MASTER

Production planning in a specialised hospital in the Netherlands

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Production planning in a specialised hospital in the Netherlands
by
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in partial fulfillment of the requirements for the degree of
Master of Science
in Operations Management and Logistics

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Series Master Theses Operations Management and Logistics

Subject headings: healthcare, forecast patient arrivals, scheduling, personnel planning, production planning, production goals, decision support system.
Preface

This thesis is the result of my graduation project executed in partial fulfillment of the requirements for the degree of Master of Science in Operations Management & Logistics (for healthcare). The research is conducted at the orthopedics department of the Sint Maartenskliniek in Nijmegen, the Netherlands.

I always had a passion for healthcare and that is also the reason why the project at the Sint Maartenskliniek was very applicable to me. The combination of healthcare and logistics provides the opportunity to carry out a technical project, but on the other side also a better environment for the patient can be accomplished. The assignment to improve the schedule of orthopedics in the Sint Maartenskliniek was triple sided. Not only the management of the SMK could benefit from a better alignment to the production goals, also the patients and the orthopedics.

During my thesis a lot needed to be done on the design of the production plan. Therefore, a lot of analyses were carried out on the current situation. These analyses lead to a complete view of the planning strategy currently performed at the orthopedic department. It gave both me and the schedulers some new insights into the way of planning they are accustomed. They were also encouraged a lot by the manager and the Logistics department to change to a better way of planning. Besides the encouragement, they were very willing to change, which was very helpful.

From the SMK I want to thank the employees of the department Zorglogistiek for their help every time I needed it, especially the manager Remco Weber. From the department Logistiek Bedrijf I want to thank Nikky Kortbeek for his feedback on my model. You made me think twice of every decision I made. Lastly, I want to thank Rob Vromans for his daily support. You always tried to improve the analyses and the way of reporting. Sometimes it was hard to explain my thoughts about the model, but you tried to understand and translated this to a way we both understood.

Lastly, I want to thank my TU\e supervisor Nico Dellaert for his support during my graduation. You helped my find this project and helped me in every phase of my thesis. You tried me to think about my model in a different way, which improved the model substantially. Although you never worked with R, you tried to make the model conceptually good, so I could program it. Also Shaunak Dabadghao, thanks for you thoughts about my thesis. It really helped me to deliver a better model and thesis. Besides my supervisors at the TU\e, I want to thank all other people who helped me with my thesis. Although you maybe not always knew what I was talking about, it really helped me to structure my thoughts.

Bregje van der Staak
Eindhoven, August 2016
Management summary

Growing healthcare costs and a rising population takes care of a healthcare sector that needs to be efficient with the available resources. Therefore, a good planning system, combined with quantifiable goals can be of great importance. However, literature research has shown that a lot of attention is paid to the separate parts of the planning process, but less to the integration of the different steps (Hulshof, 2013). To overcome this problem a methodology is designed that matches the production goals with the personnel planning. Therefore, a production plan on weekly base is made. This means that for every week, the number of hours on the Outpatient department (OD) and Operation Theater (OT) is determined in such a way that the production is as high as possible and balanced across the different units.

Model

To make a decision on the number of patients treated in the OD and OT every week, a number of steps need to be taken. First of all, for the prediction of patient demand the Holt-Winters forecasting technique is used. This technique takes into account both seasonalized and trended data. Furthermore, the number of available OTs, ODs, orthopedics and supporting medical staff must be known for every week. Besides the resources, the model assumes that there are four states in which the patient can be: New injury (NK), Follow-up consult (VC), Operation theater (OT) and Dismissal consult (OC). Lastly with the transition matrix, which includes the chance of moving from state X to state Y, the number of patients in the different states can be calculated. This is used as constraint to the model. The model then calculates for every week the production ratio, the number of patients treated in the current year divided by the production goal. The higher the production ratio, the least chance of getting an OD or OT assigned, since equal distribution across groups is desired. With this production ratio, the group with the lowest ratio will get assigned one OT whenever possible with the number of patients, OTs and orthopedics available. The same is done for OD. This will continue till all groups has no more patients, orthopedics or OD/OT rooms to perform more treatments.

Case study

This model is implemented on the orthopedic department of the Sint Maartenskliniek. In this department they are currently dealing with the problem of integrating their production goals with their personnel planning. The model must help them to divide the treatments across the year in such a way that there are always enough patients, orthopedics and treatment rooms available. This is done according to the research question: “In what way should the production- and session planning of the SMK be organized, such that the realisation of the production goals can be better managed?”
Results
The planning supporting tool on unit level is able to predict the number of incoming patients and the number of patients every week in the different states. With this prediction, OT and OD are distributed to the six different units. The realisation of the OT related to the production goals varies between a realisation of 66% for the Foot unit and a realisation of 141% for the Child unit. This means that the requirement of equal distribution across units is not met. This is due to an unbalanced distribution of patients and orthopedics across units. The units Hip, Foot and Upper Extremity have after 4 years a low number of waiting patients. This results in a stabilized production after 4 to 4.5 years. For the Knee, Spine and Child unit, enough patients are available and production can rise.

Four different applications to the model were tested. The production plan with half instead of full days leads to a more balanced production between units. Since this is a very low difference it is questionable whether this improvement is significant. Second, supporting medical staff is added and removed from the OD hour. This leads to less patients available for OT when no supporting medical staff is added and a higher production when extra supporting medical staff is added. Furthermore, an optimal OD schedule, based on the transition matrix, is used. This should lead to a better production ratio, since this reflects the optimal division of NK, VC and OC places within the OD hour. Simulation has shown that this OD schedule leads to a higher production ratio. Lastly, the actual forecast of patient arrivals does lead to a lower production ratio for the units that already had a lower production ratio.

Recommendations
Since little research is performed on the integration of the different steps of the planning process, the first scientific recommendation is to use the same model in a comparable environment. Then a definite conclusion can be drawn on the outcomes of this study. Furthermore, the impact of the OD schedule turned out to be very large. Therefore additional research should performed on the optimal OD schedule. The hypothesis is that the OD schedule does not only depends on the transition matrix, but also on the holidays, sickness of the orthopedic etc. Lastly, also attention should be paid to the optimization technique used. In this case study, the optimization technique is based on a heuristic. However, when only short predictions need to be made, maybe a direct optimization technique would more valuable.

Practical recommendations to the SMK are to integrate the planning decision tool in their current way of planning. It will help the schedulers to make solid decisions regarding the personnel planning. Since the tool is generalisable, it is also valuable to implement the tool in the other departments of the SMK. The rheumatology department and the rehabilitation clinic also need to deal with personnel planning and compliance to production goals.
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1 Introduction

This master thesis is written in partial fulfillment of the requirements of the Masters degree in Operation Management and Logistics (for healthcare) at Eindhoven University of Technology. A methodology is designed to match the production goals, which are set every year, with the schedule of the doctors and their supporting staff.

1.1 Focus of the methodology

The focus of the methodology is to match the realised production with the proposed production. Whenever there is spare capacity, this will be spent on specialty treatments. However, this is not the focus of this methodology. Furthermore, the production must comply to some requirements of the hospital, e.g. focus on certain treatments, but this must not impede the production on regular treatments. To match this problem with existing models, literature research is done. This pointed out that research on the relation between the production goals and the personnel planning is scarce. Hulshof (2013) is one of few who researched this relationship. He modeled the need to comply to the production goals as weights in a mathematical model. Contrary to healthcare, in complex transportation systems, a lot of research is conducted on this topic (e.g. Freling, Huisman & Wagelmans, 2003; Klabjan et al., 2002). However, it is questionable whether these theories can be applied to healthcare, since the healthcare sector is different from the service sector (De Vries, Bertrand & Vissers, 1999; Helderman, Bevan & France, 2012; Gunawan & Lau, 2013). Hence, research on this topic is relatively scarce. Therefore, a case study is performed at a specialized hospital in the Netherlands, which deals with the problem of the integration of personnel planning and production planning.

1.2 Thesis outline

This thesis is structured as follows. Chapter 2 shows the literature review conducted on this topic. This is the cause for the case study, as explained in Chapter 3. Chapter 4 describes the current way of planning. This leads to the problem statement, research objective and research question, as given in Chapter 5. Then the model is given in Chapter 6. The outcomes of the model and the application on the data of the SMK is given in Chapter 7. Conclusions are drawn in Chapter 8 and the discussion is given in Chapter 9.
2 Literature review

In the literature, a lot of research is performed on the different parts of the planning process, like case mix planning and personnel planning. However, integration of the separate parts is not researched extensively. In this section, a short overview is given on the different steps taken in the planning process and the integration of these different steps. However, first an explanation is given on the importance of planning in healthcare.

2.1 Importance planning in healthcare

Due to rising healthcare costs and a rising population, there is an urgent need for efficient use of resources and cost reduction. According to De Vries, Bertrand & Vissers (1999), healthcare is hard to manage and hard to control. This is because the management functions of hospitals are mainly filled by medical specialists. They do manage the clinical processes, but not the non-clinical processes. Therefore, the efficient use of resources becomes more important and this can be achieved with for example an optimal planning (Brandeau, Sainfort & Pierskalla, 2004).

2.2 Frameworks for planning and control

To determine which steps are present within the planning process, different frameworks can be looked into. For example the framework of Vissers and Beech (2005), where the planning process can be divided into five stages, from strategic planning to patient planning and control. The framework is based on the idea that a hospital is organized in relatively independent units. It focuses on resource capacity planning and does not take into account medical planning, financial planning and material coordination (Van Houdenhoven, 2007). According to Van Houdenhoven (2007), a different approach can be applied. Different levels can be defined within the planning process, namely 'Strategic planning', 'Tactical planning' and 'Operational planning'.

2.3 The planning process

The planning process starts with the determination of the case mix goals, which is the decision on the number of patients to be treated from a certain pathology group in a certain year (Ma & Demeulemeester, 2013). Research on this step in the planning process is scarce. Some models are developed for this problem, they all have a different goal function. Where Adan and Vissers (2002) focus on minimizing the deviation between the target and the realisation, Ma et al. (2011) try to maximize the profit of the hospital within the given resource capacity. All models are formulated as mathematical models and solved by different optimization techniques.
The case mix goals must be matched with the personnel planning. However, a lot of research is done on nurse rostering (Ernst et al., 2004; Petrovic & Berghe, 2008), but not on physician rostering (Raman, 2002). The latter is much more driven by the preferences of the physicians and their side activities (Beaulieu, 2000). This is less relevant for nurse rostering. Different constraints are present within the personnel planning problem (Demeulemeester, Cardoen & Beliën, 2013), namely hard constraints, which cannot be violated, and soft constraints, which can be violated. According to Gunawan and Lau (2013) there are four ways in which the physician scheduling problem can be solved, namely mathematical programming, column generation, tabu search and constraint programming. Also a classification can be made in cyclic and non-cyclic schedules (Beaulieu, 2000). Where cyclic schedules can for example be solved by a Master Surgery Schedule (Van Oostrum et al., 2008; Blake & Donald, 2002; Beliën & Demeulemeester, 2004) and non-cyclic schedules can be solved by for instance optimization techniques.

After the personnel planning, patients must be planned for the outpatient department and for the operation theater (OT). In the outpatient department, appointment scheduling can be divided in static and dynamic (Cayirli & Veral, 2003). Static appointment planning is the process where appointments are made before the start of the consultation hour (e.g. GP) and dynamic appointment scheduling is the process where the schedule depends on the arrivals of the patients (e.g. emergency department). Regarding the operation theater, a lot of research is done on the management of the OT time. Three stages can be defined, namely (1) distribution of OT time to surgeons, (2) the schedule of OT time available and (3) scheduling of elective patients (Testi, Tanfani & Torre, 2007). These different stages must lead to optimal use of the OT time. The performance of the OT can be evaluated on a number of factors, for example the waiting time of patients and surgeons, the efficiency of the OT time used and the use of resources.

