Master scheduling of medical specialists

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Summary

Medical specialists perform different activities in hospitals: seeing patients in clinics in the outpatient department, performing surgical procedures on patients in sessions in operating theatre departments, seeing patients at the ward during a ward round, being on call for seeing unscheduled patients at the emergency department. To co-ordinate these activities the group of specialists belonging to the same discipline uses a schedule that describes the timing of these activities on a weekly basis.

This case study deals with the process of developing master schedules for the activities of medical specialists organised in a specialty practice in a hospital. A model has been developed to describe and analyse the problem. The model has been implemented in a tool called MediPlan that not only increases the performance of the master schedules, but also decreases the process time needed to generate such schedules. The optimisation procedure implemented in MediPlan is based on simulated annealing, a well-known local search technique. The performance of the tool is tested by means of a case study for the specialty of orthopaedics within a hospital in the Netherlands.

Keywords: master scheduling, hospitals, specialty practice, optimisation, local search

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1. Introduction

Medical specialists are the key operators in hospital processes. Patients will see a medical specialist in different phases of their journey through the hospital: during a visit in the outpatient department for discussing the complaint, the diagnosis, the therapy or the follow up after an admission; during a diagnostic procedure in a diagnostic department or a surgical procedure in the operating theatres department; during a ward round in cases where the patient is admitted. These activities of medical specialists are organised in sessions: a clinic session in the outpatient department, in which the specialist sees a number of outpatients; an operating theatre session in the operating theatre department; a ward round, visiting all patients admitted to a nursing ward.

From the perspective of operations management of hospitals, medical specialists represent a very important hospital resource. However, the topic of planning of medical specialists is often not covered in hospital planning. Frequently, the availability of specialists is a bottleneck for the efficient use of other resources. Therefore, the planning of capacity of specialists, in terms of their availability for performing operations, is an important area for improvement. This is a challenge as specialists do not like to be scheduled or regarded as a resource. One area and opportunity for working together with specialists on improving the performance of specialist planning, is to develop a schedule for the different activities of specialists in a hospital, for instance outpatient clinic sessions, operating theatre sessions, ward rounds, etc.

Box 1: The case study hospital

The case-study hospital - that acted as a pilot setting for the development of the model - is a 400 beds hospital in the Netherlands, operating on two sites separated by a distance of 20 km. The pilot concerned the specialty of orthopaedics. This specialty struggled with their schedule as they had to operate on the two sites of the hospital, with only five orthopaedic surgeons available. The questions they wanted to answer were:

- *what was the performance of the current schedule of activities?*
- *what would be the gain in performance if activities were concentrated on one site per day instead of time being lost changing sites during the day?*
- *could a schedule be developed that took better account of the preferences of individual specialists in terms of the order of activities within the day but which did not compromise the overall performance of the specialty ?*

We will use data of this specialty to illustrate the planning problem and the model.

The rest of the paper is organised as follows. Section 2 gives a more detailed description of the planning problem, together with the positioning of the case study in the reference framework of this book, and a short review of the relevant literature. In Section 3 we elaborate on the planning problem of master scheduling of medical specialists and discuss the components of a model that would allow the evaluation and optimisation of master schedules. Section 4 describes the model developed for the problem, including the solution approach implemented in MediPlan. In Section 5 we show how the developed model can be applied in practice. Section 6 gives a reflection on the strength and the weakness of the study and some recommendations for further research.

2. Planning problem

Consider the following: a group of specialists wanted to develop a new schedule for their activities in a two-location hospital setting. Based upon interviews about their current schedule and their objectives and ideas for a revised schedule, a proposal was developed that was thought to meet their objectives. The proposal was discussed with the group of specialists and received much criticism. Some of the objectives were not properly understood and formulated, new objectives were added, and many arguments, that were not very concrete, were used to propose further changes. The project team – consisting of one of the specialists, a manager and the external management consultant - developed a new schedule, taking into account the comments of the group of specialists. The process described here went on for about four months during which time eight different proposals were put forward, before a final proposal was accepted and implemented (Vissers, 1994).

