Belïen, J. (2006). *Exact and heuristic methodologies for scheduling in hospitals: problems, formulations and algorithms.* Katholieke Univesiteit Leuven, Leuven.

Belïen, J., & Demeulemeester, E. (2005). Scheduling trainees at a hospital department using a branch-and-price approach. *European Journal of Operational Research*, 175, 258-278.

Belïen, J., & Demeulemeester, E. (2006). Scheduling trainees at a hospital department using a branch-and-price approach. *European Journal of Operational Research*, 175, 258-278.

Belïen, J., & Demeulemeester, E. (2007). On the trade-off between staff-decomposed and activity-decomposed column generation for a staff scheduling problem. *Ann Oper Res*, 155, 143-166.

Brunner, J. O., Bard, J. F., & Kolisch, R. (2009a). Flexible Shift Scheduling of Physicians. *Health Care Management Science*, 12(3), 285.

Brunner, J. O., Bard, J. F., & Kolisch, R. (2009b). Midterm Scheduling of Physicians with Flexible Shifts Using Branch and Price [Elektroniske versjon]. *IIE Transactions*. Lastet.

Burke, E. K., de Causmaecker, P., Vanden Berghe, G., & van Landeghem, H. (2004). The State of the Art of Nurse Rostering. *Journal of Scheduling*, 7, 441-499.

Burke, E. K., & Kendall, G. (2006). *Search methodologies Introductory Tutorials in Optimization and Decisin Suppoert Techniques*.

Cardoen, B., Demeulemeester, E., & Belïen, J. (2009). Operating room planning and scheduling: A literature review *European Journal of Operational Research*, 201, 921-932.

Carrasco, R. C. (2010). Long-term staff scheduling with regular temporal distribution.

Carter, M. W., & Lapierre, S. D. (2001). Scheduling Emergency Room Physicians. *Health Care Management Science*, 4, 347-360.

Cheang, B., Li, H., Lim, A., & Rodrigues, B. (2003). Nurse rostering problems - a bibliographic survey. *European Journal of Operational Research*, 151, 447-460.

Chong, E. K. P., & Zak, S. H. (1996). *An introduction to optimization*.

Cohn, A., Root, S., Esses, J., Kymissis, C., & Westmoreland, N. (2006). *Using Mathematical Programming to Schedule Medical Residents*: University of Michigan, Industrial and Operations Engineering

Boston University School of Medicine.

Cohn, A., Root, S., Kymissis, C., Esses, J., & Westmoreland, N. (2009). Scheduling Medical Residents at Boston University School of Medicine. *Interfaces*, 39(No. 3), 186-195.

Cormen, T. H., Leiserson, C. E., & Rivest, R. L. (1991). *Introduction to algorithms*.

Dexter, F., Wachtel, R. E., Epstein, R. H., Ledolter, J., & Todd, M. M. (2010). *Analysis of Operating Room Allocations to Optimize Scheduling of Specialty Rotations for Anesthesia Trainees*.Upublisert manuskript, Iowa City.

EBSCOhost. (2010). *Ebsco host*. Lastet, fra www.ebscohost.com.

Ernst, A. T., Jiang, H., Krishnamoorty, M., & Sier, D. (2004). Staff scheduling and rostering: Areview of applications, methods and models. *European Journal of Operational Research*, 153, 3-27.

Franz, L. S., & Miller, J. L. (1993). Scheduling Medical Residents to Rotations: Solving the Large-Scale Multiperiod Staff Assignment Problem. *Operations Research*, 41(No. 2), 269-276.

Gendreau, M., Ferland, J., Gendron, B., Hail, N., Jaumard, B., Lapierre, S., m.fl. (2006). Physician Scheduling in Emergency Rooms. I: *PATAT 2006* (s. 53-66): Springer-Verlag Berlin Heidelberg.

Google_Scholar. (2010). *Google Scholar*. Lastet, fra http://scholar.google.com.