### 2.4 Integration case mix planning with personnel planning

As the literature review shows, a lot of research is done on the separate parts of the planning process, but research on the integration of these separate parts is scarce. Hulshof (2013) is one of few who did research on the integration of personnel planning and case mix planning. He modeled the production goals as weights in a mathematical model. A performance ratio gives the amount of patients that had to be treated, related to the number of patients that were actually treated.

Concluding from the literature, the step where the case mix goals are translated into personnel planning, seems to be the best way to integrate the production goals with the planning, since the other parts of the planning are derived from this personnel planning.
3 Case description

As stated in the literature review, the integration of different parts of the planning process is not researched extensively. Currently, the planners of the orthopedic department of the Sint Maartenskliniek in Nijmegen, are dealing with this problem and therefore a case study is carried out at this department.

3.1 The Sint Maartenskliniek

The Sint Maartenskliniek (SMK) is a specialized hospital, which is leading in the field of posture and movement in the Netherlands and Europe (SMKa, 2015). The ambition of the SMK is to provide excellence in diagnosis, treatment and care for those diseases where patients need specialized care (SMKb, 2015). They try to reach this ambition by focusing on the following five goals:

1. Satisfied patients  
2. Responsible and satisfied employees  
3. Safe and efficient healthcare  
4. Focus on quality, service and throughput time  
5. Performance and growth

The SMK consists of different units: e.g. the orthopedic department, rheumatology department, rehabilitation clinic, Maartenspharmacy and the sport medical department, where the focus of this thesis is on the orthopedic department. Appendix A gives the organizational overview of the SMK.

3.2 Orthopedic department

The orthopedic department is located in Nijmegen, Boxmeer and Woerden. Annually, they perform around 600 Spine, 1700 Knee, 1000 Hip, 800 Foot and 1100 Upper Extremity surgeries. Besides the planned surgeries, there is an acute health department, where patients can come 24/7 with acute injuries, just like a sprained ankle or fracture. Next to the outpatient department and the acute health department, the orthopedic intervention center is designed to perform surgeries under local anesthetics, pain treatment and radio-diagnostic treatment. There are also some supporting facilities like the plaster room, physiotherapy, radio-diagnostics, and the nursing department.

Six different units are active within the orthopedic department: Knee, Hip, Spine, Upper Extremity, Foot and Ankle and Child unit. They all have different external waiting times, time till the first appointment on the outpatient department. Some units have divided waiting times for their treatments. The waiting times are given in Table 1 (SMKd, 2015), and can differ between the locations. This is due to the specialized care, which is mainly performed at the location in Nijmegen. The waiting times for the treatments are quite long, since the Treknorm suggests a maximum waiting time of 4 weeks until the first visit on the outpatient department.
The orthopedic department located in Woerden provides orthopedic care together with the Zuwe Hofpoort hospital, which gives less specialized care than the department in Nijmegen. The location at Boxmeer provides orthopedic, rheumatologic and rehabilitation care together with Maasziekenhuis Pantein. Furthermore, they are specialized in child care.

| Table 1: Waiting times orthopedic department (weeks) |
|----------------|--------|--------|
|                 | Nijmegen | Woerden | Boxmeer |
| Children (spine and neck) | -       | 7       | 2       |
| Knee             | 8       | 10      | 4       |
| Hip              | 10      | 5       | 4       |
| Spine and neck   | 36      | 7       | 5       |
| Shoulder and elbow | 6       | 7       | 4       |
| Hand and wrist   | 6       | 8       | 4       |
| Foot and ankle   | 12      | 10      | 5       |

For the orthopedic department, also some logistical statements are set by the management.

1. We provide excellent orthopedic treatment and we are a tertiary center. This means that we want to grow on special treatments, probably at the expense of the regular treatments.
2. The division in special and regular treatments is decided upon our quality norm.
3. We want to grow on child orthopedics, at the expense of adult orthopedics.
4. Balance between the units must be guaranteed to maintain our identity as SMK.

3.3 Current way of planning

A number of steps need to be taken before the patient can be scheduled for surgery or for an appointment on the outpatient department. The first step in this process is the development of the production goals for one year, the case mix goals. Also, the session planning is made. This means that every half a day an activity is assigned to the medical specialists. These activities are for example outpatient department or operation theater. Within the medical specialists, two groups can be classified: the orthopedic surgeons and the supporting medical staff. A classification is given in Table 2. The supporting medical staff is given in order of level of expertise.

The medical- and supporting medical staff have different activities, which need to be planned on half day base. These activities are the most common ones: outpatient department (OD), operation theater (OT), administration (A), non-clinical day
### Table 2: Medical staff

<table>
<thead>
<tr>
<th></th>
<th>Medical staff</th>
<th>Supporting medical staff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orthopedic</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Doctor in training to become a specialist (AIOS)</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Fellow</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>Doctor not in training to become a specialist (ANIOS)</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>Nurse Practitioner Physician Assistant</td>
<td>-</td>
<td>X</td>
</tr>
</tbody>
</table>

(NKD) and day-off. Besides the session plan, also the schedule of the operation theater, outpatient department and ward is made. The different steps that are taken, are further explained in this section.

#### 3.3.1 Session planning

As starting point for the session planning, the availability of the (supporting) medical staff during the month and the number of OTs available every day is taken. The (supporting) medical staff need to submit their availability during one particular month five months earlier in MedSpace (MedSpace, n.d.). With the availability of medical specialists, the session planning of one month is made. This is done by trial and error. The number of OTs, number of ODs, administration days and non-clinical days is based on a standard schedule. The aim is to schedule two days of OT, one and a half day of OD, half a day of A and one NKD every week. However, this is not always possible within one week, so an attempt is made to balance this among the month. The number of OTs available is used as starting point, because the OTs must always be filled. Since the orthopedics are in the lead on the OT, they are planned first. The supporting medical staff is planned afterwards.

When the session planning of one month is finished, one week will be chosen as ResWeek. The ResWeek is used to steer the waiting list of the orthopedic. The week in which most orthopedics are available and the week with less reduction of OT will be chosen as ResWeek. This week will be cleared in the schedule and will be filled again nine weeks in advance. This is done based on the waiting list of the orthopedics. When an orthopedic has a long waiting list, he will be planned for OT and when the orthopedic has a very short waiting list he will be planned for OD. The session planning is released four months in advance, but the ResWeek is released eight weeks in advance. Changes in the session planning are communicated with the planners and they decide if the proposed changes are possible and which changes need to be made in the schedule. Because the ResWeek is not a particular week in the month it is hard to give a releasing scheme for the year. However, a fictive scheme is given in Table 3.
### 3.3.2 Grids

With the session planning as base, the set up of the consultation hours of the outpatient department is decided. To provide a good balance between new patients, control visits and dismissal consults, a precise schedule is made within the consultation hours. To every five minutes time slot a code is assigned, which tells which kind of patient can be seen in that time slot. The grids are the result of a project executed in 2013, Project Gemini. For every unit, different grids are available.

<table>
<thead>
<tr>
<th>Month</th>
<th>Release schedule</th>
<th>Release ResWeek (e.g.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>26 September</td>
<td>14 November</td>
</tr>
<tr>
<td>February</td>
<td>26 October</td>
<td>7 December</td>
</tr>
<tr>
<td>March</td>
<td>16 November</td>
<td>20 January</td>
</tr>
<tr>
<td>April</td>
<td>26 December</td>
<td>13 February</td>
</tr>
<tr>
<td>May</td>
<td>26 January</td>
<td>17 March</td>
</tr>
<tr>
<td>June</td>
<td>26 February</td>
<td>12 April</td>
</tr>
<tr>
<td>July</td>
<td>26 March</td>
<td>15 May</td>
</tr>
<tr>
<td>August</td>
<td>26 April</td>
<td>20 June</td>
</tr>
<tr>
<td>September</td>
<td>26 May</td>
<td>10 July</td>
</tr>
<tr>
<td>October</td>
<td>26 June</td>
<td>11 August</td>
</tr>
<tr>
<td>November</td>
<td>26 July</td>
<td>21 September</td>
</tr>
<tr>
<td>December</td>
<td>26 August</td>
<td>15 October</td>
</tr>
</tbody>
</table>

There are three different kind of outpatient department consultation hours: uno, duo and trio consultation hours. At an uno OD, an orthopedic has consultation hour by himself. Where at a duo OD, an orthopedic with an assistant has consultation hour. Lastly, at a trio OD, an orthopedic with two assistants has consultation hour. The different kinds of consultation hours also have different grids. For example, in a duo consultation hour, two patients can come at the same time, where in a trio consultation hour, three patients can come at the same time.

The grids are manually implemented in Chipsoft. Chipsoft is a software program, which stores all information of patients. The grids are implemented for both the consultation hours and the plaster room. With the grid, the employees of the outpatient department and the Contact & Service center can plan the consultation for the patients. However, when changes need to be made in the roster, also (manually) changes need to be made into the grid in Chipsoft.

### 3.3.3 Operation Theater

Every year a schedule is made for the availability of operation theaters during the next year. The number of OTs that are opened each day are based on the holidays
and other events within the SMK, like an inspection. On days with full utilization, six OTs are available. When there is reduced utilization, four or zero OTs are available. This is all defined in the OT session plan. For every OT-day, 535 minutes of surgery time is available. The filling of the OT-time is based on two parts. First the duration of the surgery, including twenty five minutes cleaning, which is provided by the orthopedic, and second the scheduling rules, which include for example rules concerning the availability of surgical instruments.

When scheduling patients, OT-planners are confronted with some constraints. For example, a maximum of ten patients can be scheduled in one OT day. Taking into account all planning rules, the OT-planners try to fill the available OT-time as good as possible. Patients are planned on urgency and alphabetical order, on the basis of initial favorable availability in the schedule. This means that for example a surgery of 110 minutes will be planned in a 150 minute time space in the OT-schedule. The aim is to fill the OT-time in such a way that a minimum amount of time of the OT schedule is not filled. Some places in the OT schedule are reserved for emergency patients, this is two hours a day. However, data analysis showed that only 40% of this space was used. So, in May 2016, a pilot started in which three times a week this space can be filled with non urgent patients. In this case study, emergency patients are not taken into account, because this is a decision on a lower level than the production plan.

In case the surgery needs to be canceled, e.g. due to absenteeism of the doctor or sickness of the patient, the surgery will be re-planned. When a lot of patients must be rescheduled this is mostly done on chronological order, where a couple of patients will be rescheduled a few days/weeks, instead of moving one patient a couple of months. When only one patient need to be rescheduled, the reason of cancellation will determine if the patient has priority on other patients. There are no specific key performance indicators (KPIs) for the percentage of the available OT-time that need to be filled, but there is a goal for rescheduling. The goal is a maximum of 15% rescheduled patients, this is both positive rescheduling and negative rescheduling. Positive rescheduling means that the patient can have surgery before the planned surgery date and negative rescheduling means that the patient will be planned later than the original planned surgery date.

### 3.3.4 Ward

Patients are scheduled in a bed on the ward based on their scheduled OT. On the day the patient has surgery, he is first admitted to ward G1. Ward G1 is designed in such a way that patients have a place to wait for their surgery, but are not yet fully hospitalized. This is done, because it diminishes the pressure on the general ward in the morning. Less beds are needed in the morning, since the patients wait at G1 for surgery. After the OT, the patient is moved to a ward where he will stay until he is discharged from the hospital. On this general ward, enough beds are available to
hospitalize all patients. At some peak moments, there are only a few beds available for acute patients and none for regular patients. It happens only a few times a year that patients cannot have surgery due to no availability of beds. When the patient is discharged from the hospital, a return visit on the outpatient department is planned by the nurses on the ward.
4  Context analysis

The context analysis describes the current way of planning of the Sint Maarten-skliniek. A categorization is made in the control mechanism, the way in which the planning is made, and the performance of the orthopedic chain, where the production goals are compared with the realisation of the production.