In the evaluation of the process the project team concluded that the process could have been speeded up considerably if they had possessed a tool that would be able to handle the different performance criteria and capacity restrictions related to the planning problem and would be able to generate a number of alternatives. In this contribution we will concentrate on the planning problem for a single specialty within a hospital. More specifically, the present case study deals with the evaluation and optimisation of the basic schedules for a specialty, the so-called *master schedules*. Each specialty has its own master schedule. These schedules may vary a bit from week to week, due to absence of specialists, but in principle each week-schedule is derived from this master schedule. A complicating factor in the development of a master schedule is the fact that not all activities have to be carried out every week. A small fraction of the activities follows a bi-weekly, or even a four-weekly, pattern.

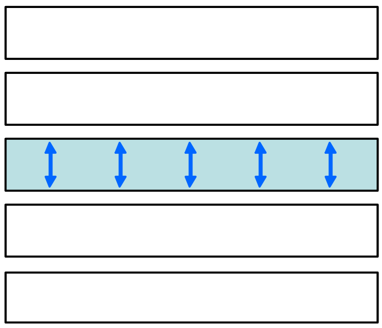
In the case study hospital we wanted to avoid the pitfalls described above by developing a tool that enabled the generation of master schedules for specialist activities in hospitals. In this contribution we aim to answer the following research question: *How, in a reasonable amount of time, to construct master schedules for the activities of specialists which deliver good performance while satisfying given capacity restrictions?*

There are a number of criteria that need to be taken into account to develop a good master schedule. First of all, a master schedule needs to meet the output targets for the hospital at annual level. From the point of efficient use of resources, it is also important to have activities of one type (for instance operating theatre sessions) well spread throughout the week. Then also preferences of individual specialists have to be taken into account, for instance the order of activities within one day or the avoidance of a transfer within one day between different sites of a hospital.

Position in planning framework

Figure 1 illustrates the position of this case study in the framework for operations management introduced in Chapter 6.

Figure 1: position of the case study in the planning framework



Unit logistics application
Focus on specialist capacity
Level of resources planning & control.

As shown in Figure 1, the planning problem addressed in this case study, is positioned at the third level of the framework, i.e. resources planning & control. We concentrate on one key resource, i.e. specialist capacity, but also consider the use of other related resources such as outpatient clinics and operating theatre facilities. Therefore, the approach followed is according to the unit logistics perspective. The next higher level of ‘volume planning and

control' defines the amount of sessions of each type to be organised in order to meet the volumes agreed upon at an annual level.
The level we consider in this case study is concerned with the issue how to organise these sessions in order to provide the service levels agreed upon, while maintaining an efficient organisation of activities. Efficiency is a key issue at this level, because the way sessions in outpatient departments and the operating theatre department are allocated, determines whether or not peaks and troughs are introduced in the workload of diagnostic departments and wards. See also the distinction between 'leading' and 'following' resources in Chapter 4 on unit logistics. The way resources are allocated at the level of 'resources planning & control' acts also as a restriction for scheduling patients and resources at the next lower level in the planning framework, i.e. patient group planning & control. Therefore, the issue discussed in this chapter is an important link between the more strategic and the more operational planning levels of the framework.

Literature review
The issue addressed in this chapter, i.e. specialist capacity planning, has received little attention previously e. Most literature on scheduling of hospital resources concerns beds (Wright, 1987; Bagust *et al.*, 1999; Ridge *et al.*, 2000), operating theatres (Blake, 2002; Guinet *et al.*, 2003, Sier *et al.*, 1997), outpatient departments (Brahimi and Worthington, 1991; Lehaney and Paul, 1994; Rising *et al.*, 1974; Cayirli *et al.*, 2003). These refer all to departments where interaction takes place between resources of a specific department and specialist capacity. However, the above illustrations only focus on a part of the capacity of the specialist. Literature references to papers that take into account the total capacity of a specialist, and concentrate on scheduling all the activities of specialists are scarce and hard to find.
The planning problem as such was first addressed by Vissers (1994); a very simple spreadsheet type of model was developed to describe master schedules for specialists and analyse their resource effects. As a follow up of this study a decision support tool called SOM (*Schedule Optimisation Model*) was developed (Klaasen, 1996; Vissers 1997). Although the tool developed has been used in a number of hospitals in the Netherlands, it has one serious shortcoming. The tool cannot handle activities with a bi-weekly or four-weekly pattern.