Hiller, F. S., & Lieberman, G. J. (2006). *Introduction to Operational Research* (Eighth Edition utg.): McGraw-Hill.

Hillier, F. S., & Lieberman, G. J. (2006). *Introduction to Operational Research* (Eighth Edition utg.): McGraw-Hill.
Hillier, F. S., & Lieberman, G. J. (2010). *Introduction to Operations Research* (9th utg.): McGraw-Hill International Edition.
Jacobsen, D. I. (2005). *Hvordan gjennomføre undersøkelser? Innføring i samfunnsvitenskapelig metode* (Vol. 2. utgave).
Maringer, D. (2005). *Portfolio Management with Heuristic Optimization*.
Mathematical_Optimization_Society. *What is mathematical optimization?* Lastet ned June 23rd 2010, fra http://www.mathprog.org/?nav=about.
Ovchinnikov, A., & Milner, J. (2008). Spreadsheet Model Helps to Assign Medical Residents at the University of Vermont's College of Medicine. *Interfaces*, 38(No. 4), 311-323.
Pinedo, M. L. (2005). *Planning and Scheduling in Manufacturing and Services*: Springer.
PubMed. (2010). *PubMed*. Lastet, fra www.pubmed.gov.
Puente, J., Gómez, A., Fernández, I., & Priore, P. (2009). Medical doctor rostering problem in a hospital emergency department by means of genetic algorithm. *Computers & industrial engineering*, 56, 1232-1242.
Rousseau, L.-M., Gendreau, M., & Pesant, G. (2002). A General Approach to the Physician Rostering Problems. *Annals of Operations Research*, 115, 193-205.
Saunders, M., Lewis, P., & Thornhill, A. (2007). *Research Methods for Business Students*.
Schniederjans, M. (1995). *Goal Programming*.
Sherali, H. D., Ramahi, M. H., & Saifee, Q. J. (2002). Hospital resident scheduling problem. *Production Planning & Controll*, 13, 220-233.
Topaloglu, S. (2006). A multi-objective programming model for scheduling emergency medicine residents. *Computers & industrial engineering*, 51, 375-388.
Topaloglu, S. (2008). A shift Scheduling Model for Employees with Different Seniority Levels and an Application in Healthcare. *European Journal of Operational Research*.
Vine, R. (2006). *Google Scholar*. Lastet, fra http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1324783/.
White, C. A., & White, G. M. (2003). *Scheduling Doctors for Clinical Training Unit Rounds Using Tabu Optimization*.
Yin, R. K. (2009). *Case Study Research Design and Methods* (4. Edition utg.).

Appendix 1: List of relevant papers

1. Beaulieu et al. 2000 - A mathematical programming approach for scheduling physicians in the emergency room
2. Belïen 2006a - Exact and heuristic methodologies for scheduling in hospitals - problems, formulations and algorithms
3. Belïen et al. 2006b - Scheduling trainees at a hospital department using a branch and price approach
4. Belïen et al. 2007 - On the trade-off between staff-decomposed and activity-decomposed column generation for staff scheduling
5. Brunner et al 2009a Flexible Shift Scheduling of Physicians
6. Brunner et al 2009b Midterm Scheduling of Physicians with Flexible Shifts Using Branch-and-Price
7. Burke et al. 2004 – The state of the art of nurse rostering
8. Cardoen et al. 2010 Operating room planning and scheduling problem A classification scheme
9. Carrasco -Long-term staff scheduling with regular temporal distribution
10. Carter et al. 2001 - Scheduling Emergency Room Physicians
11. Cheang et al. 2003 - Nurse rostering problems – a bibliographic survey
12. Cohn et al. 2006 - Using Mathematical Programming to Schedule Medical Residents
13. Cohn et al. 2009 Interfaces - Scheduling medical residents at Boston University School of Medicine
14. Dexter et al. 2010 - Analysis of Operating Room Allocations to Optimize Scheduling of Specialty Rotations for Anesthesia Trainees
15. Ernst et al. 2004a - Staff scheduling and rostering - A review of applications, methods and models
16. Franz et al. 1993 - Scheduling Medical Residents to Rotations Solving the Large-Scale Multiperiod Staff Assignment Problem
17. Gendreau et al. 2007 Physician Scheduling in Emergency Rooms
18. Ovchinnikov 2008 - Spreadsheet model helps to assign medical residents at the University of Vermont's College of Medicine
19. Puente et al. 2009 – Medical doctor rostering problem in a hospital emergency department by means of genetic algorithms