4.1  Control mechanism

The aim of the analysis of the control mechanism is to get a complete view of the different steps taken in the planning of the orthopedics in the chain. Every single step taken in the process is evaluated on a number of factors:

1. Which decision is made?
2. Who decides and when?
3. Which way of working is used?
4. Which supporting information is used?
5. Which planning supporting information and software is used?

The Integral Production- and Capacity Management program (IPCM) is a program of the SMK to optimize the performance of the orthopedic chain. They designed a framework, Figure 1, in which the different steps of the planning of the orthopedic chain are stated. For these different steps in the planning process, the control mechanism is evaluated.

![Figure 1: Framework IPCM program SMK](image)

15
With the formation budget, and part of the production budget, a schedule is made for the orthopedics for every week. This schedule contains for every half day the activity that needs to be performed by the orthopedic. In the schedule, for every OT and OD day, the type of patient that will be seen within these hours is set. For example, on an ‘OTh day’, only patients with a hip surgery should be planned according to the schedule. However, this is not done in practice. Every patient of a certain orthopedic will be planned during this OT session. Furthermore, a standard grid of two days OT, 1.5 day OD, 0.5 day of administration and 1 non-clinical day for every week is used to make the schedule. This means that no integration takes place between the production goals and the planning.

The analysis of the control mechanism can be divided into three levels (Vissers & Beech, 2005):

1. **Strategic**: Case mix goals are not based on the achievements, but on the goals of previous year. Production goals are also based on historical data, where it is not clear whether this historical data is still applicable.
2. **Tactical**: The schedule of the activities performed by the orthopedics is not based on the production goals, set at the beginning of the year. Furthermore, corrections only take place to reduce the waiting list of the orthopedic, and not to work towards the production goals.
3. **Operational**: On the level of patient planning, there is no insight into the production goals.

In conclusion, due to the lack of integration of different schedules on yearly, monthly and half day base, it is not possible to regulate and control the production.

### 4.2 Performance analysis

The performance of the orthopedic chain is evaluated on a number of factors. First, a framework is built in which the dependencies of the different parts of the orthopedic chain are given. The two main components are the access time to the OD and the access time to the OT. These access times have a direct relationship with the production, on the OD and OT respectively. As underlying factors, for example the utilization of the OD session, case mix profile and session length OT are defined. What is remarkable is the fact that no selection process is used at the OD of the SMK. All patients, referred by either a specialist or general practitioner get an appointment at the OD consultation hour, even when the waiting times of the treatments become intolerable.

Figure 2 gives the full dependencies within the orthopedic chain. This framework can be applied to different layers of the organization. The whole orthopedic chain can be evaluated according to this framework, but also the performance of one specific unit or orthopedic. The performance analysis for the different layers is done for 2015, since this is the most recent year and therefore most valuable for this case.
The performance of the orthopedic chain is split up in four parts. First the whole orthopedic chain is evaluated. Then, the performance for the specific units, orthopedics and treatment groups are evaluated. Since the performance of the orthopedic chain and the units are of the greatest importance in this case, only these two will be described in this section.

### 4.2.1 Orthopedic chain

The performance of the orthopedic chain is evaluated on the number of surgeries budgeted and realised, gross and net occupation of the OD, number of OT and OD budgeted and realised and number of OT and OD planned and realised.

As Table 4 show, more surgeries are performed than budgeted and less OT and OD days are realised than budgeted in 2015. Furthermore, the gross occupation of the OT was set at 98% at the production budget, but it has been 94% in 2015.

<table>
<thead>
<tr>
<th>Performance measures</th>
<th>Budgeted</th>
<th>Realised</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of surgeries</td>
<td>5,337</td>
<td>5,346</td>
<td>100.17%</td>
</tr>
<tr>
<td>Gross occupation OT</td>
<td>-</td>
<td>-</td>
<td>94%</td>
</tr>
<tr>
<td>Net occupation OT</td>
<td>-</td>
<td>-</td>
<td>75%</td>
</tr>
<tr>
<td>Number of OT days</td>
<td>2,777</td>
<td>2,604</td>
<td>94%</td>
</tr>
<tr>
<td>Number of OD days</td>
<td>1,917</td>
<td>1,507</td>
<td>79%</td>
</tr>
</tbody>
</table>
4.2.2 Unit

The performance of the units is evaluated on the following characteristics: number of surgeries performed and budgeted, capacity of the supporting staff and the number of OT and OD budgeted and realised. As shown in Table 5, the units Knee and Upper Extremity have performed more surgeries, with more OT days. The units Spine, Hip and Foot have performed less surgeries than budgeted and had less OT days realised than budgeted. All units had less OD days than included in the production budget.

Table 5: Performance orthopedic chain

<table>
<thead>
<tr>
<th></th>
<th>Spine</th>
<th>Knee</th>
<th>Hip</th>
<th>Foot</th>
<th>Upper Extremity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of surgeries</td>
<td>83%</td>
<td>103%</td>
<td>112%</td>
<td>91%</td>
<td>106%</td>
</tr>
<tr>
<td>performed vs budgeted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of OT days</td>
<td>81%</td>
<td>121%</td>
<td>84%</td>
<td>97%</td>
<td>106%</td>
</tr>
<tr>
<td>performed vs budgeted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of OD days</td>
<td>56%</td>
<td>88%</td>
<td>94%</td>
<td>88%</td>
<td>75%</td>
</tr>
<tr>
<td>performed vs budgeted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For the capacity of the supporting medical staff, the number of planned uno, duo and trio ODs is analysed. In the production budget, standard a duo OD is included, but in practice also uno and trio ODs are scheduled. When there is less supporting medical staff available, a duo OD will become an uno OD and the reverse is true for trio ODs. So, the number of uno, duo and trio ODs is an indication of the capacity of medical staff available across the year. As shown in Table 6, only the Hip unit had more uno ODs than trio ODs, which means that there was a deficiency of supporting medical staff. The other units all had more trio than uno ODs, so there was no deficiency of supporting medical staff.

Table 6: Capacity supporting medical staff

<table>
<thead>
<tr>
<th></th>
<th>Uno</th>
<th>Duo</th>
<th>Trio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spine</td>
<td>17%</td>
<td>45%</td>
<td>38%</td>
</tr>
<tr>
<td>Knee</td>
<td>8%</td>
<td>52%</td>
<td>40%</td>
</tr>
<tr>
<td>Hip</td>
<td>24%</td>
<td>55%</td>
<td>22%</td>
</tr>
<tr>
<td>Foot</td>
<td>14%</td>
<td>57%</td>
<td>30%</td>
</tr>
<tr>
<td>Upper Extremity</td>
<td>11%</td>
<td>45%</td>
<td>44%</td>
</tr>
</tbody>
</table>
4.3 Conclusion

The context analysis has given some insights into the orthopedic chain. The analysis of the control mechanism has shown that the current way of planning is not related to the production goals. On the other hand, the analysis on the performance has shown that the orthopedic chain performs very accurate to their production goals, 100.17%. However, the performance on the specific units is not well balanced, where the Hip unit has a performance of 112% and the Spine unit of 83%. Since the SMK wants a balanced production between the units, a model will be built to establish this. This model will be evaluated on a number of factors.

1. **Achieve production goals.** The SMK has set production goals for the different units. These production goals reflect the requirements of the SMK, so the main goal is to reach these production goals. Since, the production goals of 2015 differentiated between units, this will also be tested in the model. A deviation of 10% of the production goal is assumed to be acceptable, since the arrivals of patients are fluctuating. This deviation of 10% is also used in the performance analysis.

2. **Distribution of production across units.** Since this is one of the main requirements of the SMK, the number of surgeries performed by the different units will be compared to their production goals. In the current situation, the overall performance of 100.17% is acceptable for the SMK. However, the performance across the different units is unbalanced, one unit performs more surgeries in terms of percentage where the other unit performs less. Therefore, the goal for the difference between the units is set to be maximum 10%.

3. **External waiting time.** The SMK wants to focus on quality, service and throughput time. Since the waiting time of the patient starts when the first appointment is scheduled, the goal is to minimize the external waiting time. Also, throughput time will be minimized. This can be reached by minimizing the internal waiting time. As Figure ?? shows, the external waiting time varies between 50 to 250 days. Since the SMK wants low access time, these waiting times are too high. This is also in line with the Treecnorm, where the waiting time is 4 weeks for the first visit at the OD (Ministerie van Volksgezondheid, Welzijn en Sport, 2014).

4. **Number of OT days calculated and reached.** The capacity of the orthopedics, together with the production goals can be used to calculate the required number of OT days. This will be used to test whether a standard schedule will lead to different results than an optimization model.

5. **Grow on child orthopedics.** One of the goals of the SMK is to grow on child orthopedics. Since this unit is new it is not taken into account in the performance analysis. However, production goals are set for 2016 for the Child unit. So, a growing production on this unit should be reached. This means that a production beyond 100% is desired.
5 Research design

5.1 Problem statement

According to the control mechanism analysis of the SMK, it becomes clear that the main problem of the SMK is the lack of control on the production goals. Since a base schedule is used to make the personnel planning it is not possible to intentionally reach the production goals. Also, no differences are made in the base schedule for the different units. Where the Spine unit has a lower production goal and less orthopedics, a different base schedule should be used than for example the Knee unit where a lot of (short) surgeries need to be done in one year. Besides the base schedule, also no integration is made between the months. The schedule for the separate months are unattached. When a surgeon has performed a lot of OT in one month due to spare capacity of the OT, this is not related to the next month, where probably a lot of dismissal consults should be performed. Lastly, the OT schedule is leading for the arrangement of the personnel schedule. Whenever one OT is not filled, a lot will be changed in the schedule to use that OT. This can lead to an imbalance between the different units.

Some sub-problems can be identified to come to the main problem of the SMK.

1. **Duplication of work**: A lot of scheduled activities must be re-planned. This is can have several reasons, e.g. sickness of an orthopedic or an orthopedic who has other activities. As stated by Graban (2011, chapter 2), work earlier done can be classified as waste, where waste can be defined as “any problem that interferes with people doing their work efficiently or any activity that does not add value for the customer”. Graban (2011) also states that reduction of waste reduces delays and improves quality. So, it is questionable what causes the duplication of work. Is it the lack of flexibility due to releasing the session planning four months in advance? Or is it the lack of control on the production goals?

2. **Lack of flexibility**: The session planning is made five months in advance and due to the used base schedule, it is very inflexible. Since the schedulers do not deviate extensively from the base schedule, responding to rapid changes in the schedule is hard. However, the ResWeek is designed to deal with this problem, but with the ResWeek only corrective actions can be taken. This does not particularly lead to better alignment with the production goals.

3. **Lot of constraints**: The session planning of the orthopedic department depends on a lot of constraints. There are rules for the number of OTs, ODs, administration days, etc. for every orthopedic, which make the planning a complicated problem. This is mainly due to the manual session planning construction process, which is repeated each month. It is very labor intensive and probably does not lead to an optimal planning.

4. **Fragmented planning**: Different parties in the SMK have a share in the scheduling of the separate parts of the orthopedic chain. This makes it some-
times hard to coordinate the chain in such a way that the planning is optimal. For example, the department in Boxmeer does their own scheduling, which makes it labor intensive to communicate in a proper way and to make an optimal planning.