3. Elaboration

This section elaborates on the planning problem of master scheduling for medical specialists. In particular, we will discuss the data of a specialty of orthopaedics in a two-site hospital. We start with presenting the current master schedule used by the orthopaedic surgeons, and then reflect on the different components that should be taken into account when modelling the planning problem. We emphasise here that the presented schedule is a stylised reflection of the original schedule used by the specialty of orthopaedics. Several minor and major adjustments have been made to the data of the pilot hospital in order to facilitate the problem description, the model formulation and the presentation of the results. Nevertheless, the case study still clearly demonstrates the problematic nature of master scheduling for medical specialists as well as the virtues of the developed model in a practical setting.

Suppose we deal with a group of five orthopaedic surgeons working on two locations, Location A and Location B. Table 1 provides information on the activities of each of the surgeons per day of the week.

Table 1: current master schedule orthopaedic surgeons
(OT: operating theatre, OPD: outpatient department, DIAG: diagnostic procedures, Ward: scheduled ward round, A: location A, B: location B, Other: other activities, OT A^2 : bi-weekly operating theatre session at location B, etc.)

	MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Surgeon 1	OT A	Other A	Other A	OPD A	OT A	Ward A	OPD A	Free	OPD A	Free
Surgeon 2	OPD A	Ward A	DIAG A^2	Ward B	OPD B	OT B	OT A	OT A^2	OPD B	DIAG B
Surgeon 3	OPD B	Ward B	OT A	Ward A	OT B	OPD B	OPD A	OPD A	OT A	Free
Surgeon 4	Free	OT B	Ward A	Ward B	OPD A	OT A	OPD B	OPD B	OPD A	OT A
Surgeon 5	OPD A	OT A	OPD A	OT A^2	Free	Ward A	OPD B	Free	OT B	OPD B

Based on this schedule and also some interviews with surgeons and managers from operating theatres and outpatient departments, one can make the following observations that play a role in a proper description of the planning problem:

- the surgeons perform a number of different types of activity;
- most of these activities are organised on a weekly basis, a few on a bi-weekly basis;
- each day of the week is divided into two parts: AM and PM;
- the number of activities that need to be scheduled each week should be sufficient to meet the annual output targets;
- the way sessions of one type (for instance: operating theatre sessions) are distributed over the days of the week, is bounded by a restriction on the availability of this type of resources (for instance: only one operating theatre available for orthopaedics per day of the week);
- preferences in order of activities within a day exist at the level of individual specialists;
- in evaluating the performance of a schedule different criteria play a role.

We will discuss these components of the planning problem below.

3.1 Freque ncy of activities

Each day of the week is divided into a fixed number of blocks, so-called *day-parts*. The specialty of orthopaedics uses two day-parts for planning during a day. Tables 2 and 3 provide information on the weekly and bi-weekly activities that have to be carried out by the individual specialists. The majority of the activities follow a normal weekly pattern. Notice that the orthopaedic surgeons do not have to carry out activities with a four-weekly pattern.

Table 2: Weekly activities for the specialists

	OPERATING		OUTPATIENT		WARDS		DIAGNOSTIC		OTHER	
	A	B	A	B	A	B	A	B	A	B
Surgeon 1	2	0	3	0	1	0	0	0	2	0
Surgeon 2	1	1	1	2	1	1	0	1	0	0
Surgeon 3	2	1	2	2	1	1	0	0	0	0
Surgeon 4	2	1	2	2	1	1	0	0	0	0
Surgeon 5	1	1	2	2	1	0	0	0	0	0

Table 3: Bi-weekly activities for the specialists

	OPERATING		OUTPATIENT		WARDS		DIAGNOSTIC		OTHER	
	A	B	A	B	A	B	A	B	A	B
Surgeon 1	0	0	0	0	0	0	0	0	0	0
Surgeon 2	1	0	0	0	0	0	1	0	0	0
Surgeon 3	0	0	0	0	0	0	0	0	0	0
Surgeon 4	0	0	0	0	0	0	0	0	0	0
Surgeon 5	1	0	0	0	0	0	0	0	0	0

3.2 Capacity restrictions

The co-ordination between the specialty under consideration and the rest of the hospital (for instance, other specialties and departments) takes place via so-called *capacity restrictions*. These restrictions may under no circumstances be violated by the master schedule. The following capacity restrictions are to be included in the model:

- All activities of an individual specialist have to be scheduled in the master schedule in order to meet the production targets of the specialty;
- The number of operating theatres and outpatient units available for the specialty at each day-part and at each location is limited.