20. Rousseau et al. 2002 - A General Approach to the Physician Rostering Problem
21. Sherali et al. 2002 - Hospital resident scheduling problem
22. Topaloglu 2008 - A shift scheduling model for employees with different seniority levels and an application in healthcare
23. Topaloglu 2006 - A multi-objective programming model for scheduling emergency medicine residents
24. White 2003 - Scheduling Doctors for Clinical Training Unit Rounds Using Tabu Optimization

APPENDIX 2: KEY INFORMATION OF THE RELEVANT LITERATURE

Author(s):	Huguette Beaulieu, Jacques A. Ferland, Bernard Gendron and Philippe Michelon
Title:	A mathematical programming approach for scheduling physicians in emergency room
Published:	Health Care Management Science 3 (2000) 193-200
Abstract:	

Preparing a schedule for physicians in the emergency room is a complex task, which requires taking into account a large number of (often conflicting) rules, related to various aspects: limits on the number of consecutive shifts or weekly hours, special rules for night shifts and weekends, seniority rules, vacation periods, individual preferences, In this paper, we present a mathematical programming approach to facilitate this task. The approach models the situation in a major hospital of the Montréal region (approximately 20 physicians are members of the working staff). We show that the approach can significantly reduce the time and the effort required to construct a six-month schedule. A human expert, member of the working staff, typically requires a whole dedicated week to perform this task, with the help of a spreadsheet. With our approach, a schedule can be completed in less than one day. Our approach also generates better schedules than those produced by the expert, because it can take into account simultaneously more rules than any human expert can do.

Author(s):	*Jeroen Beliën*
Title:	Exact and heuristic methodologies for scheduling in hospitals: problems, formulations and algorithms
Published:	PhD Thesis, Springer-Verlag 2006
Abstract:	

This text summarizes the PhD thesis defended by the author in January 2006 under the supervision of Professor Erik Demeulemeester at the Katholieke Universiteit Leuven. The thesis is written in English and is available from the author's website (http://www.econ.kuleuven.be/jeroen.belien). In this research we propose a number of exact and heuristic algorithms for various scheduling problems encountered in hospitals. The emphasis lies on the design of new methodologies as well as on the applicability of the algorithms in real-life

Environments. The main contributions include a new decomposition approach for a particular class of staff scheduling problems, an extensive study of master surgery scheduling algorithms that aim at leveling the resultant bed occupancy and an innovative method for integrating nurse and surgery scheduling.

Author(s):	*Jeroen Belïen and Erik Demeulemeester*
Title:	Scheduling trainees at a hospital department using a branch-and-price approach
Published:	European Journal of Operational Research 175 (2006) 258–278
Abstract:	
Scheduling trainees (graduate students) is a complicated problem that has to be solved frequently in many hospital departments. We will describe a trainee-scheduling problem encountered in practice (at the ophthalmology department of the university hospital Gasthuisberg, Leuven). In this problem, a department has a number of trainees at its disposal, which assist specialists in their activities (surgery, consultation, etc.). For each trainee one has to schedule the activities in which (s)he will assist during a certain time horizon, usually one year. Typically, this kind of scheduling problem is characterized by four types of constraints: work covering constraints, formation requirements, non-availability constraints and setup restrictions. In this paper, we will describe an exact branch-and-price method to solve the problem to optimality.	