5.2 Research objective

The objective of this research consists of three parts:

1. The effect of the production- and session plan on the performance of the chain is analysed.
2. A systematic way of planning will be implemented to come to an integral and optimal production- and session plan. This will be realised with a transparent and clear planning process.
3. The matching organization structure will be designed to take the lead when changes need to be made to the original production- and session plan.

The second step will be realised by developing a model that minimizes the gap between the proposed number of patients who should have surgery, and the actual number of patients who had surgery, while taking into account the given constraints. First a mathematical model will be made. Whenever it is not possible to solve this mathematical problem, a heuristic will be designed to solve it. For this model a number of steps need to be taken, as shown in Figure 3.

![Figure 3: Project plan](image-url)
5.3 Scope

As seen in the context analysis, the planning of the SMK consist of different parts: the production- and session planning, OT planning, OD planning and planning of the supporting parties. These parts of the planning are all interrelated, but the focus is on the production- and session planning, with the resources planning as base. This is the start of the chain and the point at which control of production goals is best possible. The other parts in the planning are derivatives of the production- and session plan, so if the production- and session plan is sub-optimal, the rest will also be.

5.4 Research question

Five steps need to be taken to develop a model that can translate the proposed production to a monthly/weekly set of activities that will be scheduled by the roster planners. The context analysis, step one of Figure 3, was preliminary research. The following research question is derived from the context analysis:

**In what way should the production- and session planning of the SMK be organized, such that the realisation of the production goals can be better managed?**

There are also a number of sub-questions:

1. How can the monthly production plan be related to the number of patients entering the orthopedic chain?
2. Does hiring additional medical staff lead to a higher production ratio?
3. Does planning on half day base lead to a higher production ratio?
6 Model

To overcome the problem of integrating the production goals with the personnel planning, a model is built. This model consists of two phases. First, patient demand is predicted. The data is checked for a trend and/or seasonal effect. Second, the model for automatic resources planning is built. This is done in a couple of stages. First a Discrete-Time Markov chain (DTMC) is used to determine for every week the number of patients in a certain state (Kulkarni, 2011). The DTMC is uses a transition matrix to defined the chance of moving from state X to state Y. There are four states in the model: New Complaint (NK), Follow-up consult (VC), Operation Theater (OT) and Dismissal consult (OC). Figure 4 defines the possibilities from moving from state NK to another state and moving from other states to the NK state. These transitions are the same for the other three states.

![Figure 4: Discrete-Time Markov Chain](image)

The capacity of the orthopedics, OTs and ODs will be matched with the number of patients in every state. This means that every week a decision is made on the number of patients treated from every state. In this model, also a delay is added to the DTMC, since the patients are not moving from state X to state Y without delay. This delay is in the most favorable situation based on desired delays of the orthopedics. However, the orthopedics could not give the desired delays, because it deviated extensively between patients. Therefore the delays are based on historical data. For example the delay from OT to OC is 6 weeks.

6.1 Forecast of patient demand

Forecasting is used to make predictions of future performance, based on historical and current data (Kalekar, 2004). Since the aim of this forecast is to predict patient demand, historical data of patients arriving at the orthopedic department at the SMK will be taken as input for the model. Data from 2013 to 2015 is used, since a proper prediction of trend and/or seasonality must be based on at least three years of data (Chatfield & Yar, 1988). A wide variety of forecasting techniques is available, but the decision on the one to use depends on e.g. the objectives, properties of the data, number of series to forecast (Chatfield, 1988). Since, the Holt Winters Model for exponential smoothing takes into account both trend and seasonal data, this forecasting technique will be used.
The Holt Winters model uses exponential smoothing in order to make forecasts. The forecast is based on past observations, where the weight on recent observations is larger than on observations that are already a long time ago. These weights decline exponentially. The Holt Winters method checks for trend, seasonality and irregular factors. The forecasted values depend on the level, slope and seasonal components of the time series (Goodwin, 2010). The Holt Winters model is useful, because it can easily adapt to trends and/or seasonality in the time series.

For the prediction of arrivals in the outpatient department, the number of patients arrived in the period 2013 to 2015 is used. Every first visit to the OD is classified as a patient who comes to the SMK to the state 'New Complaint' (NK). Figure 5 gives an overview on the number of new patients during 2013 to 2015.

![Patient arrivals 2013-2015](image)

**Figure 5: Patient arrivals 2013-2015**

### 6.1.1 Decomposition of time series

Using the historical data of 2013 to 2015, different components can be defined within the time series: trend, seasonality and irregular components. The decomposition of the time series is given in Figure 6. Both a declining trend and seasonal pattern are present in the time series. For example, the seasonal factor can be noticed in the low patient arrivals in the 1\textsuperscript{st} and 53\textsuperscript{rd} week of the year. The declining trend is also seen in Table ??, where the number of orthopedic surgeries declines in the period 2013-2015.
6.1.2 Definition model

A decomposition of the time series shows both a trend and seasonality factor within the historical data of patient arrivals. Therefore, the triple exponential smoothing model of Holt Winters is applied, because this model takes into account both trend and seasonality components. The time series in the triple exponential smoothing model can be defined as (Kalekar, 2004)

\[ y_t = b_1 + b_2 t + S_t + \epsilon_t \]  

(1)

Where \( b_1 \) is the permanent component, \( b_2 \) is the linear trend component, \( S_t \) is the additive seasonal component and \( \epsilon_t \) is the random error component.

Three types of smoothing can be defined.

1. **Overall smoothing**

\[ \tilde{R}_t = \alpha (y_t - \tilde{S}_{t-L}) + (1 - \alpha) \cdot (\tilde{R}_{t-1} + \tilde{G}_{t-1}) \]  

(2)

Where \( \tilde{R}_t \) is the estimate of the deseasonalized level, \( \alpha \) is the smoothing constant and \( L \) is the length of the season.

2. **Smoothing of trend factor**

\[ \tilde{G}_t = \beta \cdot (\tilde{S}_t - \tilde{S}_{t-1}) + (1 - \beta) \cdot \tilde{G}_{t-1} \]  

(3)

Where \( \tilde{G}_t \) is the estimation of the trend and \( \beta \) is the second smoothing constant.
3. Smoothing of the seasonal index

\[ S_t = \gamma \cdot (y_t - \bar{S}_t) + (1 - \gamma) \cdot \bar{S}_{t-L} \]  

Where \( \gamma \) is the third smoothing constant. The seasonal component is based on the most recent seasonal factors taking into account the demand, \( y_t \), divided by the deseasonalized series level estimate, \( R_t \), and the previous best seasonal factor estimate for this time period.

The values for \( \alpha \), \( \beta \) and \( \gamma \) are given in Table 7. For the upcoming five years, separate \( \alpha \), \( \beta \) and \( \gamma \) can be defined, since the forecast is based on the previous years.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha )</td>
<td>0.0999</td>
<td>0.0996</td>
<td>0.0896</td>
<td>0.0864</td>
<td>0.0893</td>
</tr>
<tr>
<td>( \beta )</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>0.415</td>
<td>0.413</td>
<td>0.421</td>
<td>0.445</td>
<td>0.495</td>
</tr>
</tbody>
</table>

6.1.3 Forecast

The forecast for the next point in the time series, is given by

\[ y_t = \bar{R}_{t-1} + \bar{G}_{t-1} + \bar{S}_{t-L} \]  

The forecast for five years, derived with Holt Winters triple exponential smoothing, is given in Figure 7. As can be seen from the figure, the forecasted patient arrivals, the red line, decline during the years. A similar pattern can be seen in the different years, this is due to the seasonality pattern in the data. The seasonality can for example be seen from the lower patient arrivals in for example week 1 and 53. Less deviation can be seen during the years, this is because the years all depend on each other. Where the decline in patient arrivals is around 9% for the first year, this is around 8% for the fifth year. Lastly, in some weeks there are zero patient arrivals. This is due to the negative forecast of the Holt-Winters method. Since negative patient arrivals are not possible with this model, this forecast is set to zero patient arrivals.

Note that the forecasted arrivals of patients are lower than the actual arrivals. The decline in patient arrivals is too steep, which means that the deviation from the actual situation increases during the five years. This is because the used data set is incomplete, therefore a factor of 1.4 is used in the model to correct this.
The forecast contains also the 80% confidence interval, given in blue and the 95% confidence interval, given in grey. This means that in respectively 80% and 95% of the samples the forecast will in between the higher and the lower bound. The confidence interval for the first year is given in Figure 8. The summary of the forecast of the first year is given in Table 8, since this is the most interesting year for the SMK.

<table>
<thead>
<tr>
<th>Point forecast</th>
<th>Lower 80%</th>
<th>Higher 80%</th>
<th>Lower 95%</th>
<th>Higher 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min.</td>
<td>0.00</td>
<td>-126.91</td>
<td>-39.75</td>
<td>-152.369</td>
</tr>
<tr>
<td>1st Qu.</td>
<td>0.07</td>
<td>-39.60</td>
<td>47.30</td>
<td>-64.009</td>
</tr>
<tr>
<td>Median</td>
<td>5.68</td>
<td>-14.23</td>
<td>62.17</td>
<td>-34.254</td>
</tr>
<tr>
<td>Mean</td>
<td>8.44</td>
<td>-14.57</td>
<td>59.68</td>
<td>-34.226</td>
</tr>
<tr>
<td>3rd Qu.</td>
<td>14.86</td>
<td>13.09</td>
<td>74.54</td>
<td>-4.509</td>
</tr>
<tr>
<td>Max.</td>
<td>28.15</td>
<td>55.07</td>
<td>102.02</td>
<td>42.883</td>
</tr>
</tbody>
</table>
6.1.4 Validation

The forecast for the number of patients entering the system is validated for the first part of 2016. Historical data is compared to the Triple Exponential smoothing forecast. As shown in Figure 9, the historical data line, the green line, is covered by the 95% confidence interval lines, the red and blue lines. This means that in 95% of the samples, the green line is in between the red and the blue line. Furthermore, as can be seen from Figure 9 at one data point the historical line does not fall in between the 95% confidence interval lines. This is expected since, due to the 95% confidence interval, in 1 out of 20 predictions the forecast is not in between these lines. Since the forecast from a long period from now is less accurate, it would be more valuable to predict as little weeks as possible. This will lead to a more accurate forecast and a more accurate production plan. This can also be seen in Figure 9 where the first 10 weeks of the forecast better matches the historical data.

![Figure 9: Validation forecast](image)

6.2 Production plan

The production plan describes the number of OTs, ODs and administration days for every week required to reach the production goals. The number of patients treated every week for the NK, VC, OT and OC states are derived from this. A mathematical model and a design for the production plan is made.