The capacity restrictions for the number of operating theatres are listed in Table 4, in which the number of available operating theatres is given for each day-part on both locations. Furthermore, there are always two and one outpatient unit(s) available for orthopaedics at Location A and Location B, respectively. Notice that the capacity restrictions for the number of operating theatres at Location B are tight, i.e. the specialty needs at least four operating theatre sessions a week at this location to perform all the operations and this is exactly the number of sessions available each week.

Table 4: Capacity restrictions for operating theatres

	MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
LOCATION A	1	1	1	1	1	1	1	1	1	0
LOCATION B	0	1	0	0	1	1	0	0	1	0

3.3 Evaluation criteria

To be able to evaluate the performance of a master schedule, different *criteria* should be included in the model. These criteria may be violated if necessary, but each violation decreases the performance of the master schedule. The criteria address the following issues:

1. The need to sequence activities in any day such that a transfer between locations for an individual specialist is avoided;
2. The need to accommodate the wishes of individual specialists in terms of their preferred day-part for a specific activity or preferred sequencing of activities;
3. The need to spread activities (operating theatre sessions and outpatient clinic sessions) over the day-parts of the week per group of specialists and per location;
4. The need to spread of activities (operating theatre sessions and outpatient clinic sessions) over the day-parts of the week per individual specialist.

We held interviews to investigate the preferences of the orthopaedic surgeons with respect to day-parts for activities or sequences of activities:

- Surgeon 1 preferred to have the activities indicated by *other* at Location A on Monday afternoon and Tuesday morning;

- Surgeon 2 preferred to perform the *diagnostic sessions* at Location B on Thursday afternoon;
- Surgeon 3 wanted the *half day-off* to be preceded by a *ward round* at Location B;
- Surgeon 4 wanted to do the *wards round* at Location A on Tuesday morning;
- Surgeon 5 had no specific preferences.

Moreover, we used these interviews to discuss the importance of the above evaluation criteria according to the orthopaedic surgeons. Table 5 shows the weighting factors, which reflect the relative importance of the criteria. This means that the preferred sequences of activities are very important, whereas transfer between locations within one day and preferred day-parts for specific activities are considered only of medium importance. Finally, spreading of activities for both the individual specialists and within the specialty is of (almost) no importance to the orthopaedic surgeons.

Table 5: Weighting factors for relative importance of criteria

CRITERIA	WEIGHT
Location transfer	5
Preferred day-part	7
Preferred sequence	10
Spreading of activities for specialists	0
Spreading of activities within the specialty	2

4. Model

In this section we translate the presented scheduling problem into a mathematical model in the form of an integer quadratic program (IQP). In the following section 4.1 we first describe the solution approach. In Section 4.2, the mathematical model is formulated. Section 4.3 describes the implementation of the solution approach in a software tool, called MediPlan. For more detailed information, see De Kreuk and Winands (2001).

4.1 Solution approach

To find optimal master schedules for medical specialists in which the bi-weekly and four-weekly activities are integrated, three steps have to be followed:

1. Construction and optimisation of a schedule with the *weekly activities*;
2. Addition of the *bi-weekly activities* to the weekly schedule and optimisation of this bi-weekly schedule;
3. Addition of the *four-weekly activities* to the bi-weekly schedule and optimisation of this four-weekly schedule.

Integer quadratic programming (IQP) is used to formulate a mathematical model that finds the optimal schedules. In the optimal schedules the capacity restrictions mentioned in the previous section have to hold, while the number of criteria that are violated is minimised.

4.2 Mathematical model

In this section the optimisation model is described mathematically. For the ease of presentation, we only show the mathematical model for the weekly activities. Let t denote the day-parts in one week ($t \in \{1, \ldots, 10\}$), and let S denote the total number of specialists. All possible activities get a number, which is shown in Table 6.

Table 6: Activities

NUMBER	ACTIVITY	NUMBER	ACTIVITY
1	Operating theatre, location 1	6	Operating theatre, location 2
2	Outpatient clinic, location 1	7	Outpatient clinic, location 2
3	Ward rounds, location 1	8	Ward rounds, location 2
4	Diagnostics sessions, location 1	9	Diagnostics sessions, location 2
5	Other, location 1	10	Other, location 2
		11	Day-part off, no location

To describe the capacity restrictions, the following parameters are introduced:

- $f_{a,s}$ is the number of day-parts for which specialist s ($s \in \{1,\ldots,S\}$) has to perform activity a ($a \in \{1,\ldots,11\}$). So $\sum_{a=1}^{11} f_{a,s} = 10$;
- $g_{a,t}$ is the maximum number of specialists that can perform activity a on day-part t ($t \in \{1,\ldots,10\}$).