Author(s):	*Jeroen Belïen and Erik Demeulemeester*
Title:	On the trade-off between staff-decomposed and activity-decomposed column generation for staff scheduling problem
Published:	
Abstract:	
In this paper a comparison is made between two decomposition techniques to solve a staff scheduling problem with column generation. In the first approach, decomposition takes place on the staff members, whereas in the second approach decomposition takes place on the activities that have to be performed by the staff members. The resulting master LP is respectively a set partitioning problem and a capacitated multi-commodity flow problem. Both approaches have been implemented in a branch-and-price algorithm. We show a trade-off between modeling power and computation times of both techniques.	

Author(s):	*Jens O. Brunner, Jonathan F. Bard and Rainer Kolisch*
Title:	Flexible Shift Scheduling of Physicians
Published:	Health Care Management Science 12 (2009)
Abstract:	
This research addresses a shift scheduling problem in which physicians at a German university hospital are assigned to demand periods over a planning horizon that can extend up to several weeks. When performing the scheduling it is necessary to take into account a variety of legal and institutional constraints that are imposed by a	

national labor agreement, which governs all physicians in German university hospitals. Currently, most medical departments develop their staff schedules manually at great cost and time.
To solve the problem, a new modeling approach is developed that requires shifts to be generated implicitly. Rather than beginning with a predetermined number of shift types and start times, shifts are allowed to start at every pre-defined period in the planning horizon and extend up to 13 hours with an hour-long break included. The objective is to find an assignment such that the total hours that have to be paid out as overtime are minimal under the restrictions given by the labor agreement. The problem is formulated as a mixed-integer program and solved with CPLEX. During the solution process individual lines-of-work are constructed for each physician. Using data from an anesthesia department in a German hospital, computational results indicate that high quality schedules can be obtained much more quickly than by current practice.

Author(s):	*Jens O. Brunner, Jonathan F. Bard and Rainer Kolisch*
Title:	Midterm Scheduling of Physicians with Flexible Shifts Using Branch and Price
Published:	Journal: IIE Transactions March 2010
Abstract:	

We present a new methodology to solve the flexible shift scheduling problem of physicians when hospital administrators can exploit flexible start times, variable shift lengths, and overtime to cover demand. The objective is to minimize the total assignment cost subject to individual contracts and prevailing labor regulations. A wide range of legal restrictions, facility-specific staffing policies, individual preferences, and on-call requirements throughout the week are considered. The resulting model constructs shifts implicitly rather than starting with a predefined set of several shift types. To find high quality rosters, we develop a branch-and-price (B&P) algorithm that uses two different branching strategies and generates new rosters as needed. The first strategy centers on the master problem variables while the second is based on the subproblem variables. Using data provided by an anesthesia department of an 1100-bed hospital as well as an extensive set of randomly generated test instances for 15 and 18 physicians, computational results demonstrate the efficiency of the B&P algorithm for planning horizons of up to 6 weeks.

Author(s):	Edmund K. Burke, Patrick De Causmaecker, Greet Vanden Berghe and Hendrik Van Landegheim
Title:	The state of the art of nurse rostering
Published:	Journal of Scheduling 7: 441-499, 2004
Abstract:	

Nurse rostering is a complex scheduling problem that affects hospital personnel on a daily basis all over the world. The need for quality software solutions is acute for a number of reasons. In particular, it is very important to efficiently utilize time and effort, to evenly balance the workload among people and to attempt to satisfy personnel preferences. A high quality roster can lead to a more contented and thus more effective workforce.

In this review, we discuss nurse rostering within the global personnel scheduling problem in healthcare. We begin by briefly discussing the review and overview papers that have appeared in the literature and by noting the role that nurse rostering plays within the wider context of longer term hospital personnel planning. The main body of the paper describes and critically evaluates solution approaches which span the interdisciplinary spectrum from operations research techniques to artificial intelligence methods. We conclude by drawing on the strengths and weaknesses of the literature to outline the key issues that need addressing in future nurse rostering research.