6.2.1 Mathematical model

The mathematical model describes the goal of the SMK to best match the production with the production goals, together with the constraints. The model is partly based on research of Hulshof et al. (2013), where similar research is conducted, but a different goal function is used.
\[ \text{Minimize } \left| \sum_{i=1}^{t} \sum_{k=1}^{n} \frac{R_{i,k} - R_{t,k}}{n} \right| \]  

(6)

where

\[ R_{t,k} = \frac{\sum_{i=1}^{t} C_{i,k}}{\sum_{i=1}^{5} P_{i,k}} \]  

(7)

subject to

\[ W_{t,k} = \lambda_{t,k} + \sum_{k \in K} q_{i,j} \cdot C_{i,t-d_{i,j},k} \]  

(8)

\[ W_{t,k} = W_{t-1,k} - C_{t-1,k} \]  

(9)

\[ C_{t,k} < W_{t,k} \]  

(10)

\[ \sum_{k \in K} s_{k,r} \cdot C_{t,k} \leq \phi_{t,k} \]  

(11)

\[ W_{t,k} < S_{k} \lor \phi_{t,k} = 0 \lor \beta_{t} = 0 \]  

(12)

The goal function, Equation (6), minimizes the deviation between the different ratios, \( R_{t,k} \). This means that an equal distribution across the different specialisms is tried to be achieved. In the goal function, \( n \) is defined as the number of production groups and \( k \) as the different production groups. Equation (7) defines the ratio as the number of patients that had a surgery from a certain production group, \( C_{t,k} \), till this moment in time, divided by their production goal. The following production groups can be defined: (1) Hip, (2) Foot, (3) Knee, (4) Upper Extremity, (5) Spine and (6) Child, so \( n \) is 6 in this case. The number of patients waiting in the queue is given by Equation (8). This is the sum of patients that arrived during this time period plus the number of patients from an earlier state that are transferred to this state though the Discrete-Time Markov chain. The number of patients waiting for a treatment is given by Equation (9). This is defined as the number of patients waiting for a treatment in the previous period minus the number of patients already treated. Equation (10) states that not more patients can be treated than the number of waiting patients. Equation (11) refers to the resource capacity. Not more resources can be used than the multiplication of the number of patients and their time spend on a certain activity. Equation (12) states that for every week, the number of patients that are waiting to have surgery must be smaller than the number of patients that can have surgery in one day, \( S_{k} \), or the number of orthopedics available is zero, \( \phi_{t,k} \), or the number of OT rooms is zero, \( \beta_{t} \).
6.2.2 Design of the production plan

With the mathematical model as base, there are multiple ways in which the production plan can be configured. For example a production plan can be based on treatment codes, units, OTs or orthopedics. However, the question is at which level the production plan should be made to cover the whole orthopedic chain from production goals to appointment planning. Since in the current production plan units are used to define OTs and ODs, it will be evaluated whether this choice is a proper one.

Treatment codes are used at the most detailed level of activity registration, the surgery for example. In the SMK 495 treatment codes are used for the orthopedic department. The treatment code tells exactly what kind of surgery a patient had, for example a hip surgery on the left side with an implant. However, the number of patients treated every year from a certain treatment code is very low, maximum of 10 each year. So, an analysis is done in which way these treatment codes can be covered by the different units.

Since there are a lot of treatment codes which are only used once, it is questionable if all these treatment codes should be evaluated to decide whether they can be covered by the unit level. So, to simplify the problem it is checked whether 80% of the treatments can be described with 20% of the treatment codes. This is known as the Pareto principle (Reh, 2005). When the Pareto principle holds, only these 20% of the treatment codes could be used to check whether the unit level is a proper level for the production plan. Figure 10 shows the Pareto principle, where on the horizontal axis 23.68% of the treatment codes can be described with 80% of the treatments on the vertical axis. So, in the analysis on the proper layer of the production plan, only this 23.68% of the treatment codes is used, to prevent pollution of the outcomes.

![Pareto principle treatment codes](image)

Figure 10: Pareto principle treatment codes
The first step in defining the proper layer of the production plan, is to check whether treatment codes can be described by units. In the treatment codes, the unit name is incorporated. For example the code ‘ORT17H32’ should reflect a hip treatment, since the H in the treatment code reflects ‘hip’. Analysis on the 23.68% treatment codes also proves that every treatment code belongs to a certain unit. There are some minor deviations in the units, but this is due to overlapping treatments, which can both be classified as for example Upper Extremity or Hip.

The same is done for the orthopedics. Orthopedics are connected to certain units, and analysis has shown that they are also connected to these treatment codes. So the orthopedics and their treatment codes can be derived from the units in which they are employed.

Besides the units and orthopedics, also an analysis is done on the different OTs. In the SMK, two types of OTs are used. There are four OTs on which all surgeries can be planned (OK) and two OTs on which only treatments without difficult anesthesia (OIC) can be planned. Analysis on these OTs show that only Spine surgeries cannot be planned on the OIC. All other surgeries from the other units can be planned on both the OK as the OIC.

Lastly, the division is made in reporting group. A reporting group describes a certain group of treatments like for example hip replacement with implant. Since the treatment codes describe the same in more detail it is expected that the reporting group can be derived from the treatment codes, which seemed to be true. Furthermore, the data shows that a reporting group is part of a unit.

In conclusion, treatment codes can be described in various ways. However, all these can be derived from the higher layer ‘unit’. So a production plan on the unit layer seems appropriate.

6.2.3 Heuristic

Since the mathematical problem is complex, due to the delays in patients entering a next state and the large amount of states, a heuristic will be used to solve the problem of the SMK. Also, Hulshof (2013) shows that the implementation of a mixed linear integer program (MILP) on a similar problem takes a long time to solve. For example, 70 queues and 8 time periods already takes 3,741 seconds, where 70 queues and 4 time periods only took 134 seconds. So, when at least 53 weeks need to be predicted, it probably takes too long to solve the MILP. Furthermore, they also did not take into account the delays of the patients entering a new state, which is very important for practical implementation of the model in the SMK. Therefore, a heuristic will be built for this problem.
The heuristic consists of a number of steps. First, a number of initial values must be entered, e.g. the capacity of the orthopedics for every week, the number of OTs available and the initial number of patients in the different states. Second, a production problem will be executed for every single week. This starts with the calculation on the number of patients in every state. For example the number of patients waiting for an NK treatment in week \(i\) for group \(j\) is defined as

\[
W_{i,k}^{NK} = W_{i-1,k}^{NK} + q_{NK,NK} \cdot C_{i-d_{NK,NK},k}^{NK} + q_{VK,NK} \cdot C_{i-d_{VK,NK},k}^{VK} + q_{OT,NK} \cdot C_{i-d_{OT,NK},k}^{OT} + q_{OC,NK} \cdot C_{i-d_{OC,NK},k}^{OC} + \lambda_{i,k}
\]

Where \(d_{i,j}\) is the delay from state \(i\) to state \(j\) and the transition matrix \(q_{i,j}\) is given by

\[
q_{i,j} = \begin{pmatrix}
NK & VC & OT & OC & Home
\end{pmatrix}
\]

When the number of patients waiting in every state is known, a decision must be made on the number of treatments to be performed for that week. This decision is based on a number of factors: (1) the number of patients waiting in a certain state, (2) capacity of OTs, (3) capacity of orthopedics and the ratio of performance for the current year. The ratio gives an overview of the current realisation of surgeries of the year, related to the production goals. The higher the ratio, the higher part of the production goals already performed. The ratio is given as

\[
R_{t,k} = \frac{\sum_{i=1}^{t} C_{i,k}}{P_k}
\]  

(13)

For every week the following iteration is performed

1. Calculate ratio for six production groups.
2. Choose production group with the lowest ratio.
3. Plan OT when the following constraints for the chosen group are true:
   - (a) Enough patients on the waiting list.
   - (b) Orthopedic has spare capacity.
   - (c) OT capacity available.
4. Update realisation OT, capacity of orthopedic and capacity of OT for this group.
5. Plan OD when the following constraints are true:
   - (a) Enough patients on the waiting list.
   - (b) Orthopedic has spare capacity.
6. Update realisation OD and capacity of orthopedic of this group.
7. Recalculate ratio, when a production group cannot perform OD and OT, this group is blocked, and the optimization procedure is continued.
8. When all production groups cannot perform OT and OD, the production of this week is maximized.

This procedure is performed for every simulated week.

The number of patients treated in one OT is different for the six production groups. This is because it is related to the surgery time of one patient. Since one spine surgery takes longer than one knee surgery, more knee surgeries can be performed in one OT day than spine surgeries. Furthermore, a scheme is used for the OD. This means that a combination of NK, VC and OC is treated in one OD day.
7 Results

A case study is conducted to test the usability of the model. The model is implemented into the schedule of the orthopedics of the Sint Maartenskliniek (SMK). Since, the SMK wants to have a production plan for the upcoming periods, the model is set to predict the number of OTs and ODs needed for every week in the upcoming 5 years.

7.1 Initialization

The model needs some input variables, like the capacity of the orthopedics, the OT schedule, the number of OTs in one day and the transition matrix. A short description will be given on the initialization of these parameters.

7.1.1 Capacity orthopedics

The orthopedics need to submit their holidays five months in advance. This means that for the upcoming five years not the complete availability of orthopedics for every week is known. However, there is some information on the number of days every year they need to spend on patient care, OT and OD and on the percentage division of orthopedics across units. Together with the OT schedule, a prediction is made on the number of orthopedic days available every week for every unit. The OT schedule mentions some weeks in which it is only partially opened, the reduction periods. In these periods, also partially deployment of orthopedics is assumed. This prediction can be changed when the actually holidays of the orthopedics are known.

7.1.2 Capacity OT

The OT capacity is not fixed every week, due to holidays and other SMK activities like OT maintenance. Therefore, an OT schedule is available for every day with the number of OTs available. This schedule is used as input for the model. However, since the OT schedule of five years from now is not finished yet, the OT schedule of 2016 is used multiple times.

7.1.3 Realisation OT July 2015 - June 2016

The model uses data of previous treatments to determine the number of patients in the different states every week. Therefore, the realisation of the number of patients on OT and OD of the previous year (July 2015-June 2016) is needed. This realisation of patients is split up into the six different units. This is also done for the current waiting list. The number of planned NK, VC, OT and OC is used as the current waiting list, because all patients are planned immediately when they arrive at the SMK. Since the waiting list of OT patients of the unit Child is not known it is assumed to be 100 waiting patients.
7.1.4 Number of treatments in one day

Two different sessions are planned for the different units, OT and OD. Since sessions are assigned to a unit, only patients with similar diseases will be scheduled. At the moment, sessions are scheduled with patients of different units, but with this strategy it is really hard to control the number of sessions needed to comply to the production goals. Therefore, the sessions will be planned for a unit instead of for an orthopedic. The number of patients that can have surgery within one surgery day is determined on historical data. The average surgery duration, together with the set up time, is used to determine the average number of patients treated within one surgery day. The number of surgeries in one day is given in Table 9.

Table 9: Number of surgeries in one OT day

<table>
<thead>
<tr>
<th>Unit</th>
<th>Number of surgeries in one day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>4.2</td>
</tr>
<tr>
<td>Foot</td>
<td>4.4</td>
</tr>
<tr>
<td>Knee</td>
<td>4.2</td>
</tr>
<tr>
<td>Upper Extremity</td>
<td>4.6</td>
</tr>
<tr>
<td>Spine</td>
<td>2.6</td>
</tr>
<tr>
<td>Child</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Besides the number of patients treated in one OT session, also the number of patients treated in one OD session is determined. This is based on the current OD schedule of the SMK. The OD schedule is given in Table 10. This OD schedule is a duo OD session, which means that one orthopedic has consultation hour together with one supporting medical staff.