To describe the criteria, for which the violations have to be minimised, the following parameters are introduced:

- c_i is the weight of a violation of criterion i ($i \in \{1,\ldots,5\}$);
- $w_{s,t}$ is equal to the number corresponding to the activity that specialist s *wants* to perform on day-part t ($w_{s,t} \in \{1,\ldots,11\}$). $w_{s,t}$ equals zero if specialist s has no preference on the corresponding day-part.

For every day-part an activity has to be assigned to every specialist. This gives the following decision variable:

- $x_{s,t}$ is equal to the number corresponding to the activity that specialist s *has* to perform on day-part t ($x_{s,t} \in \{1,\ldots,11\}$).

The capacity restrictions form the constraints of the optimisation model. The first capacity restriction is that all activities of an individual specialist have to be scheduled in the master schedule in order to meet the production targets of the specialty, i.e.:

$$\sum_{t=1}^{10} 1[x_{s,t} = a] = f_{a,s} \text{ for all } a \in \{1,\ldots,11\}, s \in \{1,\ldots,S\}.$$

($1[x]$ is the indicator function, which becomes one if x occurs). The second type of capacity restrictions is that the number of operating theatres and outpatient units available for the specialty at each day-part and at each location is limited. This is given by:

$$\sum_{s=1}^{S} 1[x_{s,t} = a] \leq g_{a,t} \text{ for all } a \in \{1,6\}, t \in \{1,\ldots,10\},$$

$$\sum_{s=1}^{S} 1[x_{s,t} = a] \leq g_{a,t} \text{ for all } a \in \{2,7\}, t \in \{1,\ldots,10\}.$$

The criteria that have to be minimised form the objective of the optimisation problem.
The first criterion is that it is preferable that no sequence of activities is scheduled in one day that requires a transfer between locations for an individual specialist. This criterion is described by:

$$\sum_{s=1}^{S}\sum_{t=1}^{5} 1[x_{s,2t-1} \leq 5 \wedge 6 \leq x_{s,2t} \leq 10] + \sum_{s=1}^{S}\sum_{t=1}^{5} 1[6 \leq x_{s,2t-1} \leq 10 \wedge x_{s,2t} \leq 5]$$

A second criterion is that a violation should be given if the preferred day-part for a specific activity for an individual specialist is not assigned, i.e.:

$$\sum_{s=1}^{S}\sum_{t=1}^{10} 1[w_{s,t} \neq 0 \wedge x_{s,t} \neq w_{s,t}].$$

There are also (not)-preferred sequences of activities for individual specialists. Here, only the mathematical formulation is given to violate if preferred sequences of activities do not occur, but the formulation for the non-preferred sequences is almost identical. That is,

$$\sum_{s=1}^{S}\sum_{t=1}^{10} 1[x_{s,t} = a \wedge x_{s,t+1} \neq b],$$

where a and b represent the first and second activity in the preferred sequence, respectively. The other criteria have to do with the spreading of the activities over the day-parts per week per group of specialists and per location and also the spreading per individual specialist. These criteria are included in the model by calculating the spreading of the activities in the usual way. The mathematical formulations are not given here, since it would make the model look unnecessary complex. For more information on these formulations, see De Kreuk and Winands (2001).

Summarizing, the problem of master scheduling of medical specialists can be formulated by the following IQP:

Minimise

$$c_1\left(\sum_{s=1}^{S}\sum_{t=1}^{5} 1[x_{s,2t-1} \leq 5 \wedge 6 \leq x_{x,2t} \leq 10] + \sum_{s=1}^{S}\sum_{t=1}^{5} 1[6 \leq x_{s,2t-1} \leq 10 \wedge x_{x,2t} \leq 5]\right) +$$
$$c_2\left(\sum_{s=1}^{S}\sum_{t=1}^{10} 1[w_{s,t} \neq 0 \wedge x_{s,t} \neq w_{s,t}]\right) + c_3\left(\sum_{s=1}^{S}\sum_{t=1}^{10} 1[x_{s,t} = a \wedge x_{s,t+1} \neq b]\right)$$