Author(s):	Brecht Cardoen, Erik Demeulemeester and Jeroen Belïen
Title:	Operating room planning and scheduling problems: A classification scheme
Published:	
Abstract:	

The increasing interest in the domain of operating room planning and scheduling leads to a proliferation of problem types. The statement and the scope of the particular problems, however, are often unclear. In this paper, we report on a scheme to classify operating room planning and scheduling problems using multiple fields. Each field describes a specific set of characteristics of the particular problem by means of parameters, elements and optional further specifications. We also elaborate on the use of delimiters to separate the entries in the classification notation. Next to the formulation of the scheme, we examine its applicability on a range of problems that are encountered in recent literature. With the development of the classification scheme, we hope to structure and to clarify forthcoming research in this domain.

Author(s):	Rafael C. Carraco
Title:	Long-term staff scheduling with regular temporal distribution
Published:	Computer methods and programs in biomedicine (2010) (Article in press)
Abstract:	

Although optimal staff scheduling often requires elaborate computational methods, those cases which are not highly constrained can be efficiently solved using simpler approaches. This paper describes how a simple procedure, combining random and greedy strategies with heuristics, has been successfully applied in a Spanish hospital to assign guard shifts to the physicians in a department. In this case, the employees prefer that their guard duties are regularly distributed in time. The workload distribution must also satisfy some constraints:
In particular, the distribution of duties among the staff must be uniform when a number of tasks and shift types (including some unfrequent and aperiodic types, such as those scheduled during long weekends) are considered. Furthermore, the composition of teams should be varied, in the sense that no particular pairing should dominate the assignments. The procedure proposed is able to find suitable solutions when the number of employees available for every task is not small compared to the number required at every shift. The software is distributed under the terms of the GNU General Public License.

Author(s):	*Michael W. Carter and Sophie D. Lapierre*
Title:	Scheduling Emergency Room Physicians
Published:	Health Care Management Science 4, 347–360, 2001
Abstract:	

This paper introduces the problem of scheduling emergency room physicians. We interviewed physicians from six hospitals in the greater Montreal, Canada area, in order to understand the emergency room scheduling problem. Extracting the real scheduling problem is difficult because physician working conditions are based on informal mutual cooperation which is usually not documented. We present the characteristics of the scheduling problem and the scheduling techniques currently used in the six emergency rooms we analyzed. Using the scheduling problems of Charles-Lemoyne Hospital and the Jewish General Hospital, we show how to modify a hospital's existing scheduling rules to develop techniques which produce better schedules and reduce the time needed to build them.

Author(s):	B. Cheang, H. Li, A. Lim and B. Rodrigues
Title:	Nurse rostering problems – a bibliographic survey
Published:	European Journal of Operational Research 151 (2003) 447-460
Abstract:	
Hospitals need to repeatedly produce duty rosters for its nursing staff. The good scheduling of nurses has impact on the quality of health care, the recruitment of nurses, the development of budgets and other nursing functions. The nurse rostering problem (NRP) has been the subject of much study. This paper presents a brief overview, in the form of a bibliographic survey, of the many models and methodologies available to solve the NRP.	

Author(s):	Amy Cohn, Sarah Root, Justin Esses, Carisa Kymissis and Niesha Westmoreland
Title:	Using Mathematical Programming to Schedule Medical Residents
Published:	Technical Report 06-06, Boston School of Medicine
Abstract:	
This paper presents our experience in using mathematical programming techniques to develop an on-call schedule for medical residents. We present models, solution techniques, and computational results from a real-world problem at Boston University School of Medicine. In addition, we discuss key challenges encountered in this project and how they shaped the research process. We focus primarily on two issues: 1) the critical nature of collaboration between the operations researchers and the healthcare practitioners throughout the research process, not just in the initial stages of problem definition; and 2) the difficulties encountered in defining a quantifiable objective function. We believe that both of these issues appear in many other healthcare applications of operations research as well.	