Table 10: Number of treatments in one OD day

<table>
<thead>
<tr>
<th>Unit</th>
<th>NK</th>
<th>VC</th>
<th>OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>15</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>Foot</td>
<td>10</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Knee</td>
<td>13</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>Upper Extremity</td>
<td>14</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>Spine</td>
<td>16</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>Child</td>
<td>12</td>
<td>18</td>
<td>8</td>
</tr>
</tbody>
</table>
7.1.5 Transition matrix

The transition matrix is used to determine the number of patients in every state. This is done by using historical data on the transitions between the states. The frequency of a transition determines the chance that a patient will move from state X to state Y. Historical data gives the following transition matrix.

\[
q_{i,j} = \begin{pmatrix}
0.027783 & 0.391313 & 0.454314 & 0.017413 & 0.109176 \\
0.019375 & 0.476789 & 0.127310 & 0.113434 & 0.263092 \\
0.007984 & 0.574989 & 0.040292 & 0.376660 & 7.46 \cdot 10^{-5} \\
0.015726 & 0.676011 & 0.044558 & 0.014473 & 0.249231 
\end{pmatrix}
\]

For example when a patient is currently in state NK, he has a chance of 2.8% of becoming NK again, 39% of going to VC, 45% of going to OT, 1.7% of going to OC and 10.9% chance of going home. Also a delay matrix is used to decide how long it takes if a patient moves from state X to state Y. This delay matrix, in weeks, is given as \(d_{i,j}\). However, these delays are based on the fact that a patient can be planned immediately. However, since the orthopedic chain has also a general mean waiting time of 2 weeks, the delays are increased with 2 weeks. This takes care of a proper delay between the different states.

\[
d_{i,j} = \begin{pmatrix}
20 & 12 & 10 & 10 & - \\
21 & 15 & 9 & 6 & - \\
10 & 6 & 2 & 8 & - \\
25 & 13 & 7 & 9 & - 
\end{pmatrix}
\]

7.1.6 Production goals

The production goals for five years are based on the inflow of patients and the transition matrix. During five years, the arrivals of patients decreases with around 9% each year. However, only 65% of these patients actually get a surgery according to the transition matrix. Therefore, the decline in patient arrivals is around 6.5%. This is taken into account in the production goals. The production goals for the separate five years are given in Table 11 and are based on the previous year. Equation (14) is used to calculate the production goals. Where \(q_{i,3}\) reflect the chance of moving from one of the four states to the OT state.

\[
P_{t,k} = P_{t-1,k} \cdot \frac{\lambda_{t,k}}{\lambda_{t-1,k}} \cdot \sum_{i=1}^{4} q_{i,3}
\]
<table>
<thead>
<tr>
<th>Unit</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage growth surgeries</td>
<td>-0.0666</td>
<td>-0.0664</td>
<td>-0.0597</td>
<td>-0.0576</td>
<td>-0.0595</td>
</tr>
<tr>
<td>Hip</td>
<td>1,088</td>
<td>1,016</td>
<td>955</td>
<td>900</td>
<td>847</td>
</tr>
<tr>
<td>Foot</td>
<td>922</td>
<td>861</td>
<td>809</td>
<td>763</td>
<td>718</td>
</tr>
<tr>
<td>Knee</td>
<td>2,017</td>
<td>1,883</td>
<td>1,771</td>
<td>1,669</td>
<td>1,570</td>
</tr>
<tr>
<td>Upper Extremity</td>
<td>1,206</td>
<td>1,126</td>
<td>1,059</td>
<td>998</td>
<td>938</td>
</tr>
<tr>
<td>Spine</td>
<td>670</td>
<td>626</td>
<td>588</td>
<td>555</td>
<td>521</td>
</tr>
<tr>
<td>Child</td>
<td>281</td>
<td>263</td>
<td>247</td>
<td>233</td>
<td>219</td>
</tr>
</tbody>
</table>

### 7.1.7 Number of OT and OD days suggested to reach production goal

Besides the mathematical model, a calculation can be made on the number of OD and OT days that need to be scheduled every week to reach the production goals. For example, production goal for the Hip unit is 4,807 surgeries in five years. Since 4.2 surgeries can be performed in one OT, 4,807 / 4.2 OT days are needed. In total 2,335 days of patient centered care is available for this unit, so besides the 1,145 days OT needed, also 1,190 OD days remain. Since 48 weeks are fully available in one year, without holidays, respectively 4.8 and 5.0 OT and OD days must be scheduled in one regular week for the Hip unit. The same is done for the other five units. The results are given in Table 12.

| Number of days orthopedics available | Hip | 2,335 | 2,080 | 3,745 | 2,335 | 2,550 | 1,150 |
| Production goal                     | 4,807 | 4,075 | 8,910 | 5,327 | 2,960 | 1,245 |
| Number of surgeries one OT day      | 4.2   | 4.4   | 4.2   | 4.6   | 2.6   | 3.7   |
| Suggested OT days                   | 1,145 | 926   | 2,121 | 1,158 | 1,138 | 336   |
| Available OD days                   | 1,190 | 1,154 | 1,624 | 1,177 | 1,412 | 814   |
| OT days in one week                 | 4.8   | 3.9   | 8.8   | 4.8   | 4.7   | 1.4   |
| OD days in one week                 | 5.0   | 4.8   | 6.8   | 4.9   | 5.9   | 3.4   |

### 7.2 Outcomes

After the initialization, the model generates some outcome variables. First, the number of NK, VC, OT and OC patients treated is compared to the production goals, which is expressed in the ratio.

\[
\text{Cumulative number of patients treated} \over \text{Production goals} \quad (15)
\]
Furthermore, the waiting list, capacity of orthopedics and capacity of the OT are evaluated.

7.2.1 Number of OT and OD days in one week

The model determines the number of OT and OD days for every week. As calculated with the mathematical model, a certain number of OT and OD weeks per unit are suggested to reach the production goal. As can be seen from Table 13, the suggested number of OT days is not reached for all units. Only the Child unit has planned enough OT days to reach its production goals. The reason why less OT is planned will be further explained in the Results section.

For the OD days no unit has performed ’enough’ OD days. However, this suggested number of OD days is related to the capacity of the orthopedics available. Whenever there is spare time for the orthopedic, it is assumed that OD will be performed. However, also other activities can be performed in the spare time.

<table>
<thead>
<tr>
<th></th>
<th>Hip</th>
<th>Foot</th>
<th>Knee</th>
<th>UE</th>
<th>Spine</th>
<th>Child</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suggested OT days in one week</td>
<td>4.8</td>
<td>3.9</td>
<td>8.8</td>
<td>4.8</td>
<td>4.7</td>
<td>1.4</td>
</tr>
<tr>
<td>Realised OT days in one week</td>
<td>3.1</td>
<td>2.3</td>
<td>6.9</td>
<td>3.3</td>
<td>4.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Suggested OD days in one week</td>
<td>5.0</td>
<td>4.8</td>
<td>6.8</td>
<td>4.9</td>
<td>5.9</td>
<td>3.4</td>
</tr>
<tr>
<td>Realised OD days in one week</td>
<td>3.1</td>
<td>2.4</td>
<td>6.4</td>
<td>3.3</td>
<td>4.2</td>
<td>1.7</td>
</tr>
</tbody>
</table>

7.2.2 Realisation of OD

The number of patients treated in the different categories is based on the OD schedule and the number of patients treated earlier in the OD and OT. However, when there are not enough patients in one of the three states to plan one full OD, OD will still be planned. However, empty space remains for the states that do not contain enough patients, in this case mostly NK and OC. This takes care of a decline in waiting patients for the states that have a long waiting list, VC in this case. This also relates to the requirement of the SMK, where a short waiting list is desired.

Figures 11 - 14 give the realisation of NK, VC, OT and OC for five years. As shown in Figure 11 the realisation of NK is much larger in the first half year than in the following 4.5 year. This is due to the buffer of NK patients at the start of the simulation. Since within half a year this buffer is used to fill the OD sessions, this amount drops to a lower point. After 0.5 year the pattern of NK patients realised is comparable to the forecast on the number of NK patients coming in the system. Since the NK state contains mostly arrivals of patients, the number of NK patients that can be treated also decreases. Figure 12 shows the realisation of VC patients.
As can be seen for four years the same pattern is visible for the units. It is almost stable on a certain level with some drops. These drops are due to the number of orthopedics available. In some periods there are less orthopedics available, which means that less OD can be planned. After 3.5 years, a decline can be seen in the realisation of VC. This is due to the number of patients in the system. Since during the five years there is a decreased decline in incoming patients, as shown in Figure 7, also the number of patients within the VC state will be lower. The same pattern is present for the OT, Figure 13. Almost a stable number of patients has surgery every week with some drops due to availability of OTs and orthopedics. Also a drop in realisation is present after the third year, which is due to less patients in the system. However, there is an increase in the number of OTs performed by the Knee unit. This is due to the availability of orthopedics and the number of patients entering the OT state. This is higher due to a higher number of ODs performed. For the realisation of OC, 14, the number of patients treated is almost stable for the different units. This means that a stable number of ODs is planned across the period.

7.2.3 Realisation of OT production goals

The production goals for five years are defined for every unit. This is given in Table 14. It also gives the realisation and the ratio after five years. As shown in this table,
the Spine and Child unit have performed more than their production goals in five years, respectively 108% and 141%. The units Hip, Foot and Upper Extremity have performed around 70% of their production goals. The unit Knee has also not reached its production goal, with a production of 87%. There are a lot of different variables causing the differences in production ratio. For example the capacity of the orthopedics is relatively large for the Child and Spine unit, which can explain the production ratios of 141% and 108%.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Realisation</th>
<th>Production goal</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>3,473</td>
<td>4,807</td>
<td>0.723</td>
</tr>
<tr>
<td>Foot</td>
<td>2,684</td>
<td>4,074</td>
<td>0.659</td>
</tr>
<tr>
<td>Knee</td>
<td>7,724</td>
<td>8,910</td>
<td>0.867</td>
</tr>
<tr>
<td>Upper Extremity</td>
<td>3,974</td>
<td>5,327</td>
<td>0.746</td>
</tr>
<tr>
<td>Spine</td>
<td>3,185</td>
<td>2,960</td>
<td>1.076</td>
</tr>
<tr>
<td>Child</td>
<td>1,750</td>
<td>1,245</td>
<td>1.406</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22,790</strong></td>
<td><strong>27,323</strong></td>
<td><strong>0.834</strong></td>
</tr>
</tbody>
</table>

Figures 15 and 16 show the cumulative realisation of Hip and Foot OT across the year. As can be seen, both units perform worse than their production goals, respectively 72% and 66%, given as the black line. Furthermore, both figures show a stationary realisation, after 3.5 to 4 years. This is because less patients are entering the system, which also means that less patients can have surgery. This can also be seen in a declining realisation of OT in Figure 13. Furthermore, an almost constant increase of the production can be seen in the first 4 years, this is due to the (almost) stable number of OTs planned for the different units. Some drops can be noticed in the reduction periods. However these drops are present in the realisation of the OT of all six units.

Figures 17 and 18 show two units who do almost reach their production goals within five years. In the Knee unit, an upward trend can be noticed, which is at 87% after 5 years. The Upper Extremity unit also show an upward trend in the realisation of patients on the OT in the first 4 years. This upward trend stabilizes,
which is the same as for the Hip unit. This is due to the low amount of patients on
the waiting list for an OT in 4 years. This will be further explained in the Section Waiting list.

![Figure 17: Production goals Knee](image1)

![Figure 18: Production goals UE](image2)

Lastly, Figures 19 and 20 show the units who do reach their production goals within
4 to 4.5 years. The performance is respectively 108% and 141%, related to the pro-
duction goals. Since the capacity of orthopedics of these units is rather high com-
pared to the other four units and their production goals are relatively small, they
are able to reach their production goals. Furthermore, these units do not have rapid
decline in patients on the waiting list for OT, since enough OD can be planned.

![Figure 19: Production goals Spine](image3)

![Figure 20: Production goals Child](image4)

### 7.2.4 Waiting list

The waiting list of the different units and four states is given in Figures 21 - 24. The
waiting list of NK positions is almost zero for the five years. This is due to the
relatively low amount of NK patients entering the system. Since the OD will be
planned when either one patient is in the NK, VC or OC state, this will lead to zero
waiting patients in the NK state. However, in some weeks there are waiting NK
patients. These weeks are mostly the last weeks of the year, New Year, in which
almost zero capacity of orthopedics is available. No orthopedics available also
means that no OD can be planned. The waiting list of the VC state increases in the
first weeks. This increase is due to the realisation of OD sessions before the start of
the simulation. A large amount of patients had some treatment, which means that their control visit and dismissal consult are transferred to this model. Therefore, the model needs to adapt the amount of patients, where after the 13th week the amount of waiting VC patients drop drastically. This is because the buffer, which is built in the first 13 weeks, is used to fill the OD sessions for the weeks after it. The drop in the waiting list of VC for the Knee unit is drastic. This is because the Knee unit has the highest number of VC places within the OD consultation hour. So, when there are a lot of patients on the waiting list to get a VC consult and a large amount of OD is planned, Figure 12, the waiting list for VC treatments will decline. The other units also show a decline in the waiting list for VC. However, due to the lower amounts of VC patients that can be treated in one OD and the lower amount of planned OD, this decrease is less steep.