Subject to

$$\sum_{t=1}^{10} 1[x_{s,t} = a] = f_{a,s} \quad \text{for all } a \in \{1,\ldots,11\}, s \in \{1,\ldots,S\}$$
$$\sum_{s=1}^{S} 1[x_{s,t} = a] \leq g_{a,t} \quad \text{for all } a \in \{1,6\}, t \in \{1,\ldots,10\}$$
$$\sum_{s=1}^{S} 1[x_{s,t} = a] \leq g_{a,t} \quad \text{for all } a \in \{2,7\}, t \in \{1,\ldots,10\}$$
$$x_{s,t} \in \{1,\ldots,11\}$$

4.3 Implementation

The model described in the previous section is implemented in a software tool called MediPlan. MediPlan uses the solution approach consisting of three steps, i.e. constructing and optimising a schedule with weekly activities, addition of the bi-weekly activities and addition of the four-weekly activities. Each of the steps in the solution procedure consists of two parts: *the construction of an initial schedule* and *the development of alternative schedules* with a higher performance. The development of alternative schedules in each step is continued until the decision maker is satisfied with the schedule and wants to proceed to the next step.

The following two steps are followed to construct the initial weekly schedule:

1. Schedule the weekly activities for which capacity restrictions are imposed (i.e. operating theatre sessions and outpatient clinic sessions) in such a way that these capacity restrictions are satisfied;
2. Schedule the rest of the weekly activities (i.e. diagnostics sessions, ward rounds and other activities) randomly over the idle day-parts of the schedule.

It is important that the number of activities that have to be scheduled does not exceed the number of day-parts that are available for the different activities. The initial bi-weekly schedule is made in the same way. This means that we firstly schedule the bi-weekly activities with capacity restrictions in the doubled weekly schedule without violating these capacity restrictions. Secondly, the remaining bi-weekly activities are randomly added to the schedule. The initial four-weekly schedule is constructed by applying the exact same procedure to the bi-weekly schedule.

To generate an alternative schedule, two different activities of a specialist in the schedule are selected and exchanged. When generating alternative weekly schedules all activities may be chosen and exchanged. However, in the optimisation of the bi-weekly schedule the weekly activities are fixed, which means that they cannot be selected for exchange. When optimising the four-weekly schedule, the weekly and bi-weekly activities are fixed. In the exchanging process capacity restrictions are constantly checked. In this way a variant of the current schedule is made that is feasible given the capacity restrictions.

After the exchange of the activities, the score of this schedule variant is computed. In order to decide whether the variant will be accepted or not, we make use of a technique called *simulated annealing*, belonging to the family of *Local Search* (see e.g. Aarts and Korst (1989)). Local Search methods have the goal to find a solution in a large solution-set in a smart and fast way and concentrate on problems that can be formulated unambiguously in terms of mathematical terminology and notation. Furthermore, it is assumed that the quality of a solution is quantifiable and that it can be compared to that of any other solution. Finally, it is assumed that the set of solutions is finite.

Simulated annealing comes down to the following steps:

1. Generate a variant of the current schedule as explained above;
2. Calculate the score of the variant;
3. If the variant has a higher performance than the current schedule accept the variant as a new schedule, if not the variant is accepted as the new schedule with a pre-determined probability (the probability of acceptance of lower performing variants gradually decreases);
4. Continue with Step 1.

The probability of acceptance of a variant with a lower performance helps to overcome local optima. Local optima are schedules that have a better score than all the schedules that can be obtained by exchanging activities, but are not the best possible schedule (global optimum). By gradually reducing the probability of accepting lower performance variants, the algorithm is able to find an optimal (global) solution by only using a limited number of runs.

5. Results

In this section we will show the output of MediPlan for this case study, i.e. the optimal schedule together with its score, and present a discussion of the output.

The master schedule for the specialty of orthopaedics generated by MediPlan is shown in Table 7. For the ease of presentation, we only depict and discuss the weekly schedule. This master schedule was constructed in only a couple of minutes, which is a significant reduction in process time compared to the old situation as sketched in the Section 2.

Table 7: Final weekly master schedule for the specialty of orthopaedics.