Author(s):	Amy Cohn, Sarah Root, Justin Esses, Carisa Kymissis and Niesha Westmoreland
Title:	Scheduling Medical Residents at Boston University School of Medicine
Published:	Interfaces Vol. 39, No 3 May-June 2009, pp. 186-195
Abstract:	
The chief residents in the psychiatry program at Boston University School of Medicine (BUSM) must construct a schedule that simultaneously assigns residents to five types of call shifts, spanning three different hospitals, over a 365-day planning horizon. We show how user expertise and heuristic approaches alone fail to find acceptable solutions to this complex combinatorial problem; likewise, mathematical	

programming techniques alone are inadequate, largely because they lack a clearly definable objective function. However, by combining both approaches, we were able to find high-quality solutions in a very short time. The resulting schedule, which BUSM uses currently, has yielded substantial benefits; the solution quality has improved, and the effort required to develop the solution has been reduced.

Author(s):	Franklin Dexter, Ruth E. Wachtel, Ricard H. Epstein, Johannes Ledolter and Michael M. Todd
Title:	Analysis of Operating Room Allocations to Optimize Scheduling Specialty Rotations for Anesthesia Trainees
Published:	International Anesthesia Research Society, August 2010, Vol. 111, No. 2
Abstract:	

INTRODUCTION: Because specialty workloads and corresponding operating room (OR) allocations vary among days of the week, anesthesia residents and student nurse anesthetists are sometimes assigned to cases off rotation (e.g., scheduled for cardiac surgery but assigned to urology for the day). We describe a method to create hybrid rotations of two specialties (e.g., cardiac and vascular surgery), thereby reducing the numbers of days that trainees are “pulled” from their scheduled rotations.

METHODS: Raw data were the number of hours of OR time used by each surgical specialty on each workday for the preceding 9 months. These OR workloads were converted to the number of ORs to be allocated to each specialty for each day of the week on the basis of maximization of the efficiency of use of OR time. We considered all potential hybrid rotations of pair wise combinations of specialties to which trainees could be assigned. Integer linear programming was used to calculate the maximum number of trainees who could be scheduled to hybrid rotations and receive daily assignments matching those rotations.

RESULTS: Validity of the results was shown by using data from a small facility for which the optimal solution could be discerned by inspection. Validity (appropriateness) of the constraints was demonstrated by the exclusion of each constraint, resulting in answers that are obviously incorrect. Novelty and usefulness of the method was evidenced by its choosing from among hundreds of thousands of potential combinations of specialties and its identifying appropriate assignments that were substantively different from current rotations.

CONCLUSIONS: We developed a methodology to determine rotations consisting of combinations of specialties to be paired for purposes of trainee scheduling to

reduce the incidence of daily assignments off rotation. Practically, with this method, anesthesia residents and student nurse anesthetists can be assigned cases within their scheduled rotations as often as possible.

Author(s):	A.T. Ernst, H. Jiang, M. Krishnamoorty and D. Sier
Title:	Staff scheduling and rostering: A review of applications, methods and models
Published:	European Journal of Operational Research 153 (2004) 3 -27
Abstract:	
This paper presents a review of staff scheduling and rostering, an area that has become increasingly important as business becomes more service oriented and cost conscious in a global environment. Optimized staff schedules can provide enormous benefits, but require carefully implemented decision support systems if an organization is to meet customer demands in a cost effective manner while satisfying requirements such as flexible workplace agreements, shift equity, staff preferences, and part-time work. In addition, each industry sector has its own set of issues and must be viewed in its own right. There are many computer software packages for staff scheduling, ranging from spreadsheet implementations of manual processes through to mathematical models using efficient optimal or heuristic algorithms. We do not review software packages in this paper. Rather, we review rostering problems in specific application areas, and the models and algorithms that have been reported in the literature for their solution. We also survey commonly used methods for solving rostering problems.	