Figure 23 shows the waiting list for the OT treatments for the different units. As can be seen from this figure, there is a decline in the number of patients waiting for an OT treatment, not taken into account the Child unit. This is due to the declining number of patients entering the orthopedic department, Figure 7. The waiting list increases the first 13 weeks. The same reason applies for this increase as for the increase in VC patients. These are patients transferred from the states before the actual simulation has started. The drop in the number of waiting patients for the Spine unit is less steep, since this unit has relatively more capacity to perform OD and less patients can be treated within one OT session. The waiting list for OT for the Child unit is increasing. This is due to the large amount of planned OD. This takes care of a great amount of children in the waiting list for OT. The waiting list for OC is comparable to the waiting list for NK consults. An increase is present in the waiting list for the first 13 weeks, which is due to the start of the simulation. Furthermore, there are some peaks on the number of OC patients on the waiting list. However, these peaks are in the periods that no orthopedics are available due to holiday.
7.2.5 Capacity orthopedics

The capacity of orthopedics is given in Figure 25. It shows the unused capacity of the orthopedics after the optimization of treatments on NK, VC, OT and OC. So, when the orthopedic has some spare capacity, this means that either no OT capacity or patients were available or that no OD could be planned due to no patients in the NK, VC and OC state. As can be seen from Figure 25, all units have almost zero spare capacity for the first four years. After these four years the orthopedics of the Hip, Foot, Knee and Upper Extremity unit get some more spare capacity. This is due to the low amounts of patients that are in the system for these units. The waiting lists are almost zero for these units, so less OT can be planned, and more OD.

7.2.6 Capacity OT

The spare capacity of the OT is given in Figure 26. The figure shows a growing number of OTs unused. This is because of the low amounts of patients in the OT states at the end of the simulation period. When a low amount of patients is entering the system, less OTs can be planned. Furthermore, in the first 3.5 years the spare capacity of the OT is due to lack of capacity of the orthopedics. Since, they need to perform both OD and OT, the full capacity of the OT cannot be used. Whenever priority is given to perform OD, this will lead to less patients in the OT.
state a few weeks later, since less patients have been seen on the OD, which causes less patients available for OT.

![Figure 26: Spare capacity OT](image)

### 7.3 Scenarios

To test whether the model reacts on minor changes, some scenarios will be evaluated. Whether these scenarios give better results or more reliable results will be checked. The following four scenarios will be tested.

1. What is the effect of planning of half day base instead of day base?
2. What is the effect of employing supporting staff?
3. What is the effect of planning with an optimal OD schedule?
4. What is the effect of adjusted production goals and patient arrivals?

#### 7.3.1 Scenario 1: Planning on half day base

In the current model planning is based on daily base. That means that an orthopedic has a full day OT or OD. However, in practice it is also possible to plan on half day base. So, for example an orthopedic can have OD in the morning and administration in the afternoon. The effect of this different planning strategy is given in Table 15. As stated in Table 15, the units Hip, Foot and Upper Extremity have around 6% more production in the scenario with planning on half day base. The units Spine and Child have a decreased production of <17%. The changes are in favor of the units that had a lower production ratio. This means that a more balanced production is established with this way of planning.
Table 15: Scenario 1: Planning on half day base

<table>
<thead>
<tr>
<th>Unit</th>
<th>Ratio current situation</th>
<th>Ratio Scenario 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>0.723</td>
<td>0.795</td>
</tr>
<tr>
<td>Foot</td>
<td>0.659</td>
<td>0.720</td>
</tr>
<tr>
<td>Knee</td>
<td>0.867</td>
<td>0.885</td>
</tr>
<tr>
<td>Upper Extremity</td>
<td>0.746</td>
<td>0.801</td>
</tr>
<tr>
<td>Spine</td>
<td>1.076</td>
<td>1.004</td>
</tr>
<tr>
<td>Child</td>
<td>1.406</td>
<td>1.244</td>
</tr>
</tbody>
</table>

Besides a changing production ratio, the spare capacity of orthopedics is less than in the original situation, Figure 27. This also leads to less spare OT time, Figure 28. However, since an OD session is started when there is either one NK, VC or OC patient, no major difference can be noticed in the spare capacity of the orthopedic and the OD. There is some change in the spare time of the orthopedics between the different units, since the production ratio has changed some between the units.

![Figure 27: Scenario 1: Spare capacity of orthopedics](image)

![Figure 28: Scenario 1: Spare capacity OT](image)

### 7.3.2 Scenario 2: Plan with supporting medical staff

In the model, the OD sessions are planned as duo sessions. This means that one orthopedic has consultation hour, together with one supporting medical staff. However, it is also possible to plan two supporting medical staff instead of one or no supporting medical staff. This scenario checks whether planning supporting medical staff leads to a better performance on the OT. Tables 16 - 17 show the OD schedule for a trio and uno OD session. Since the Child unit has only one kind of consultation hour, the schedule is the same for uno, duo and trio OD.
Table 16: Schedule Trio OD

<table>
<thead>
<tr>
<th>Unit</th>
<th>NK</th>
<th>VC</th>
<th>OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>18</td>
<td>21</td>
<td>11</td>
</tr>
<tr>
<td>Foot</td>
<td>12</td>
<td>18</td>
<td>11</td>
</tr>
<tr>
<td>Knee</td>
<td>21</td>
<td>23</td>
<td>10</td>
</tr>
<tr>
<td>UE</td>
<td>20</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>Spine</td>
<td>17</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>Child</td>
<td>12</td>
<td>18</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 17: Schedule Uno OD

<table>
<thead>
<tr>
<th>Unit</th>
<th>NK</th>
<th>VC</th>
<th>OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>8</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Foot</td>
<td>7</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Knee</td>
<td>8</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>UE</td>
<td>10</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Spine</td>
<td>8</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Child</td>
<td>12</td>
<td>18</td>
<td>8</td>
</tr>
</tbody>
</table>

In Table 18, the two OD schedules are evaluated. As can be seen from this table, the trio OD does lead to a better production ratio for four of six units. However, this is at the expense of the Upper Extremity unit. Since the Upper Extremity unit drops very fast to zero waiting list on the OT, this low ratio is the result. This is because a lot of patients can be treated within a trio OD, and the buffer of the Upper Extremity unit is lowest. For the situation where only uno ODs are performed, the production ratio drops for three out of six units with 6.2% to 29.9%. This is because less patients can be seen within one OD, which lead to less patients that are ready for OT.

Table 18: Scenario 2: Supporting medical staff

<table>
<thead>
<tr>
<th>Unit</th>
<th>Ratio duo OD (Current situation)</th>
<th>Ratio trio OD</th>
<th>Ratio uno OD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>0.723</td>
<td>0.881</td>
<td>0.505</td>
</tr>
<tr>
<td>Foot</td>
<td>0.659</td>
<td>0.878</td>
<td>0.597</td>
</tr>
<tr>
<td>Knee</td>
<td>0.867</td>
<td>0.888</td>
<td>0.568</td>
</tr>
<tr>
<td>UE</td>
<td>0.746</td>
<td>0.441</td>
<td>0.784</td>
</tr>
<tr>
<td>Spine</td>
<td>1.076</td>
<td>1.098</td>
<td>1.116</td>
</tr>
<tr>
<td>Child</td>
<td>1.406</td>
<td>1.364</td>
<td>1.554</td>
</tr>
</tbody>
</table>

Figure 29 also show that in the uno consultation hours, the orthopedic has less peaks in their spare capacity. This is due to the more consultation hours needed to reach the same amount of patients ready for OT.

Figure 29: Scenario 2: Spare capacity of orthopedics
7.3.3 Scenario 3: OD schedule according to transition matrix

Besides the OD schedule provided by the SMK, also an optimal OD schedule can be calculated. This OD schedule is based on simulation on the number of patients entering every state every period, the transition matrix. For every week the rate on the number of patients in the NK, VC and OC state is determined. This is used to find the stable situation, where the OD schedule is optimal. This optimal division is used to calculate the optimal OD schedule. This schedule is provided in Table 19.

<table>
<thead>
<tr>
<th>Unit</th>
<th>NK</th>
<th>VC</th>
<th>OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>7</td>
<td>22</td>
<td>11</td>
</tr>
<tr>
<td>Foot</td>
<td>5</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>Knee</td>
<td>7</td>
<td>22</td>
<td>11</td>
</tr>
<tr>
<td>Upper Extremity</td>
<td>7</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>Spine</td>
<td>6</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td>Child</td>
<td>7</td>
<td>21</td>
<td>10</td>
</tr>
</tbody>
</table>

The optimal OD schedule is used to recalculate the performance ratios. These ratios are compared to the ratios of the current situation, and are given in Table 20. The ratios are for four out of six units higher than the current ratio, which means that this OD schedule performs better than the schedule currently used at the SMK. Only the Spine and Child units have a lower production ratio than the current situation. However, these units had already reached its production goals. So, for a more balanced division of production between the units, this OD schedule can be better used.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Ratio (Current situation)</th>
<th>Ratio optimal OD schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>0.723</td>
<td>0.915</td>
</tr>
<tr>
<td>Foot</td>
<td>0.659</td>
<td>0.903</td>
</tr>
<tr>
<td>Knee</td>
<td>0.867</td>
<td>0.898</td>
</tr>
<tr>
<td>UE</td>
<td>0.746</td>
<td>1.007</td>
</tr>
<tr>
<td>Spine</td>
<td>1.076</td>
<td>1.046</td>
</tr>
<tr>
<td>Child</td>
<td>1.406</td>
<td>1.138</td>
</tr>
</tbody>
</table>
7.3.4 Scenario 4: No adjustment in the arrivals of patients

The forecast of the patient arrivals of the SMK has turned out to be too low. This is due to the incomplete data set provided by the SMK. The impact of this change in patient forecast will be evaluated in this scenario. Since the forecast was too low, the patient arrivals were multiplied by a factor 1.4. This factor took care of a more reliable number of patients entering the system. However, when this factor 1.4 is not applied, four out of six units will have a lower production ratio, shown in Table 23. This includes the units that already had the lowest production ratios. So, the lower amount of patients entering the system takes care of an earlier lack of patients in these units, which leads to a more unbalanced production ratio between the different units. This can also be seen in the waiting list of the OT, the units Hip, Foot and Upper Extremity are earlier without patients on the waiting list, which takes care of less patients that can have surgery, also shown in Figure 30.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Ratio (Current situation)</th>
<th>Ratio no adjusted forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>0.723</td>
<td>0.692</td>
</tr>
<tr>
<td>Foot</td>
<td>0.659</td>
<td>0.631</td>
</tr>
<tr>
<td>Knee</td>
<td>0.867</td>
<td>0.855</td>
</tr>
<tr>
<td>UE</td>
<td>0.746</td>
<td>0.722</td>
</tr>
<tr>
<td>Spine</td>
<td>1.076</td>
<td>1.079</td>
</tr>
<tr>
<td>Child</td>
<td>1.406</td>
<td>1.441</td>
</tr>
</tbody>
</table>

Figure 30: Scenario 4: Waiting list OT
8 Conclusion

Literature review has shown that extensive research is carried out on different parts of the planning process, for example on case mix and personnel planning. However, limited research is done on the integration of different steps in the planning process (Hulshof, 2013). The Sint Maartenskliniek in Nijmegen, is currently facing the problem of integrating the production goals with the personnel planning on monthly and weekly base. Currently, the planning method is based on a fixed schedule, which did not represent the production goals. To overcome this problem, a planning supporting tool is built. With this tool a prediction can be made on the amount of operation theater and outpatient department hours required to optimally schedule patients.