	MONDAY		**TUESDAY**		**WEDNESDAY**		**THURSDAY**		**FRIDAY**	
	AM	**PM**	**AM**	**PM**	**AM**	**PM**	**AM**	**PM**	**AM**	**PM**
Surgeon 1	OPD A	Other A	Other A	OPD A	Free	OT A	Ward A	Free	OT A	OPD A
Surgeon 2	OT A	Free	Free	OPD B	OT B	OPD B	Ward B	DIAG B	OPD A	Ward A
Surgeon 3	Ward A	OT A	OPD A	OPD A	OPD B	OT B	OPD B	OT A	Ward B	Free
Surgeon 4	Ward B	OT B	Ward A	OT A	OT A	OPD A	OPD A	Free	OPD B	OPD B
Surgeon 5	OPD B	OPD B	Free	Ward A	OPD A	Free	OT A	OPD A	OT B	Free

Table 8 summarises the performance of the above master schedule on the different criteria included in MediPlan. This master schedule satisfies the imposed capacity restrictions with respect to the limited number of operating theatres and outpatient units. It immediately strikes the eye that the generated schedule violates no criteria concerning preferred sequences and day-parts of activities. Furthermore, in the entire week only one orthopaedic surgeon has to transfer between locations within one day. The bottom line of Table 8 shows the total score of the master schedule.

Table 8: Score for the master schedule

CRITERIA	**# VIOLATIONS**	**SCORE**
Location transfer	1	5
Preferred day-part	0	0
Preferred sequence	0	0
Spreading of activities for specialists	----	0
Spreading of activities within the specialty	----	3.8
TOTAL		8.8

If we compare this with the performance of the original schedule (Table 1), we can make the following observations:

- The original schedule showed also one transfer on Tuesday (Surgeon 4) between locations, contributing 5 points to the score.
- In the original schedule one wish for a preferred day-part (Surgeon 2 on Thursday afternoon) was violated, contributing 7 points to the score.
- Also the sequence order of activities for Surgeon 3 (half day off preceded by ward round at location B) was violated, contributing 10 more points to the score of the original schedule.
- Spreading of activities was not considered in the original schedule, and will certainly produce a higher contribution to the score for the original schedule than the revised schedule.

Summarising, the score of the original schedule is much higher than that of the revised schedule. The new schedule shows less violations and a better spreading of activities.

6. Reflection and Further development

We want to start this section with a discussion of the quality of the model on both the performance of the generated master schedules and the speed of the process involved. After all, the aim of the present research was the development of a method or a tool that could both *improve* and *speed up* the process of constructing master schedules. Besides the case study presented, MediPlan has been tested on various theoretical examples and on the speciality of gynaecology within the same hospital (see De Kreuk and Winands (2001), for more details). Based on these implementations of MediPlan we may conclude that the model worked successfully with respect to the performance of the generated master schedules. Furthermore, MediPlan also reduced the process time of developing master schedules significantly in the practical implementations. Once the decision maker had been able to define relevant performance criteria and capacity restrictions, the generating of a schedule with maximal performance took only a couple of minutes. Although further testing is needed, the first (positive) applications of the model encourage further use for other specialties and other hospitals.

We would like to end with a possible extension of MediPlan that can support hospitals in the co-ordination of schedules for specialties and departments such as operating theatres and outpatient departments. After all, most of the work of the specialist is regulated by these department schedules. Between these department schedules large degrees of dependency exist, i.e. a delay in one department may cause delays in successive departments. For example, if an operating session takes more time than scheduled, the specialist might not be able to start, at the correct time, a clinic session in the outpatient department. This dependence is often a bottleneck when one wants to redesign a schedule for a specific department. If, for instance, some shifts are to be made in the clinic schedule, what will be the consequences for the other activities of the specialist? A further complication is that the workload of the medical service departments is, to a large extent, dependent on the outpatient clinic schedule. At times of a fracture clinic, for example, many patients will visit the x-ray department. Therefore, a direct relationship exists between the clinic schedule of the outpatient department and the workload of some medical service departments. When looking at changes in the working day of a specialist these *second-order effects* also have to be taken into account. Therefore, an interesting topic for further research would be to analyse the match between the master schedules for individual specialties generated by MediPlan and the department schedules. Undoubtedly, there is great demand from hospitals for a decision support tool visualising and optimising the co-ordination between and within the individual specialty schedules and the department schedules.

7. References and Further reading

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