Author(s):	Lori S. Franz and Janis L. Miller
Title:	Scheduling Medical Residents to Rotations: Solving Large-Scale Multiperiod Staff Assignment Problem
Published:	Operation Research, Vol. 41, No. 2 (Mar. – Apr., 1993), pp. 269-279
Abstract:	
The resident scheduling problem is a specific case of the multiperiod staff assignment problem where individuals are assigned to a variety of tasks over multiple time periods. As in many staffing and training situations, numerous limitations and requirements may be placed on those assignments. This paper presents a procedure for addressing two major problems inherent in the determination of a solution to this type of problem: infeasibilities that naturally occur in the scheduling environment but are obscured by complexity; and the intractable nature of large-scale models with this structure. The procedure developed describes a systematic approach that allows decision makers to resolve	

systeminherent infeasibilities, and a heuristic based on rounding to develop good feasible solutions to the model. The procedure is illustrated via a case example of resident assignments for teaching and training modules in a university affiliated teaching hospital.

Author(s):	Michel Gendreau, Jacques Ferland, Bernard Gendron, Noureddine Hail, Brigitte Jaumard, Sophie Lapierre, Gilles Pesant and Patrick Soriano
Title:	Physician Scheduling in Emergency Rooms
Published:	PATAT 2006, LNCS 3867, pp. 53-66
Abstract:	
We discuss the problem of constructing physician schedules in emergency rooms. Starting from practical instances encountered in five different hospitals of the Montreal (Canada) area, we first propose generic forms for the constraints encountered in this context. We then review several possible solution techniques that can be applied to physician scheduling problems, namely tabu search, column generation, mathematical programming and constraint programming, and examine their suitability for application depending on the specifics of the situation at hand. We conclude by discussing the problems encountered when trying to perform computational comparisons of solution techniques on the basis of implementations in different practical settings.	

Author(s):	Anton Ovchinnikov and Joseph Milner
Title:	Spreadsheet Model Helps to Assign Medical Residents at the University of Vermont's College of Medicine
Published:	Interfaces Vol. 38, No. 4, July-August 2008, pp. 311-323
Abstract:	
This paper describes a spreadsheet model that MBA students enrolled in an MS course constructed to replace the manual method of assigning medical residents in radiology to on-call and emergency rotations at the University of Vermont's College of Medicine. Although it contains more than 10,000 variables, the model was easy to build and solve by practitioners who are "lightly educated" in OR/MS. Based on this group's work, we discuss an approach that end-user practitioners can take to create spreadsheet optimization models. We also provide several observations and argue that spreadsheet models can provide an alternative scheduling method for problems of a smaller scope. Despite the major advances in personnel-scheduling methodologies and software, manual scheduling is still the predominant method used for such smaller-scope problems.	

Author(s):	Louis-Martin Rousseau, Michel Gendreau and Gilles Pesant
Title:	A General Approach to Physician Rostering Problems
Published:	Annals of Operation Research 115, 193-205, 2002
Abstract:	

This paper presents a hybridization of a Constraint Programming (CP) model and search techniques with Local Search (LS) and some ideas borrowed from Genetic Algorithms (GA). The context is the physician rostering problem, whose instances can vary greatly and for which almost no general tool has been developed. It is hoped that the combination of the three techniques will lead to an algorithm that has sufficient flexibility to solve most instances with a small amount of customization. To achieve this goal we also introduce Generic constraints: these constraints are used to model several types of ergonomic constraints that are found amongst physician rostering problems.