8.1 Conclusion

Analysis on the approach of patient coding used at the SMK has resulted in the most applicable design of the production plan. A production plan on unit level turned out to be the most suitable. The different layers of coding in the SMK, e.g treatment groups and reporting groups, can on a higher level of abstraction be translated to six units. Furthermore, a production plan on unit level gives the planners only six units to focus on, which makes planning less complicated than for example with 20 treatment groups. Besides the coding strategy used by the orthopedics, also the production plan of 2017 is made on unit level. This gives the SMK a general way of planning on the highest level within the orthopedic chain.

The planning supporting tool is able to determine the number of incoming patients, and the number of patients in the four different states (NK, VC, OT and OC) with a Discrete-Time Markov Chain (Kulkarni, 2011). With the prediction of patient demand and number of patients in the four states, OT and OD are distributed to the six different units. However, Figure 21 shows a low number of incoming patients, which results in a relatively short waiting list for an NK treatment. The waiting list for the VC and OT treatments is decreasing. After four years, the waiting list for the VC treatment stabilizes. This means that around as many patients are coming into the VC state as that are treated, also shown in Figure 22. This is due to the lower amount of OD treatment hours. Since less patients are available for the consultation hour and less patient get surgery, also less patients are returning to the VC state. The waiting list for the OT treatment decreases after half a year. This is due to the buffer of the patients that were already in the system. Not as many patients are entering this buffer, compared to the number of patients treated. Note that if an OD is opened only when there are enough NK, VC and OC patients to fill one OD hour completely, the VC waiting list increases.

The realisation of the OT related to the production goals is different for the six units. The units Hip, Foot and Upper Extremity have performed around 70% of
their production goals within 5 years. This also shown in the number of planned OD and OT hours, in Table 13. For these units, relatively the lowest amount of OT days was planned in one week. The Knee unit has almost reached its production goal, with a performance of 87%, also with a lower amount of planned OT. The units Spine and Child have reached respectively 108% and 141% of their production goals, where the Spine units had less OT days planned than suggested. This difference is due to the 48 weeks on which the suggested number of OT days was based. Some spare weeks were used to reach the production goals, even with a lower rate of OT during one week. Since there is some spare OT space, as shown in Figure 26, more OT could have been planned. However, the number of OD hours is maximised, because the tool plans one OD whenever there is one NK, VC or OC patient. Therefore, also no more patients could have been in the OT state. Since the orthopedics had very little spare time in the first 4 years it can be concluded that this was the main cause for the spare time of the OT. However, in the next year a lot of spare capacity was available for the orthopedics. However, a small amount of patients was on the waiting list for OT, which resulted in an underutilised OT.

Four different scenarios were tested to evaluate the model. Scenario 1, planning on half days instead of full days, does lead to a production ratio that is more balanced across the units. The units that had a production around 70% got about 6% more OT production and the units that had a production between 108 and 141% lost between 7.3 and 16.2% production. So, this way of scheduling does lead to a more balanced production ratio. However, the difference is minimal. Scenario 2 has shown that the low number of incoming patients results in a production of 44% for the Upper Extremity Unit, with trio OD. The other units profit from the extra supporting medical staff added to the OD session with added production. The uno OD leads to less production for the units that already had a lower production ratio. The other units, with a production of 100% profit from this decrease. So, a less balanced production ratio is the result. This difference is because less patients have been seen on the OD session, which results in less patients that are ready for OT. Scenario 3 has shown that an optimal OD schedule leads to a better OT performance, according to the transition matrix. Less space remains unused due to a lack of NK and OC patients, the OD consultation hour can now be used more effectively.

Next to the conclusion based on the results of the model, also some Key Performance Indicators were defined in Section 4.3. The first KPI is to reach a better distribution of performance across units. However, the model does not fulfill this KPI due to the lower production ratio of the Foot unit, 87%. This is due to the incomplete data available. This causes an incomplete transition matrix, which causes the system to run out of NK and OC patients. The performance ratio should guarantee an equal distribution across units, but this is only possible whenever there are enough patients in the different stages of the system. The second KPI is the external waiting time. As Figure ?? shows the external waiting time for the different treatments varies between 50 and 250 days. However, the results of this research
show that the waiting time becomes one week at most for new patients, this is without the general waiting time of 2 weeks. This is related to the unequal distribution of NK, VC and OC patients. So, a definite conclusion can be drawn when the transition matrix is up to date. Lastly, the SMK wants to grow on Child orthopedics. Since the Child unit has performed 141% of their production goal, this KPI is met. However, the increase in Child orthopedics is partly due to the lack of patients in the other five units. So, this means that either a lot of orthopedics are available for the Child unit, or relatively few orthopedics and patients are available for the other units.

8.2 Recommendations

The literature review and case study give several directions for further research. The recommendations can be divided into scientific recommendations, used to perform future research on this topic, and practical recommendations.

8.2.1 Scientific recommendations

As shown earlier in the literature review, research on the integration of different parts of the planning process is scarce (Hulshof, 2013; Adan & Vissers, 2002). Therefore, it is hard to match the outcomes of this case study with scientific literature. So, one of the first recommendations to further research is to use the same model in a similar environment. With this information, a definite conclusion can be drawn on the outcomes of this study.

Furthermore, as shown in the results, the impact of the OD schedule is extensive. When a sub optimal OD schedule is used, the production ratio will be lower. This is because some space in the OD schedule is reserved for places that remain vacant. Since the optimal OD schedule leads to a higher production ratio, further research can be done on the improvement of the OD schedule. For example the research of Kaandorp and Koole (2007) can be used, where they state that a local search procedure can be used to calculate the optimal OD schedule. Besides this study, also the effect of holidays, sickness of the orthopedic and deployment of supporting medical staff can be investigated. Because, as this research shows, an optimal OD schedule would be of great value.

Lastly, when further developing the tool, attention should be paid to the optimization technique at hand. Currently, the optimization technique is based on a heuristic. In this case study, a prediction for at least one year was needed, therefore a direct optimization technique would take too long to compute. However, when only short predictions need to be made, maybe a direct optimization technique would be more valuable. Gunawan and Lau (2013) gave different optimization techniques, which could be used in these cases.
8.2.2 Practical recommendations

The recommendation to the SMK is to integrate the planning decision tool in their current way of planning. It will help the schedulers to make solid decisions regarding the schedule. It will also help them to monitor the realisation of the production goals across the year.

The planning supporting tool can also be linked to the steps taken in the IPCM program. For example the prediction on the path the patient covers within the hospital, the rush weeks at the radiology department and the occupancy of the beds at the nursing department. Furthermore, the tool will help the outpatient department to predict the rush weeks in which they need to have more employees.

Since the tool can be applied to the whole hospital, it would also be valuable to implement the tool in the other departments of the SMK. The rheumatology department and the rehabilitation clinic also need to deal with personnel planning and compliance to production goals. Therefore, it would be useful to also implement this tool in these departments. However, since these departments do not use the OT very often, the model should be adjusted. For example instead of the OT, also the rooms in the rehabilitation center can be used as constraint.
9 Discussion

The planning supporting tool gives the SMK some valuable input to improve their current way of planning. It provides them a schedule of the OTs and ODs needed for every week. Together with the spare time of the OT and the orthopedics, a substantiated decision can be made on how many OTs and ODs are planned in a particular week. However, since this study is performed in a real life situation, there are some remarks and limitations to this research.

9.1 Data issues

There are some data issues, which cause a sub optimal result of this study for the SMK. First of all, the data set on which the transition matrix and arrivals of patients are based, is incomplete. Not all patients are incorporated in this data set and not all treatments are coded in the right way. Since there was no alternative, this data set, with some additions, is used as input for the model. The lower patient arrivals are corrected with a multiplication factor, however it is not a 100% real situation. However, the model itself is very useful for the SMK, since it gives an easy and quick overview of the current waiting list and a weekly number of OTs and ODs to plan. Therefore, the simulation can be repeated when a proper input data set is available.

Besides the biased input variables, other variables needed to be assumed as well, starting with the capacity of the OT. Since the session grid of the OT of five years from now was not yet available, the session grid of the OT of 2016 is used multiple times. However, there are some minor changes in holiday periods. Therefore, using the OT schedule of 2016 multiple times can lead to a biased result. Secondly, the capacity of the orthopedics is based on the OT session grid. However, sabbaticals and holidays outside the reduction periods are not taken into account. Maximum availability and production is assumed in these weeks. However, absence of an orthopedic outside the reduction periods can have a major impact on the results. When less orthopedics are available, this leads to reduced available capacity to perform OD and OT. This can have an effect on the number of patients available for a surgery, follow up consult or dismissal consult a few weeks later. Since all weeks depend on each other, one minor change in for example capacity of the orthopedic can result in a domino effect for the weeks following. Lastly, the number of children waiting for a surgery is unknown. This is set to be 100 waiting children. However, this is an assumption, which can also lead to a biased outcome.

9.2 Implementation

Since the data set used as input for the model is incomplete, the results are also not 100% applicable to the SMK. Before the implementation can start, the data set must be improved. Thereafter, the results can be recalculated and the model
can be implemented. However, since the model is highly accessible, the actual applicable results can be obtained relatively easy. Subsequently, the model can be used to make the production plan on unit level. The number of OTs and ODs that need to be performed in one week can then be divided across the orthopedics available. This can even be done by the orthopedics themselves. Finally, when the production plan can be linked to the prediction of workload of the orthopedics, the orthopedic or scheduler can balance the workload of the orthopedics across the weeks (Hulshof, 2013).

9.3 Limitations

The heuristic used to calculate the amount of ODs and OTs for every week does not automatically lead to an optimal solution. For every week it searches for the solution which provides the optimal ratio. However, when optimal production is desired, it could be more valuable to only produce surgeries from the unit that can perform most surgeries in one OT, the Upper Extremity unit. Then, most surgeries will be performed, but this is not in line with the requirements of the SMK.

Besides the sub optimal solution of this heuristic it does also not take into account the effect of the delay of the patient moving from one state to another. For example, week 20 can have a too low amount of patients to fill all the OTs, which can be due to the lack of ODs performed in weeks 13, 14 and 15. Therefore, it would be better if the heuristic also tries to improve its own solution. For example, when little patients are available for surgery in one particular week, the planned OT of X weeks ago, will be changed in an OD. This delay was also not taken into account in the simulation of Hulshof (2013), where they had a similar mathematical model. Therefore, it is even more valuable to test this, since no research on the same problem is available.

Since the model could not be implemented, we were unable to validate the results. Therefore, is is not clear whether the model actually leads to a better and more balanced personnel planning. However, through evaluating the different scenarios, it turned out that planning on half day base does lead to a more balanced production ratio. Adding supporting medical staff does only lead to a better performance ratio whenever there are enough patients available. Lastly, an optimal OD schedule leads to a higher production ratio. Therefore, the optimal OD schedule should be used, and trio ODs should only be planned whenever there are enough patients on the waiting list.
10 Bibliography


Blake, J. T., & Donald, J. (2002). Mount Sinai hospital uses integer programming to allocate operating room time. *Interfaces, 32*(2), 63-73.


**List of Figures**

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Appendices

A Organizational overview SMK

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