Author(s):	Hanif D. Sherali, Muhannad H. Ramahi and Quaid J. Saifee
Title:	Hospital resident scheduling problem
Published:	Production Planning & Control, 2002, Vol. 13, No. 2, 220-233
Abstract:	

This paper addresses the resident scheduling problem (RSP) at hospitals concerned with prescribing work-nights for residents while considering departmental staffing and skill requirements as well as residents' preferences. Three scenarios that represent most situations and account for various departmental requirements and needs are described. Although similar scheduling problems are considered in the literature, no analysis exists that adequately deals with the specific nature of this problem. The problem is modeled as a mixed-integer program and heuristic solution procedures are developed for the different identified scheduling scenarios. These procedures exploit the inherent network structure of the problem which is an important feature that enhances problem solvability. For the sake of comparison, the problem is also solved exactly via the CPLEX-MIP (version 6.0) package. The contribution of this work is important since many hospitals are still utilizing manual techniques in preparing their own schedules, expending considerable effort and time and yet contending with limited scheduling flexibility.

Author(s):	Seyda Topaloglu
Title:	A multi-objective programming model for scheduling emergency medicine residents
Published:	Computers & Industrial Engineering 51 (2006) 375-388
Abstract:	
Scheduling emergency medicine residents (EMRs) is a complex task, which considers a large number of rules (often conflicting) related to various aspects such as limits on the number of consecutive work hours, number of day and night shifts that should be worked by each resident, resident staffing requirements according to seniority levels for the day and night shifts, restrictions on the number of consecutive day and night shifts assigned, vacation periods, weekend off requests, and fair distribution of responsibilities among the residents. Emergency rooms (ERs) are stressful workplaces, and in addition shift work is well-known to be more demanding than regular daytime work. For this reason, preparing schedules that suit the working rules for EMRs is especially important for reducing the negative impact on shift workers physiologically, psychologically, and socially. In this paper, we present a goal programming (GP) model that accommodates both hard and soft constraints for a monthly planning horizon. The hard constraints should be adhered to strictly, whereas the soft constraints can be violated when necessary. The relative importance values of the soft constraints have been computed by the analytical hierarchy process (AHP), which are used as coefficients of the deviations from the soft constraints in the objective function. The model has been tested in the ER of a major local university hospital. The main conclusions of the study are that problems of realistic size can be solved quickly and the generated schedules have very high qualities compared to the manually prepared schedules, which require a lot of effort and time from the chief resident who is responsible for this duty.	

Author(s):	Seyda Topaloglu
Title:	A Shift Scheduling Model for Employees with Different Seniority Levels and an Application in Healthcare
Published:	European Journal of Operational Research (2008)
Abstract:	
This paper addresses the problem of scheduling medical residents that arises in different clinical settings of a hospital. The residents are grouped according to different seniority levels that are specified by the number of years spent in residency training. It is required from the residents to participate in the delivery of patient care	

services directly by working weekday and weekend day shifts in addition to their regular daytime work. A monthly shift schedule is prepared to determine the shift duties of each resident considering shift coverage requirements, seniority-based workload rules, and resident work preferences. Due to the large number of constraints often conflicting, a multi-objective programming model has been proposed to automate the schedule generation process. The model is implemented on a real case in the pulmonary unit of a local hospital for a six-month period using sequential and weighted methods. The results indicate that high quality solutions can be obtained within a few seconds compared to the manually prepared schedules expending considerable effort and time. It is also shown that the employed weighting procedure based on seniority levels performs much better compared to the preemptive method in terms of computational burden.

Author(s):	Christine A. White and George M. White
Title:	Scheduling Doctors for Clinical Training Unit Rounds Using Tabu Optimization
Published:	PATAT 2002, LNCS 2740, pp. 120-128, 2003
Abstract:	
Hospitals must be staffed 24 hours a day, seven days a week by teams of doctors having certain combinations of skills. The construction of schedules for these doctors and the medical students who work with them is known to be a difficult NP-complete problem known as *personnel scheduling, employee timetabling, labor scheduling* or *rostering*. We have constructed a program that uses a constraint logic formalism to enforce certain scheduling rules followed by a tabu search heuristic optimizing algorithm to produce a call schedule that is used at the Ottawa Hospital. This call schedule can be later changed by the chief resident to accommodate last-minute personnel changes by means of a spreadsheet-based program.	